EXAMINING COMPUTER SUPPORTED COLLABORATIVE PROBLEM SOLVING PROCESSES USING THE DUAL-EYE TRACKING PARADIGM

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ABSTRACT

EXAMINING COMPUTER SUPPORTED COLLABORATIVE PROBLEM SOLVING PROCESSES USING THE DUAL-EYE TRACKING PARADIGM

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The aim of this study is to examine the computer supported collaborative problem solving processes. This study tries to identify which situations the participants' eye movements, and eye gazes overlap, and how the percentage of this overlap contribute to the collaborative problem solving process. Hypothesis of this study is that pairs whose eye movements overlap are more successful in collaboration than others. This study was conducted with 18 students from the Middle East Technical University. Participants tried to solve 10 geometry problems interacting with each other using Virtual Math Teams (VMT) environment. In the experiments, participants’ eye movements were collected with two eye trackers, and examined with eye tracking software. With these data, it was identified which part of the screen the participants looked at. Before the experiments, a questionnaire was filled by participants in order to state their demographic information. After experiments, a survey was applied including System Usability Scale and open-ended questions about participants' comments. Eye-tracker data were analyzed both quantitatively and qualitatively. For quantitative data, cross-recurrence analysis method was used. For qualitative data, interaction analysis method was used to examine experiments' videos. The results show that pairs who collaborate with higher level have more gazes overlapping than pairs having with low level. In addition to this, good pairs show more shared understanding, anticipatory gazes, and helping each other. Answers of the open-ended questions are, also, consistent with the quantitative and qualitative data. Furthermore, the interface and usability problem of VMT were presented and discussed.

Key Words: computer-supported collaborative learning, joint attention, gaze overlap, collaborative problem solving, dual eye tracking

ÖZ

BİLGİSAYAR DESTEKLİ İŞBİRLİKLİ PROBLEM ÇÖZME SÜREÇLERİNİN İKİLİ GÖZ İZLEME YÖNTEMİ İLE İNCELENMESİ

Uzunosmanoğlu, Selin Deniz
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Bu çalışmanın amacı bilgisayar destekli işbirlikli problem çözme süreçlerinin incelenmesidir. Verilen problemleri çözmeye çalışan iki kişinin göz hareketleri ve odaklanma bölgelerinin hangi durumlarda çakıştığı ve çakışma yüzdesinin işbirlikli yönteme nasıl bir katkısı olduğu, bu çalışmanın kapsamını oluşturmaktadır. Bu çalışmadaki hipotezler ise göz hareketleri çakışan grupların daha iyi bir şekilde işbirliğini sağladığı ve kullanılabilirlik unsurlarının işbirlikli çalışma sürecini etkilediğidir. Bu çalışma Orta Doğu Teknik Üniversitesi öğrencisi 18 kişi ile gerçekleştirilmiştir. Çalışmada katılımcılar, Virtual Math Teams (VMT) sitesi üzerinden 10 geometri problemini ekip arkadaşı ile tartışarak işbirlikli bir yaklaşımla çözmeye çalışmışlardır. Bu çalışmada veri toplamak için iki Tobii Eye Tracker cihazı kullanılmıştır. Bu cihaz ile katılımcıların göz hareketleri kaydedilip, bu veriler üzerinden analiz yapılmıştır. Deney öncesi kullanıcılara bir anket uygulanmış ve kullanıcılara dair bazı temel bilgiler toplanmıştır. Deney sonrasında uygulanan ankette ise sistemin kullanılabilirliğine dair bir ölçek ve açık uçlu bazı sorular yer almaktadır. Göz izleme cihazından elde edilen veriler hem nitel hem de nicel yöntemler ile incelenmiştir. Nicel veriler için çapraz yineleme yöntemi kullanılmıştır. Nitel veriler içinse, deneylerden elde edilen videolar, etkileşim analizi yöntemi kullanılarak analiz edilmiştir. Elde edilen bulgular daha iyi işbirliği sağlayan çiftlerin daha az işbirliği sağlayan çiftlere göre baktıkları yerlerin daha fazla örtüşmekte olduğuna işaret etmiştir. Buna ek olarak iyi performans gösteren çiftlerin ortak anlayış oluşturma, bir sonraki eylemin gerçekleşeceği yerleri daha sık öngörme ve birbirlerine yardım etme nitelikleri bakımından diğer çiftlerden ayrıldığı gözlenmiştir. Açık uçlu sorulara verilen cevaplar da bu bulgularla tutarlılık göstermektedir. Ayrıca VMT sisteminin arayüz ve kullanılabilirlik ile ilgili sorunları sunulmuş ve tartışılmıştır.

Anahtar Kelimeler: bilgisayar destekli işbirlikli öğrenme, ortak algı, göz örtüşmesi, işbirliğiyle problem çözme, ikili göz izleme

To my parents and my dear sister

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LIST OF ABBREVIATIONS

CSCL: Computer Supported Collaborative Learning

HCI: Human Computer Interaction

VMT: Virtual Math Teams

AOI: Areas of Interest

IS: Information Systems

CEIT: Computer Education and Instructional Technology

CHAPTER 1

INTRODUCTION

1.1 Background of the Study

People around the world can now communicate with each other at very low costs thanks to the developments in 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). ICT tools also take records of activities, so that they may be inspected by users further on. This allows various peer groups to discuss their collective studies on the internet, helping practitioners and researchers to create a synergy that would improve their medium of understanding. A research paradigm getting more and more popular called *Computer-Supported Collaborative Learning* (CSCL), a branch of Instructional Technology, analyzes the improvements that ICT technologies may offer for collective meaning-making practices created in an online environment (Stahl, Koschmann & Suthers, 2006).

Many communication technologies (such as text-chat and shared graphical workspace) are being used simultaneously in sync, with a phenomenon called *multimodal interaction spaces*. This has been used in commercial collaboration suites like Elluminate and Wimba, in order to facilitate the collective learning activities of online groups. The fusion of these different tools that provide online communication creates many advantages and disadvantages (Çakır, 2009). Being able to use a rich set of modalities facilitates the user to offer his/her reasoning in various semiotic forms. The ability of practitioners to use these modalities to create a connection with others' actions and form a collective knowledge, greatly affects the effectiveness of the enhancement of learning and understanding expected by the practitioners.

Many scholars agree upon the improvements that small-group collaboration provides on learning at the individual, small-group and classroom levels, but how this process is to occur in interaction requires further investigation, particularly in computer-mediated settings (Çakır, 2009). The use of computers in working environments needs the students themselves to share feedback on the possible techniques for the aforementioned interactive assets to be used during collaborative problem-solving tasks.

CSCL environments with multimodal interaction spaces extend the possibilities of online creation, manipulation and sharing. The interactional organization of meaning making activities, however, is still open for further research in CSCL and education fields. An online environment with multiple interaction spaces named *Virtual Math Teams* (VMT) has been created in order to fulfill the shortcomings in mathematics education (Stahl, 2009). It provides a useful tool for users to share textual and graphical contributions online. Some other tools that VMT environment offers to facilitate coordination across multiple spaces are explicit referencing and special awareness markers. The environment also provides a *Replayer* tool, which enables the replaying of a chat session to analyze the organization of joint activity among students to acquire the connections that form a deep understanding of math.

Computer Supported Collaborative Learning (CSCL) technologies bear the open challenge of developing measures and methods for better understanding the nature of learning in social interaction through technological means. It is customary to associate gaze with individual cognition, rather than with social interaction (e.g. eye-tracking studies on reading, program comprehension, etc. typically focus on the individual). CSCL, on the other hand, treats gaze in the context of collective action and forms a related methodology. Different methods have been developed to detect the level of "gaze togetherness" in relation with quality of collaboration in interaction between pairs. It can be deduced that good collaboration comes with convergent gaze. An obvious rise in gaze togetherness can be observed during verbal and deictic references. Gaze togetherness term is, also, related to other overlapping concepts such as joint attention, and gaze recurrence (Barron & Roschelle, 2009).

Joint attention phenomenon in collaborative learning has previously been studied using eye-trackers. Richardson, Dale and Kirkham (2007) have concluded that synchronization of visual attention is affected by common knowledge. A study involving student pairs observing a concept map have shown that the knowledge awareness tools (testing the knowledge of each member) are highly related to the more synchronous gazes and a better quality of collaboration couples exhibit (Sangin, 2009). Another example is an experiment conducted by Jermann, Nüssli, Mullins and Dillenbourg (2011), which used synchronized eye-trackers to observe programmers while they were working on codes, and it showed that more productive pairs have higher joint visual recurrences. Finally, an algorithm written by Cherubini, Nüssli and Dillenbourg (2008) related the miscommunication between pairs with differences in gazed points exhibited by the pairs. These findings altogether, imply that synchronized use of multiple eye-trackers are promising instruments that would help researchers understand the underlying causes of high or low quality collaboration, and provide them empirical insights for the development of more effective CSCL environments.

1.2 Statement of the Problem

Rapid development of technology also pushes forward the communication technologies. Education is one of the fields that are most affected from these improvements, particularly distance education systems, which have gone through a fast development in the last decades. Since communication technologies broaden the possibilities in terms of time and location for both students and the teacher, they draw the students' and educators' interest towards distance education systems. Teachers and students need not be in the same place at the same time. The related equipment have also become widespread, so that easy access to computers and internet are available almost everywhere. With these developments, some fields improve as branches of distance education such as virtual worlds, educational gaming, online resources, etc.

Online resources like virtual home schooling, Khan Academy of Math, YouTube videos and virtual high schools become more and more widespread among high school students. These sources, somehow, still bear inadequacies due to their current models' lack of social interaction and collaborative learning. These shortcomings are the main motivation behind Computer Supported Collaborative Learning (CSCL) research.

VMT (Stahl, 2009; Stahl, Mantoan & Weimar, 2013) – a computer-supported collaborative learning environment, namely *Virtual Math Teams* – and GeoGebra (www.geogebra.org) – a popular, open-source dynamic geometry and algebra application – have recently been brought together as part of a research project. This was achieved by making some improvements in VMT and altering GeoGebra so that it is now a multi-user application integrated into VMT. This environment opened up new ways to discuss math problems online where groups of students can co-construct and talk about dynamic representations. In the development of a socio-technical system, not only technical developments, but also a guide to group-cognitive work is necessary by means of offering helpful resources and aids to group practices. Thus, the effectiveness of integrated systems like VMT for supporting collaborative learning online needs to be subjected to empirical investigation.

Despite CSCL researchers' efforts for raising awareness on the importance of collaborative learning for online education (Stahl, Koschmann & Suthers, 2006), most educational platforms still lack collaboration features. As an example, the nowadays popular MOOCs (massive open online courses) simply inherit a lecture-style approach, in which students watch famous professors give video lectures with very limited interaction with other students.

Studies examining the effectiveness of CSCL environments tend to employ qualitative and quantitative techniques such as interaction analysis and content analysis of system logs or video recordings of students' interactions. Moreover, eye-tracking methods have become popular in education technology research, but existing studies tend to focus on general measures of individuals' attention (Pietinen et al., 2008; Pietinen et al., 2010). These results give an idea on overall gaze behavior (which may be related to knowledge and experience), but fall short on providing feedback on instant reactions that may imply different levels of collaborative interaction (Sharma, Jermann, Nüssli & Dillenbourg, 2013). Since there is a need to understand the collaborative interactions at the group level in CSCL research, eye-tracking technology can be useful to examine the collaboration processes via users' eye movements.

While examining collaboration processes, it is also important to evaluate the usability of systems such as VMT, because usability of a collaborative learning environment deeply affects such processes. However, since traditional usability evaluation methods tend to focus on single user systems, such methods need to be extended to investigate usability issues peculiar to collaborative systems. In particular, usability analysis of a collaborative learning environment requires an evaluation of the communicational affordances for coordinating user actions (Hutchby, 2001) as well as the awareness mechanisms designed for facilitating joint attention (Stahl et al., 2006). And it is, also, important to evaluate the usability of a collaborative learning environment, because most of the usability studies are conducted for individual learning environment. So although designing collaborative environment, designers used methods which is used for individual ones (Matthews, Judge & Whittaker, 2012). In brief, this thesis aim is to contribute to both CSCL and HCI fields.

1.3 Purpose of the Study

The purpose of this study is to examine the collaborative problem solving sessions mediated by the Virtual Math Teams (VMT) (Stahl, 2009) environment using dual eye-tracking paradigm, and analyze the collaboration level of each pair by using the gaze recurrence analysis method. Furthermore, usability of VMT environment is evaluated.

Particularly, the aim of this thesis is to contribute to CSCL and HCI fields by employing the dual eye tracking paradigm to investigate joint gaze indicators (1) to assess the degree of coordination and collaboration quality in CSCL environments and (2) to aid the usability evaluation of CSCL systems in terms of the effectiveness of their coordination and awareness features for helping users achieve a sense of joint attention.

1.4 Significance of the Study

This study aims to contribute to the CSCL and HCI literatures by investigating joint eye gaze features that may inform the assessment of collaboration processes and the evaluation of CSCL environments by using the dual eye-tracking paradigm. This study illustrates some important uses of dual eye tracking such as monitoring the level of collaboration between pairs, and the difficulties they face during collaborative learning. Such methods may not only inform the assessment of collaborative learning and problem solving processes, but also provide guidance for usability studies that aim to improve existing CSCL environments. 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. The 2015 version of the PISA exam will include questions aiming towards measuring collaboration skills (OECD, 2013). Therefore, designing effective environments where students can develop such collaboration skills has already become an important educational agenda item in most countries. Some of the measures investigated in this thesis may be developed further to support the need for large scale applications for assessing collaborative learning required by computerized tests such as PISA, as well as to develop more advanced awareness features to help students develop communicational and coordination skills necessary to work together as a team.

1.5 Research Questions

This study will search the following questions:

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. To what extent gaze overlaps corroborate with shared understanding evidenced in interaction?
4. How does the usability of VMT environment affect collaborative problem solving processes?

CHAPTER 2

LITERATURE REVIEW

This chapter includes three main sections. In the first section, computer supported collaborative learning, historical development of this field, and evolution of its research methods are reviewed. In the second part, HCI field is presented briefly, and usability context is introduced. Then eye-tracking and dual eye-tracking methods are explained. Third and the final section, review of dual eye-tracking and CSCL studies are presented.

2.1 Computer Supported Collaborative Learning

Computer supported collaborative learning (CSCL) is a newly developing domain of the learning sciences. It mainly concerns how people learn together doing some activities using computer environments. CSCL relates with education, so it concerns both formal education from kindergarten through graduate level, as well as informal education.

Computer and Internet have become more popular all around the world, and governments have a goal that students have access to Internet extensively. In addition to this, learning in a group, and working together on developing shared ideas are, also, emphasized in the education literature (Stahl, Koschmann & Suthers, 2006). But a challenge comes up about combining these two ideas, computer support and collaborative learning.

There are some criticisms about using computers and computer systems in education based on the argument that they promote anti-social learning environments by isolating individuals (Stahl, Koschmann & Suthers, 2006). CSCL challenges these ideas, and suggests that new computer systems, software and applications must be developed with the goal of providing users with creative and collaborative activities, so intellectual exploration and social interaction can be promoted by computer systems.

CSCL has brought together collaborative learning with e-learning, and fused them into a single entity. They are seen as the “organization of instruction across computer networks” (Stahl, Koschmann & Suthers, 2006, p. 409-426). In conventional e-learning applications, presenting educational content digitally, and spreading it to larger number of learners is the main goal. There is a widely held belief that the availability of such content would allow learners to go through educational materials at their own pace, eliminating the need for learners and teachers to be co-present in time and space as in the case of traditional classroom education. But according to Stahl, Koschmann and Suthers (2006), this content production and dissemination approach to e-learning brings some problems.

First problem is about generating learning content. Posting the content in the form of texts, slides, videos etc. directly is not enough to promote learners' motivation to learn from those materials. Content must not only be effective and interactive, but social scaffolding should also be provided along with the content to support and motivate the learners as they engage with the materials.

Second issue is that in online courses, teachers or facilitators expend more effort than the classroom lessons, because in e-learning, the aim and mission of teachers are not only posting content but also motivating, monitoring and guiding each student, and supporting their interaction with the materials. As open education institutions and the recent massively online classes demonstrate, students from all around the world may enroll in e-learning programs, and thus teachers must spend even more effort to accommodate this increasing demand by making themselves available online for longer duration of time.

In an effort to address some of these challenges and criticisms to e-learning, CSCL emphasizes collaboration among students. When students learn something new, practice, or do learning activities, they express their ideas, questions, learn from each other, and discuss content. Such collaboration activities are at the focus of the CSCL field as a form of e-learning. In order to provide students with those kind of collaborative activities, curriculum, pedagogy and technology must be combined, planned, and implemented carefully. Otherwise, interaction and collaboration are difficult to achieve.

CSCL's interest is not only limited to collaborative learning through networked computers, but also includes face-to-face (F2F) collaboration mediated by computers. For instance, students may use a computer together, try to explore a specific content, discuss, and gather information collaboratively. So CSCL studies various forms of collaborative learning with ICT technology, ranging from distant communication and e-learning to F2F interaction, either synchronously or asynchronously.

2.1.1 Cooperative vs. Collaborative

Learning in a group idea was performed before CSCL, and researchers examined cooperative learning with this idea. In this step, there is a need to distinguish cooperative and collaborative learning. Dillenburg (1999a) described this distinction as while in cooperative learning, group members divide the work into sub-tasks, solve these sub-tasks individually, and finally unite the results, in collaborative learning; group members do the whole work together. In addition to this, Roschelle and Teasley (1995) described collaboration as "Collaboration is a coordinated, synchronous activity that is the result of a continued attempt to construct and maintain a shared conception of a problem", so when collaborative learning occurs, individual learners are group members, and learning occurs socially, create shared meanings, negotiation, and engage in whole process.

2.1.2 Historical Development of CSCL

There are three early projects affecting the usage of technology in education, and giving a shape to CSCL field. The first project was ENFI Project was one of the earliest projects about "CSCWriting" (Bruce & Rubin, 1993; Gruber, Peyton, & Bruce, 1995). Students attending this project are hearing impaired, and may have problem about written communication skills. So the aim of this project was to help to see new ways of writing with a voice. Technology used in this project was developed in order to provide students with new environment for textual communication, and encourage meaning-making. In this project, texts were conversational, spontaneously developed, and not preserved.

The second effective project was performed by Bereiter and Scardamalia at the University of Toronto, and named as CSILE (Computer Supported Intentional Learning Environment). They thought that learning in classrooms does not prove students with motivation, and is superficial. Oppositely, they developed, and united technologies and pedagogies to arrange classrooms as "knowledge-building communities" (Bereiter, 2002; Scardamalia & Bereiter, 1996). The aim of the CSILE was to search how engaging students produce more meaningful writing in joint text production. By contrast with the ENFI project, CSILE texts were archival such as literature.

Third and the last project was the Fifth Dimension (5thD) Project organized by Cole and colleagues at Rockefeller University. The aim of this project was to improve reading skills (Cole, 1996). Firstly, this project started with an after-school program, but then 5thD was detailed into a system based on computer activities to improve reading and problem solving skills of students. In the beginning of this project, it was performed at four sites of San Diego, and then spread to the lots of sites (Nicolopoulou & Cole, 1993).

These three projects formed the background and emergence of CSCL, because they had a mutual goal which make instruction more meaning making oriented, and use technologies in this way. So they tried to generate a new form of social activity in learning.

Earlier approaches about using computer systems in education come into conflict with the CSCL field. Chronological order of these approaches was stated by Koschmann (1996a) as follows:

First approach is computer-assisted instruction. It was significant in the 1960's and later -that is the early years of educational computer applications- and was a behaviorist approach. It perceived learning as information to be memorized. Knowledge was prepared as pieces of information and to be served to students in a logical order as computerized exercises. This method is still common throughout commercial educational software.

Intelligent tutoring systems, second approach stated by Koshmann (1996a), involved a cognitivist approach that viewed the learning process in terms of mental models and potentially faulty representations. It stood against the behaviorist approach that did not take into consideration the representation and processing of knowledge by students. This method used computers to model the understanding of students and inspected the common errors made in student mental models, and was brought to attention in 1970's.

Third one is Logo as Latin. The Logo programming language of 1980's employed a constructivist approach, encouraging the students to build knowledge for themselves. It took the students in a stimulating environment, in order to let them use their power of reasoning via programming concepts like functions, subroutines, loops, variables, recursion, etc.

Fourth and the last approach is CSCL. CSCL method, in the mid-1990's, used an approach that used computers to facilitate the formation of learning groups in which the students could learn collectively. The philosophy would bring students together and have them build a shared knowledge, and was based on social constructivist and dialogical theories.

2.1.3 Evolution of Research Methods for CSCL

In the light of the recent reviews of CSCL researches, it is stated that history of methodological improvements of CSCL field has three stages. These are the effects paradigm, the conditions paradigm, and the interactions paradigm (Dillenbourg et al., 1995; Webb & Palincsar, 1996; Cohen. 1994; Baker, 2002). At the beginning of the CSCL researches, collaboration was seen as a black box, and effects of the collaboration was tried to measure with controlled experiments. These studies had troubled results, and most of them saw that collaborative learning is more preferable than individual learning. But there had some deficiencies about to understand of the nature of CSCL.

After the effect paradigm, researchers tried to seek, and identify the conditions under which qualified collaboration in learning can be performed instead of measuring the effects of collaboration. In order to identify the conditions, several variables such as group size, task types, group compositions (e.g., pairs at same/different educational level), and etc. were used to state the hypothesis, so some predictions about the effective collaboration were tried to be produced. But these variables interact with each other in complex ways, and this situation causes the difficulty to design experimental studies. Because of this reason, it is difficult to interpret these statistical data, and understand the relations between these variables.

In recent years, alternative methods is tried to perform in CSCL researches. These methods concentrate on micro-level, moment-to-moment details of interactions, and these are suggested as an alternative choice of the experimental methods of psychological tradition (Barron, 2000; Sawyer, 2006; Stahl, Koschmann & Suthers, 2006). In these kinds of studies, discourse analytic and conversation analytic are used in social sciences. Interactions among participants are recorded, and these recordings such as video recordings, computer logs and etc. are tried to analyze instead of pre-test, post-test, and exam scores. So interaction patterns among students and between teacher and classroom can be identified. This new kind of methodological approaches concentrate on, and try to understand how collaborative learning is performed by small groups with interactions, instead of starting with bias about effectiveness of collaboration and external measures (Roschelle, 1996; Roschelle & Teasley, 1995; Stahl, 2006; Koschmann, Stahl & Zemel, 2007; Koschmann & Zemel, 2006).

The fact that social interactions at small groups and at classrooms are of a complex nature, has given rise to use of naturalistic inquiry (Lincoln & Guba, 1985) methods for analytical purposes, along with iterative methods of instructional design as a part of longitudinal efforts to involve pedagogies of collective team work in a classroom environment (Cobb et al., 2003). The objectives and interventions of researchers are continuously reevaluated and changed in order to maintain a collective knowledge at school and/or online, which is an iterative method known as Design-Based Research (DBR). DBR has become a well known method for educational research and instructional software development thanks to its effectiveness in researches that involve learning of individuals and small groups (Barab, 2006).

2.2 Human Computer Interaction

Human computer interaction field has emerged with the idea of physical usage, in other words ergonomics, and it is named as "Man-Machine Interaction" (Gaines & Shaw, 1986). Over the years, with the development of the Information Communication Technology (ICT) HCI field has become more popular, and gained more inside in terms of software application.

HCI relates to design, evaluation, implementation and major field of computing systems in order to make easy to use for human (Hewett, Baecker, Card, Carey, Gasen, Mantei, Perlman, Strong & Verplank, 1992). They, also, described HCI as “Human-computer interaction is concerned with the joint performance of tasks by humans and machines; the structure of communication between human and machine; human capabilities to use machines (including the learnability of interfaces); algorithms and programming of the interface itself; engineering concerns that arise in designing and building interfaces; the process of specification, design, and implementation of interfaces; and design trade-offs.”

HCI discipline must be studied for several reasons. For example; there is a growth of user population all over the world, and everyone is getting a user of computer systems. In parallel with this growth, there is huge technological development, and most of the organizations pass their organizational functions to technology such as banks, trade firms and etc... In addition to these, some critical organizations such as medical and military pass their system to computer systems, and if an error occurs in the system, originating from the system design, may have fatal consequences. Other reason is that "studying humans interacting with artifacts can inform our theories and models of human capabilities and activities" (Çağıltay, 2011).

The aim of the HCI discipline is to remove or minimize the problems about interaction with human and computer systems, so people can benefit those systems easily. In addition to this, the other aim is to provide financial, personal, social and organizational benefits (Shackel, 1991), so the rate and the continuance of usage of the systems can increase. In order to provide this aim, HCI discipline has contain many discipline such as psychology, sociology, cognitive science, computer science, ergonomics, education, and etc. As it is seen, HCI is a multidiscipline field (Preece, 1994; Shneiderman, 1998).

HCI field contains two sides. First one is research side relating with designing, programming, producing and etc. Second side of the HCI field is human side having connection with psychology, human factors, cognitive sciences and etc. Universities and research laboratories develop technologies in order to bring close together these two sides, and thanks to the technologies most of the fields related to HCI have valuable gain.

2.2.1 Usability

In this section, the usability concept is examined in terms of web sites. Usability concept is used not only technological devices but also tool used in daily life, web sites, software, and etc.

In human computer interaction discipline, there are some domains that are indispensable, and those are interdisciplinary, design, effect, and usability (Çağıltay, 2011). HCI studies with other disciplines, and can solve problems with the help of other disciplines. For example; when an expert researches why some social network websites are used frequently, the expert must consider not only technical side of the web site, but also psychology of the people used those web sites. Design domain considers how we design more usable and functional product. In effect domain, we try to identify how the technology affects our life. And final and the most common domain is usability.

Usability term was firstly introduced as "ease of use" by Miller (1971), and Lazar and Preece (2002), and defined as the degree to which using particular system is perceived to be free of effort (Davis, 1989; Venkatesh, 2000). After this definition, a debate emerges that a system is easy to use, but has useless functions. In order to say that a system is usable, this is not enough saying usable. There are three points of view for usability. First one is semantic approach. In this approach, some terms are used to tell the usability of the product such as user-friendly, easy to use, transparency, and etc. (Çağıltay, 2011). But it is not clear the reference of these terms, and mean of these terms differs from one to another and subjective, so in order to define the usability clearly, there is a need specific and objective approach.

At this point, the second approach named as featured based is suggested. In this approach, usability definition is based on the feature of the interface design. But the problem is everyone may have different perception about the same interface. Because of this reason, there is a need of a definition which explains the design explicitly. According to Shackel (1991), usability is the capacity of specific users while perform specific tasks of in a specific scenarios easily and effectively. On the other hand, Nielsen (1993) defines the usability in terms of five attributes which are learnability corresponding easy to learn systems, efficiency corresponding efficient to use systems, memorability corresponding remember to use systems, errors corresponding the systems having to low error rate, and satisfaction corresponding pleasant to use systems. Because the definitions can be varied, International Standards Organization generated a document named as ISO 9241-11.

And finally, operational approach appears in this document. According to this document, usability can be seen as in Figure-2 (ISO 9241-11, 1998):

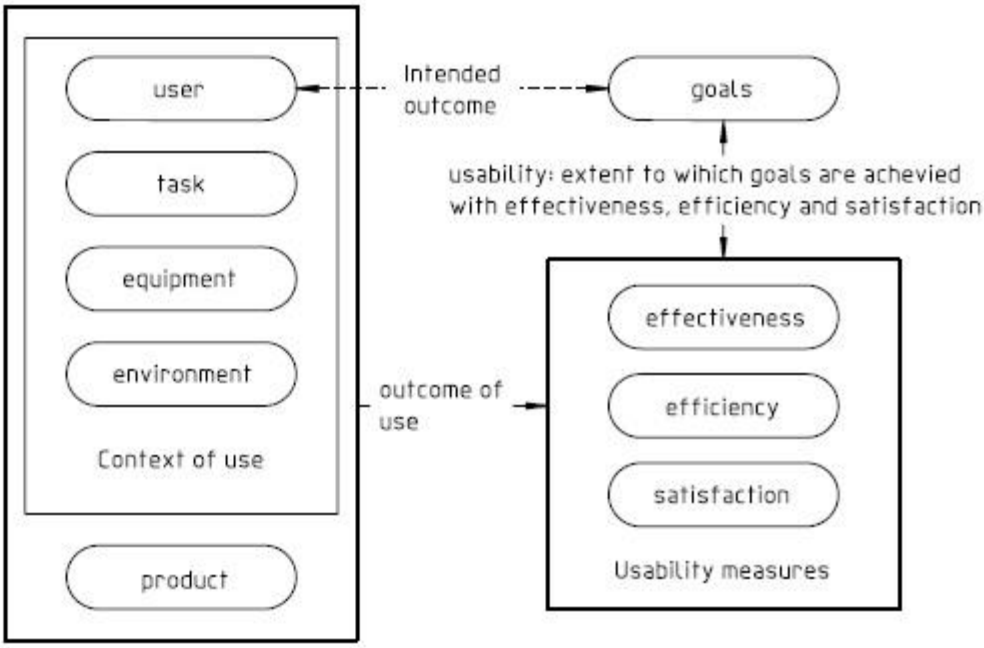

Figure 2.1 Usability Framework

According to this figure, usability measures effectiveness, efficiency and satisfaction, when those meet the need, the degree of usability of a system increase (Çağıltay, 2011), and the relationship between them affects the design phase.

In the light of those information, the scope of HCI includes how people effect their usage of technology, how technology effect the people's use, how the designers meets the people's need with the technology, how the usable technology can be designed, and how technology impact the organizations (Çağıltay, 2002), so more usable designs must be created.

Good systems design depends on four components that are user, task, toll, and environment (Shackel, 1991), and usability forms of interaction between them. Then how researchers decide that a system is usable, and how a system's usability can be evaluated. As stated in the ISO standard too, Mack and Nielsen (1994) stated in their study that usability has three dimensions for evaluation that are effectiveness, efficiency and satisfaction. Effectiveness is whether the users achieve given task or not, efficiency is error rate and time, while the users performing the given task, and satisfaction is the users how they feel while doing tasks.

The most commonly used method is user test, because real users evaluate the system under real world. Users' performance and attitudes are examined beside performance measures such as time, errors to complete tasks and etc. are considered. With the technological development, eye-tracking methodology becomes indispensable part of the usability tests. Karn, Ellis and Juliano (2000) stated that collecting the eye-tracker data is worth time and effort, because thanks to these devices give high validity of usability data (Schiessl et al., 2003).

The evaluation methods for usability are mostly developed for single user environment. But there is a need to develop new usability methods for environment support collaboration in order to evaluate not only the interface but also the collaboration processes, because adaption of collaboration tools is a major problem (Holtzblatt, Damianos & Weiss, 2010; Matthews, Whittaker, Moran, Yuen & Judge, 2011). Although there are some studies about the evaluation of collaborative environment such as groupware walkthrough (Pinelle & Gutwin, 2002), there is still a gap between usability methods and evaluation of collaboration processes. In order to look more closely to the collaboration processes, we use dual eye-tracking methodology.

Next part, eye-tracking technique is explained detailed, and the example studies about how dual eye-racking methods used in CSCL field.

2.2.2 Eye-Tracking Methodology

In this section, a general overview of the human vision, eye-movements are presented. In addition to these, eye-tracking technologies and related methodology are introduced in order to make this work understandable.

2.2.2.1 Human Visual System

Actually, the scope of this work does not contain the physiological and neurological mechanism of human vision system. But it may be beneficial to have a general overview of the basic aspects of human vision in order to make eye-movements and their analysis more understandable.

Structure of the eye comprises of a sphere with a small opening at one end, and a light-sensing surface on the other end. The light-sensing surface is connected to the nervous system via optical nerves, collecting and transmitting visual data. Aperture, at the other end of the eye contains roughly two parts that make up an optical system. First is the part that includes the lens and ciliary muscles that adjust the curvature of the lens in order to keep the eyes in focus when looking at objects at different distances. Second part contains pupil and iris that act as a diaphragm, adjusting the incoming intensity of light and depth of focus.

Not all the details in our range of sight are perceived with great accuracy. Due to non-uniform density of distribution of visual receptors on the retina, we do not see different elements in different zones of our visual field with same sharpness. Fovea, which lies at the center of the retina, is a zone that bears a high density of visual receptors. This zone has the greatest perceptive sharpness compared to surrounding zones on the retina, and corresponds to a visual angle around 2 degrees. Rest of the retina, which has considerably less sharpness in comparison to fovea, is named the peripheral vision field. To be able to acquire a clearer sight, the eyes are moved so that the image falls into the retina that has receptors with higher density. One can also assume that attention of the viewer is summoned on the objects that correspond to this zone of visual field.

2.2.2.2 Eye Movements

There is a need to mention the general aspects of eye-movements before explaining the eye-tracking technique, and eye-tracker.

Our eyes contain two main eye-movements that are fixations and saccades (Duchhowski, 2007). In this book, fixations are described as the phases while eyes do not make significant movement. So a fixation is characterized as a relatively stable eye-movement within some minimum duration which is approximately between 80 and 500 ms. The other main eye-movement is saccade that occurs between two fixations, characterized as fast eye-movement with short durations between 10 and 80 ms.

Speed of saccades has been reported differently by researchers. While Nüssli (2011) reported 200 degrees in one second (°/s) velocity of saccades, Rayner (1998) indicated the velocity of a saccade about 500°/s, and Crowder and Wagner (1992) asserted degrees about 100 to 200 in one second. Besides to these, Wilder, Hung, Tremaine and Kaur (1999) accepted the velocity of a saccade between 70 and 600°/s. Whatever its speed, saccades are like bullets, when they are started their directions cannot be changed.

These two dynamic eye-movements show the main activity of the eyes. Fixations spend 80% of the time of eye-movements (Nüssli, 2011), and saccades constitutes 6% of time of eye-movements (Crowder & Wagner, 1992).

2.2.2.3 Eye-Tracking

Eye-tracking is described as a technique that records eye-movements of people, and provides researchers with determining eye-fixation patterns of people. Eye-tracking provides researchers with getting the gaze, and direction of gaze of people via measuring the fixations and saccades of gazes (Duchowski, 2007). The gaze directions of people present the focus point of visual attention of people. So researchers can understand which part of the screen or object take the attention of participant using the data about what people look at in eye-tracking technique (Duchowski, 2003). So researchers can use eye-tracking technique in order to inferring about people cognitive processes using the relationship between eye fixations and visual attention.

The idea of the recording eye movements and the development of eye-tracking techniques have started more than one hundred years ago (Wade & Tatler, 2005). The need for recording the eye movements has led to the development of certain methods. Of these methods; we can address electrooculography (EOG) which senses the electrical signals transmitted in the eye muscles by means of electrodes, sclera search coil which involves electromagnetic induction in a metallic coil on a lens, and a device consisting of a small sphere touching the eye that transmits and amplifies the eye movements via an armand lever. Other methods are based on a focused light reflected by the eye. Then it is recorded by a camera. In order to review complete techniques, Duchowski (2007) paper should be visited. In general, the main idea is to generate a system measuring the eye-movements in precise and non-intrusive way.

Eye-tracking research areas expand different disciplines such as psychology, problem solving, and language studies. In addition to this, eye-tracking research is divided into three eras by Rayner (1998). Javal's observation related to role of eye-movements in reading process in 1876 is accepted first studies on eye-movements. Then the facts about eye-movements such as saccadic latency, perceptual span, required time to start an eye-movement, saccadic suppression were discovered until the 1920's. In the second era, researches were focused on application of eye-tracking technologies. Early studies were conducted with the bench-mounted devices, but with the technological development head-mounted devices have been used last over 50 years in order to provide participant with active moment while doing tasks.

Eye-tracking studies were limited by behaviorist approaches until 1970's. Because eye-movements are central to the visual system, react very quickly, and metabolically cheaper than other motor movements, eye-tracking technique is very powerful and accurate in order to explore cognition (Richardson et al., 2007). In the third era, after 1970's, with the effects of technological developments, mobile eye-tracking devices have emerged, and have been used for eye-tracking studies. So after 1970's, eye-tracking researches have won a new direction in terms of cognitive processes, and a great number of studies in terms of this perspective has been studied (Land, 2007). As a result of these improvements, research studies on eye-movements have become more popular especially after 1970's. The other reason why the popularity of eye-tracking studies has raised was that several different fields started to study on eye-tracking such as psychology. Jacob and Karn (2003) stated that theories on psychology explore connections between eye-tracking data and cognitive processes. Rayner (1998), and Jacob and Karn (2003), also, indicated that most of the studies conducted at this period concentrated on the relation between eye-movements and cognitive processes. The relationship between eye-movements and reasoning (Just & Carpenter, 1984), and the potential of eye-movements which reveal the cognitive process (Just & Carpenter, 1984; Rayner, 1995, 1998) were elicited during this period. So most of the conducted studies were related to connect eye behavior and cognitive processes, and tried to open a window to mind. While eye-tracking studies have become popular, at the same period there was a stop on studies interestingly, because there was a problem that eye-tracker makes huge data which make data analysis process extend (Jacob & Karn, 2003). Fortunately the advances in technology provide researchers with easier analysis process, and more accurate results (Rayner, 1998), so eye-tracking method has gained popularity again.

Since this period, there have been lots of studies conducted on eye-movements data analysis (Kliegl & Olson, 1981; Pillalamarri, Barnette, Birkmire & Karsh, 1993 cited in Rayner, 1998). In addition to these, researchers have explored the features of eye-trackers (Deubel, 1995).

In the light of those developments, researchers have found new strategies which enable them to discover the eye-movements changes while visual display occur, and have explored new theories on language and reading processes (Rayner, 1998).

A complete review of a century of eye-tracking studies can be found in Rayner's (1998) paper. In this paper, Rayner stated that eye-tracking experiments give some data that have some problems about generalization, but eye-tracking techniques are valuable because of giving data about information process, and provide researchers with observing cognitive processes.

2.2.2.4 Eye-Tracker

In this thesis, two video-based screen-mounted eye-trackers were used. Screen of eye-trackers look like normal computer screen, but there are two infrared light sources and a camera at the bottom of the eye-tracker screen. Those infrared lights are reflected on the eyes, and those reflected lights and eyes are recorded via the camera. Recorded data can be analyzed via software named as Tobii Studio Software. Before recording the eyes and reflected lights, a calibration process must be done. In this process, several points appear one by one in specific areas of the screen, and pupil and the light reflex are measured for each of the point in order to map between points and pupil-reflex vectors. But this calibration can get worse because of some conditions such as changing subject position, lightning, eyes dryness, and those conditions cause accuracy problems.

There are several important characteristics of video-based eye-trackers. We must consider sampling frequency, latency, and time precision in terms of timing aspects. Sampling frequency, measured in hertz, is described as how many gaze points are measured in one second. Latency, measured in millisecond, corresponds to the time between when the eye-position is recorded and when measure becomes available. Time precision, measured in milliseconds too, is described as the precision in the timestamps of the data. Using eye-tracker, we face two types of errors in terms of spatila aspect. First one is accuracy showing whether measured eye location correspond to the actual eye location well or nor. Second type of errors is precision indicating how much multiple measures of a same eye location have the same value.

2.2.2.5 Eye Movements and Collaboration

In the literature, there are several studies trying to investigate whether there is a relationship between eye-movements and collaboration or not. Eye-movements and gaze relate to communication. Nüssli (2011) stated that “Gaze is largely influenced by speech which is at the heart of collaboration”. While speaking or listening, an eye-voice span occurs. For the listening activity, this eye-voice span can be described as the time between hearing the object’s name and the first gaze on that object. For the speaking activities, it is described as the time delay between looking at an object, and saying its name. For instance, Meyer et al. (1998) stated that subjects looked at the object 700 ms before their expression in their study. Griffin and Bock (2000), also, stated that speakers tent to look at the object to be named 900 ms before saying the object’s name.

2.2.3 Dual Eye-Tracking

Dual eye-tracking is a novel technique attracting attention of researchers who study about collaboration and interaction. In this technique, there are two eye-trackers working at the same time, and two people studying together interactively using an online environment. This technique provides researchers with inside about cognitive processes during social interaction via online environment. There is a need to be stated that this interaction is not face to face interaction, but working together synchronously via remote and shared environment. So we can analyze the eye-movements of both participants, whether there is a mutual gaze or not, and etc.

2.3 Review of Dual Eye-Tracking and CSCL Studies

As mentioned earlier, researchers have concentrated on social learning and small group cognition in the education field. Mainly, this tendency bases on the ideas and researches of Piaget who assumed that socio-cognitive conflicts trigger cognitive reconstruction, and Vygotsky who asserted that learning processes occur on social level, after that learners internalize it. Socio-constructivist theories contain joint of these two theories. In learning, collaboration and negotiation of meaning are very important factors, and they are emphasized on socio-constructivist theories of learning. Thereby researchers interested in socio-constructivist theories focus on analyzing group interaction, and try to state characteristics of collaboration.

The effects of technology on collaborative learning have been started to study for two decades by CSCL researchers. Joint attention concept is seen as related to other overlapping concepts such as “shared cognition,” “intersubjectivity,” “grounding processes in conversation,”, “joint problem-solving,” and “distributed cognition” (Barron & Roschelle, 2009). But groups may not always function properly (Salomon & Globerson, 1989), because there can be several problems in collaborative learning activities. For example, Schneider and Pea (2013) pointed out that Free Rider effect which means that some group members do not contribute any effort, and Sucker effect which is "a tendency for participants to contribute less to a group if they expect others will think negatively of them if they work too hard or contribute too much" are problems in collaboration processes. Thereby unproductiveness, disagreement, discouragement and spending time may occur in group work. One of the studies of Barron (2003), it is emphasized that two groups generate totally different outcomes in the same case. In one group, students confirmed the correct proposal, and documented properly. But in second group, students rejected the correct proposal without any rational reason, and did not document. These kinds of differences could not be explained just considering the students' grades. Group success, also, depends on accomplishment of joint attention. Thereby, individual's characteristics and interaction between these characteristics affect the collaboration quality, so one of the finding of this study was that if a high-quality collaboration bases on the degree of the joint attention, leading the group work provides students with social interaction with high quality. In addition to Barron's study, Dillenbourg (1995) stated that "collaboration is in itself neither efficient nor inefficient. Collaboration works under some conditions, and it is the aim of research to determine the conditions under which collaborative learning is efficient". The goal of the study of Schneider and Pea (2013) is to increase the collaboration quality with technological interventions and this goal is shared many studies of CSCL field.

As mentioned earlier, eye-trackers are used for understanding the cognitive processes of participants using their eye movements such as gaze, fixation and etc. In addition to this, several eye-trackers can be used to specify the level of collaboration. For example, counting the moments when the users look at the same area at the same time is a way of indicating the collaboration level.

There are some previous studies in CSCL field using eye-trackers to examine joint attention in collaborative situations. The study of Richardson & Dale (2005) is one of the examples of these studies. They stated that there is a correlation between the level of gaze overlapping (i.e., the number of times which speakers' and listeners' gazes have recurrence.) between speaker and listener pair, and the listeners' accuracy while solving questions. In another study, Richardson, Dale and Kirkham (2007) found that the coordination of joint attention is affected positively by common knowledge grounding (i.e., training on the same information before the experiment) in a dialog. Jermann, Nüssli, Mullins and Dillenbourg (2011) used eye-tracking devices in their studies to evaluate how programmers work collaboratively, and they compared the good and bad pairs. The findings of their study proposed that high-quality collaboration is correlated with the high level of visual recurrence. In addition to these, Liu et. al. (2009) conducted a study that machine-learning techniques were used to investigate the gaze patterns of collaborative pairs. He could estimate the each participant's degree of expertise within one minute with 96% accuracy.

Cherubini, Nüssli and Dillenbourg (2008) developed an algorithm to reveal misunderstandings in the processes of remote collaboration. While developing this algorithm, they used the distance between the transmitter gaze and the receiver gaze. The results of this study showed that the more dispersion, the more misunderstandings. In addition to these studies, Brennan & al. (2008) conducted a study to understand the effect of gaze sharing and speech during a spatial search task, and the results showed that gaze sharing condition was the best among all other conditions. Furthermore, it was faster than two times, and more efficient than solitary search, and significantly faster than other conditions in collaborative processes.

Considering all of these studies, in order to provide effective collaboration, joint attention and synchronization between pair members have crucial roles. Eye-trackers are suggested as promising way to examine the collaboration processes, and affect the factors related to collaboration quality.

In this thesis, dual eye-tracking method is used in order to attain a deeper understanding of collaboration processes mediated by a CSCL environment. As our revıew of the related literature indicate, studies using the dual eye-tracking method tend to focus on quantitative analysis of eye movement data exported from eye-trackers. In these studies, cross-recurrence analysis is typically used to measure the degree of gaze coordination among participants. However, besides quantitave analysis of eye movements, as argued by Nüssli (2009) there is also a need to examine the collaboration process qualitatively to better make sense of the factors underlying the degree of gaze coordination observed during collaboration. Since there is no clear definition of good or bad collaboration, and there are many factors affecting collaboration processes, coming up with objective measures that can be used for assessing the quality of collaboration is a complex problem. In the CSCL literature it is common to distinguish between the process and the results of collaboration. The process is about quality and success of interaction such as whether peers understand each other, or they can share the work. On the other hand, result captures the output of interaction, what group members could accomplish together and if they could learn together or not. These two aspects are related to each other in non-straightforward ways, because pairs seemingly having good collaboration may still fail to produce good results, so there are many factors affecting the relationship between collaboration processes and outcomes. Because of these reasons, the collaboration process must be examined in detail, by not only using quantitative data from eye-trackers but also using qualitative methods such as moment-to-moment analysis of interaction.

To sum up, this thesis contributes to CSCL literature by investigating qualitative and quantitative aspects related to the achievement and management of joint attention and common ground during collaborative problem solving. Employing a mixed methods approach allowed us to better interpret quantitative measures of joint attention such as gaze overlap in relation to qualitative insights obtained from interaction analysis of collaborative problem solving processes. Furthermore, by focusing on the usability aspects affecting the collaboration process in a CSCL environment, the thesis also aims to contribute to the HCI field by illustrating the use of the dual eye tracking paradigm for evaluating the effectiveness of communication support provided by collaboration technologies.

CHAPTER 3

METHODOLOGY

This study seeks to understand the process of computer supported collaborative problem solving processes occurring in the VMT environment. In this chapter, we begin with presenting the research questions. Then we give details about the pilot studies conducted to observe the flow and impediment of the experiments to finalize the experimental design of the study. In this section, participants, instruments, procedure, environment, software, and data analysis are presented.

3.1 Research Questions

This study will search the following questions:

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. To what extent gaze overlaps corroborate with shared understanding evidenced in interaction?
4. How does the usability of VMT environment affect collaborative problem solving processes?

3.2 Design of the Study

In this study, mixed methods research design is used, because both quantitative and qualitative methods are employed to investigate the main research questions. As stated by Creswell and Plano Clark (2011), mixed method is a process of collecting, analyzing, and combining both qualitative and quantitative data to provide a deeper understanding of the research problem at hand.

For the quantitative part, firstly, participants filled a questionnaire containing questions about gender, age, educational background, computer usage skills and time period, Internet usage period, prior knowledge about GeoGebra, drawing and chat programs before the experiment. Then, eye tracking measures such as number of fixations, fixation counts and gaze distributions at specific areas of interests (AOI) were exported from Tobii Studio software. These eye tracking features were then further processed to produce gaze overlap (i.e. recurrence) measures. Finally, after the experiment, participants filled another questionnaire containing Likert type scale items.

For qualitative part, the case study method is employed to explore the kinds of collaborative actions occurred and the ways those actions were interactionally organized in a specific CSCL environment. In this study, as it was mentioned in Chapter-2, interaction analysis is conducted to investigate how collaborative activities are performed by small groups, instead of starting with predefined conceptions about effectiveness of collaboration and imposing arbitrary external measures (Roschelle, 1996; Roschelle & Teasley, 1995; Stahl, 2006; Koschmann, Stahl & Zemel, 2007; Koschmann & Zemel, 2006). In other words, we aimed to develop categories for describing the participants' actions grounded upon what they contribute and how they respond to each others' contributions. Finally, after the experiment, participants filled a questionnaire containing open-ended questions related to their experiences with the VMT environment.

To sum up, we use mixed method; both quantitative data collected via questionnaires and eye-trackers, and qualitative data collected from eye-trackers (exported as videos) and open-ended questions.

3.2.1 Participants

In this study, there were 18 subjects who study either at the undergraduate or graduate level at Middle East Technical University. Although participants were from different departments, they all majored in math and science during high school. Their ages were ranging between 22 and 29 and the mean age of the sample was 25.2. There were 12 females and 6 males, and all participants reported that they had basic knowledge of high school geometry. All subjects volunteered to participate in the experiment and signed an informed consent form approved by the METU Human Subjects Ethics Committee.

3.2.2 Materials, Apparatus and Software

In this study, two surveys and the Tobii Studio software were used to collect data.

The first instrument is a survey prepared for collecting the demographic information of the participants, and given in Appendix A. This survey consists of 10 questions about gender, age, educational background, computer usage skills and time period, Internet usage period, prior knowledge about GeoGebra, drawing and chat programs.

The second data collection instrument is a questionnaire containing the System Usability Scale (SUS) and the open ended questions given in Appendix B. SUS has been developed by John Brooke from Digital Equipment Corporation in 1986 to evaluate the usability of systems or products in a quick and practical way. This scale consists of ten Likert scale items with ratings between 1 and 5. While developing this scale, firstly fifty potential survey items were assembled, and those items were used as part of software tests. Finally this scale was reduced to ten items according to the test results and experts' analysis. SUS gives a usability score ranging between 0 and 100. 0 means usability of a system or product is not good and 100 means usability of this system or product is very good. In order to calculate the SUS score, 1 point is subtracted from the number 1, 3, 5, 7, and 9 questions' score. In addition to this, number 2, 4, 6, and 8 questions' scores are subtracted from 5. Then all questions' scores are added to each other, and finally multiplied by 2,5. SUS was translated from English to Turkish by five different peers using the cross translation procedure.

In this study, in order to collect participants' eye-movements, Tobii T 120 and Tobii T 1750 eye tracking devices were used. These devices track both eyes of participants, and collect data such as where the participants look on the screen, how long and how many times they look at which location on the screen using the reflectors and the infrared detector cameras. Tobii T 120 eye-tracking device has a 17 ''flat LCD screen, can capture the participants' glance with a 0.5 degree of accuracy at a 120 frames per second. The T120 can accurately monitor the eyes provided users move their heads within certain limits, i.e. 30 cm on horizontal axis, 22 cm on vertical axis, and 30 cm backward or forward to the screen. Otherwise the T120 loses the subject's eye-movements. The second eye-tracker used in this study is Tobii T 1750 eye-tracking device. It has a 17 ''flat LCD screen, can capture the participants' glance with a 0.5 degree of accuracy at 50 frames per second. The T1750 can accurately monitor the eyes provided users move their heads within certain limits, i.e. 30 cm on horizontal axis, 16 cm on vertical axis, and 20 cm backward or forward to the screen. Otherwise the 1750 loses the subject's eye-movements

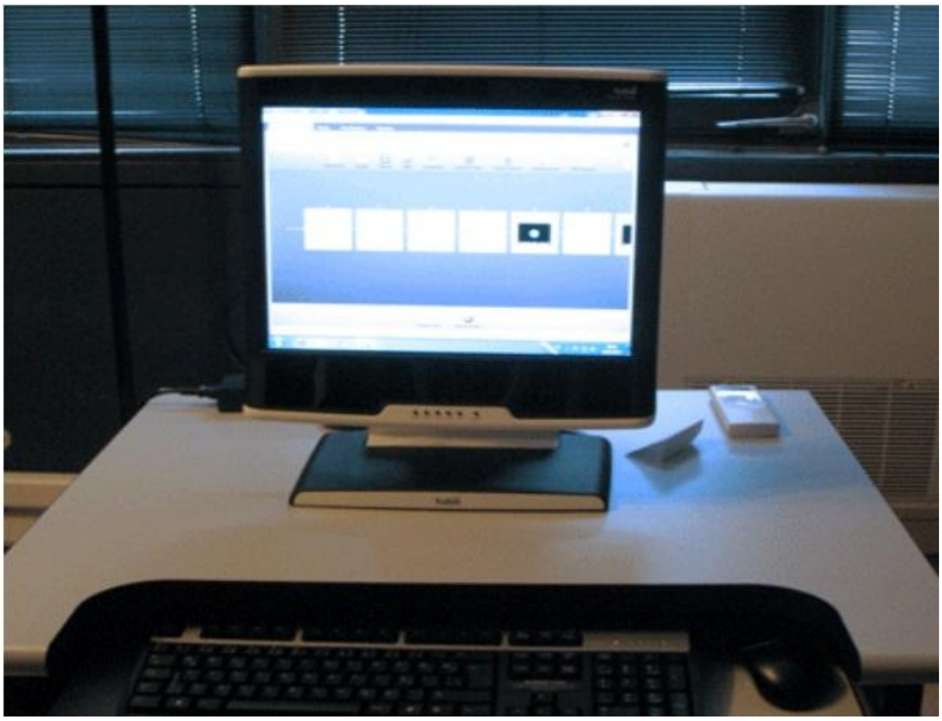

Figure 3.1 Eye-tracker at METU Computer Center

Figure 3.2 Eye-tracker at METU CEIT

The raw data recorded by the eye trackers needs to be processed to extract meaningful information to aid the interpretation of the corresponding eye movements. In order to process this raw data, Tobii Studio Software developed by the manufacturer of both eye-trackers is used. This software transforms the raw data into visual and digital data, and records them, so we can analyze them using this software' tools. While analyzing the data, Tobii Studio Software version 3.1.3 was used for this study.

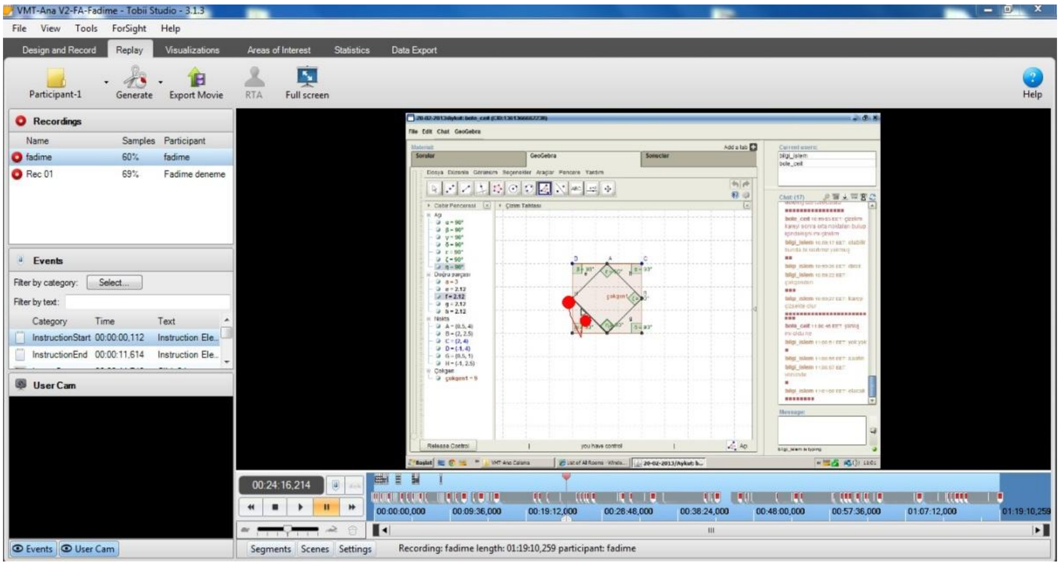

Figure 3.3 Tobii Studio Software 3.1.3

In addition to the Tobii Studio Software, Transana Transcription and Analysis Software was used to analyze the data. In this software, two videos can be seen synchronously, and recurrence of the eye-movements can be observed qualitatively.

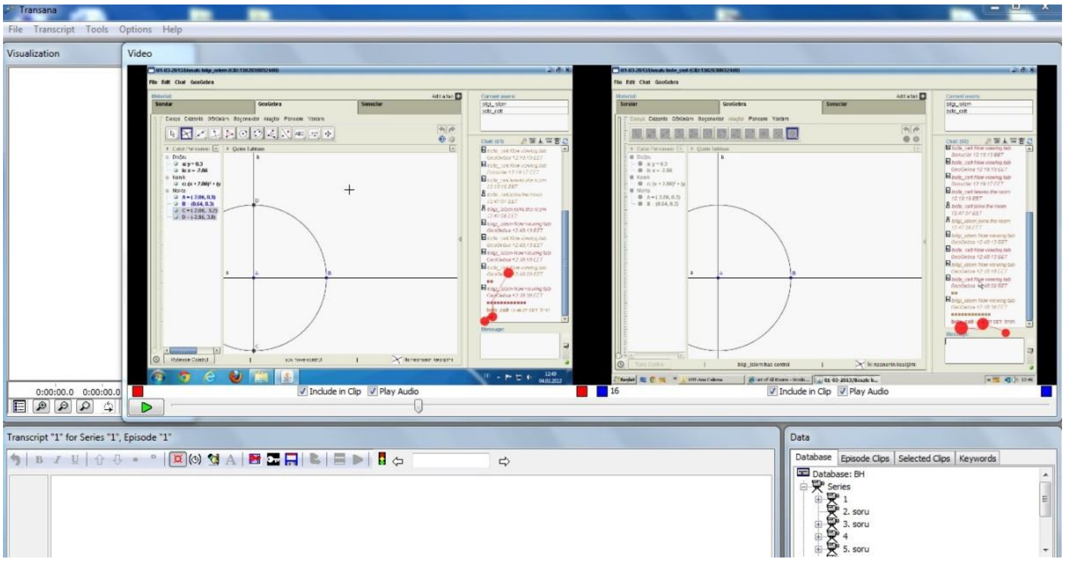

Figure 3.4 Transana Transcription and Analysis Software

In addition to these, 10 geometry problems were chosen from the book named as Dynamic-Geometry Activities with GeoGebra for Virtual Math Teams prepared by the VMT Project Team from Drexel University (Stahl, 2012). While choosing the questions, the criterion was that the questions can be solved with basic geometry knowledge given in high school. Questions are given in Appendix C.

In this study, Virtual Math Team environment developed by The VMT Project Team from Drexel University was used to host the collaborative problem solving sessions (http://vmt.mathforum.org/VMTLobby). In this environment, chat rooms can be created, and whiteboard or GeoGebra software tool can be embedded to these chat rooms. GeoGebra is a free tool that provides users tools for constructing digital dynamic geometric drawings to explore dependencies, invariants and algebraic properties among mathematical objects.

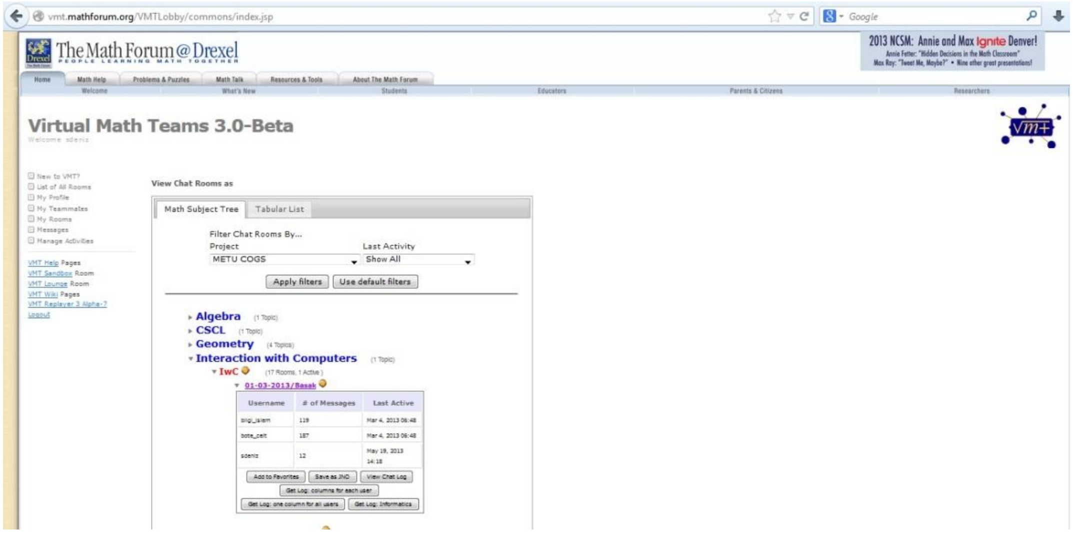

Figure 3.5 Virtual Math Team Website

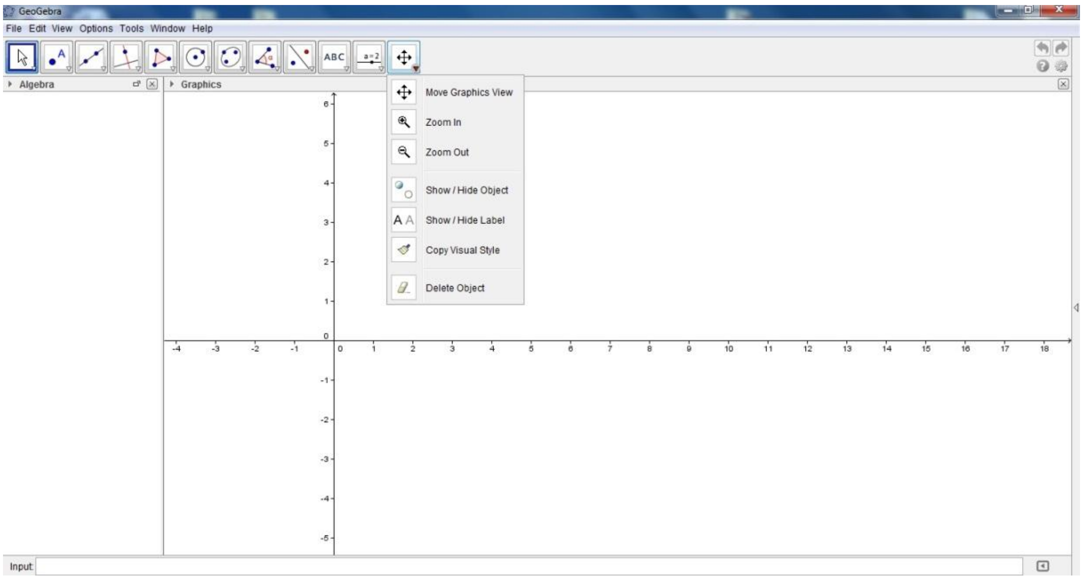

Figure 3.6 GeoGebra Software

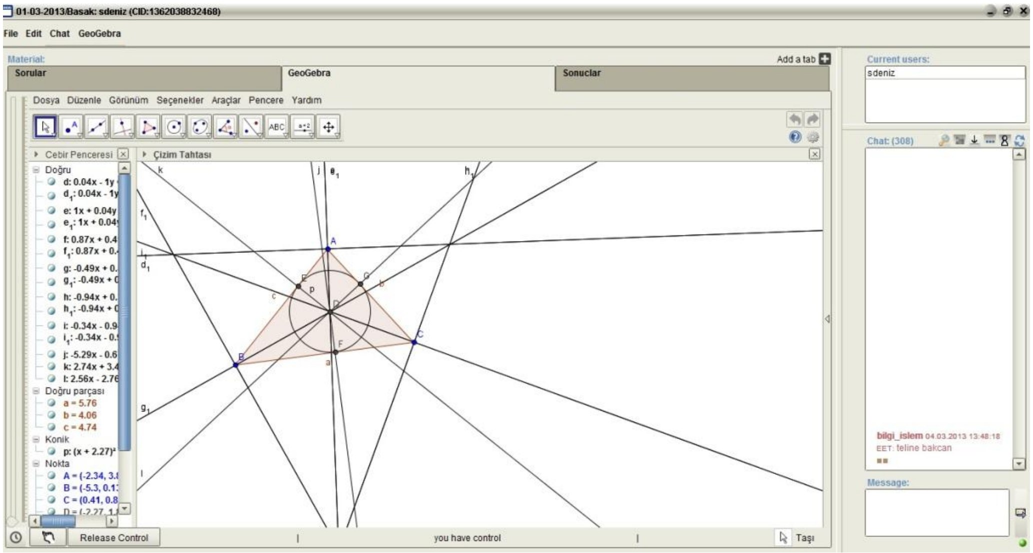

Figure 3.7 VMT Chat Room

3.2.3 Data Collection Procedure

3.2.3.1 Pilot Studies

Before the main experiments, two pilot studies were conducted with 4 participants. 2 of them were from the department of Computer Education and Instructional Technology, and the others were from the department of Mathematics Education. The aim of the pilot studies was to see whether there are impediments in the experimental setting. According to participants, questions related to geometry were understandable. However, they reported that the training part was long and had irrelevant sections, so the training part was shortened. They, also, stated that working with a familiar peer provided them with a more comfortable working environment. After pilot studies, the recorded data were examined, and it was seen that there was no problem with the eye tracking and VMT log data.

3.2.3.2 Before Experiments

Before the experiments, in order to reach participants, an e-mail explaining the aim of this study was sent to people having appropriate characteristics (i.e. majoring in a department that accepts students based on their math & science scores) for this study. People who accepted the invitation were chosen as participants. Then one more e-mail containing consent form given in Appendix D was sent to participants, and participants were informed about time and place of the experiment.

While we formed the pairs, we considered the following criteria. Firstly, both of them must be from the same department, and at the same educational level. Secondly, they must know each other. The reason why we choose partners using these criteria is mentioned the study of Nüssli (2011). According to his study, if partners know their related level of knowledge, the interaction among partners can be increased in CSCL, because this awareness provides partners with faster and better grounding between them. Furthermore, Sangin (2009) stated that if partners are aware of their knowledge, they can adapt their communication to their peer and can better estimation about what their peer say. The scope of the study is limited to peers who know each other. Such pairs would be more appropriate to control for social factors that may influence the performance of the groups. By choosing groups that are more likely to work together, we aim to focus on technological factors that impact their joint work.

3.2.3.3 Experimental Setup

In this study, 9 pairs were selected who study in natural and applied sciences departments as undergraduate, master or doctorate students. Those pairs were requested to solve geometry problems collaboratively for at least 45 minutes. 10 geometry problems were determined. All pairs attempted the problems in the VMT environment. For this study, a separate chat room was created for each pair. In these chat rooms, there are 3 tabs: Questions, Geogebra, and Results. The question tab listed all 10 questions. The Geogebra tab consists of an algebra view that provides algebraic representations of objects in the workspace (e.g.length of a line segment), and a construction area providing participants with drawing features. The construction area was the main area where pairs produced their solutions. On the result tab, participants were asked to summarize their results/proofs on the whiteboard after they solve each problem they completed. Finally, participants used the chat window on the right of the screen to exchange text messages. The chat bar displays a list of recently posted messages and awareness messages that indicate who is currently typing.

Before collaborating on geometry problems, each participant individually went through a training part lasting approximately 10 minutes which presents the basic features of the VMT environment, the Geogebra tools used frequently while solving geometry problems and an example for a quick hands on trial. The details of this tutorial are given in Appendix E.

During the experiments, pairs tried to solve problems together by communicating via the chat section. Because only one person could take control and draw in the construction area, other partner could either look at the unfolding drawings and/or give feedback via chat messages. Partners need to press the “Take Control” button to request access and lock the drawing area. Once they are done they can make the drawing area accessible to the partner by pressing the “Release Control” button. If a user sits idle for a certain amout of time, the control is automatically released. Participants took turns while they were building geometric constructions.

In order to see how pairs interact with each other, whether they follow each other or not, and recordings of eye movements of pairs, two eye-trackers (a Tobii T120 and a Tobii T1750), and Tobii Studio Software were used. Screen recordings of pairs were separated into segments for each question, exported to avi formatted video clips, and synchronized with Transana Transcription and Analysis Software.

3.2.3.4 After Experiments

At the end of the sessions, participants were required to fill an open ended survey in order to gather data related to their ideas about the environment and the collaboration process.

3.3 Data Analysis

In this study, a mixed method approach was employed for the analysis of chat logs, eye tracking data and screen recordings.

First the survey was analyzed descriptively. Descriptive statistics were used in order to identify the distributions of participants' gender, age, educational background, computer usage skills and time period, Internet usage period, prior knowledge about GeoGebra, drawing and chat programs. Descriptive statistics provide indices such as mean, median, mode (Fraenkel & Wallen, 2009), which were used to identify characteristic properties of the study's sample.

After the experiments, data gathered from eye-trackers were analyzed both quantitatively and qualitatively. For quantitative analysis, recording time stamps, local time stamps, coordination of gaze points and area of interests of the eye movements were considered, and exported from Tobii Studio Software.

Eye tracker data divided into segments and scenes for further examination. 16 AOIs that are of equal area were defined over the scenes (Figure 3.8). Each of these 16 regions was considered as an approximation of the part of the screen over which the participants were attending to at any given time. While monitoring the scene users either move their eye gaze with saccadic movements or fixate on specific locations by keeping their eyes still over a location. During a fixation event the fovea, which is the part of the retina that has the highest concentration of light sensitive cells (i.e. area producing the highest resolution image), will be oriented towards the fixated location. The fovea covers approximately 1-2 degrees of visual field. At a distance of 65 cm from a screen, 1-2 degrees of visual field corresponds to a circular area with a diameter of 2.2 cm on the screen (Duchowski). The visual attention span is considered to cover a larger area covered by the foveal projection, as evidenced in dual-task experiments (Palmer, 1999; Holmqvist et al., 2011). Since 17 inch displays with 4:3 aspect ratios were used during the experiments, the width and the length of the screen was 35 cm and 26 cm respectively. Splitting this area into 16 equal non-overlapping rectangular AOIs covers an area approximately 9 cm wide and 7 cm long. In this study this rectangle was considered as a rough approximation of where the person is attending to at any given time.

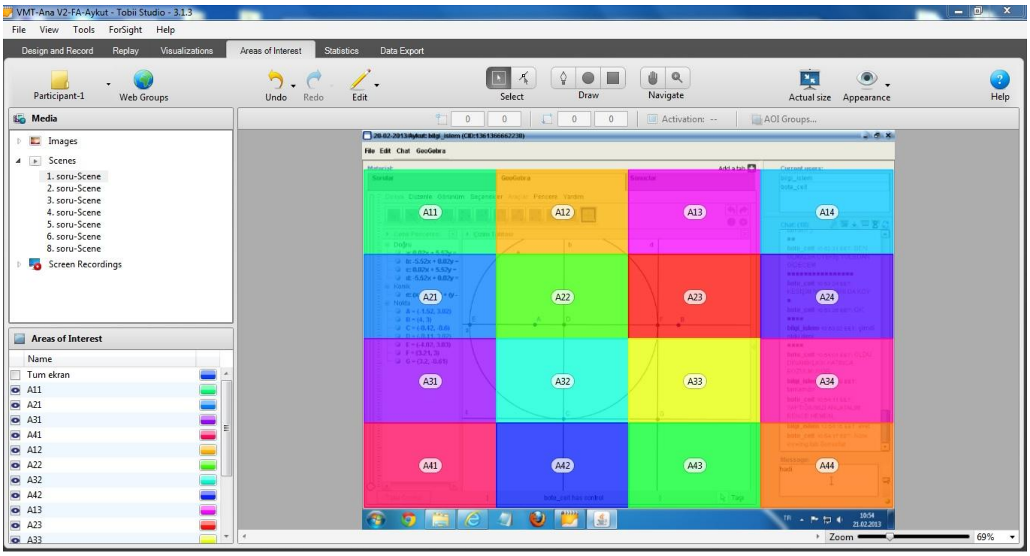

Figure 3.8 AOIs

Using the same AOI definitions on both screens allowed us to monitor gaze overlaps without considering the dynamic changes happening in the environment. Since the screens were divided equally, the probability that one of the participants allocate their attention on a given AOI is 1/16. Assuming independence of gaze events, the possibility that two people allocate their attention on the same AOI is 1/16x1/16 = 1/256. So, gaze overlapping of 2 people can not be repeated systematically by chance.

We, also, used the quantitative eye-tracker data to measure the degree of gaze overlap among the collaborating pairs. This method is called cross-recurrence analysis and was initially applied to dual eye gaze data in the studies of Richardson and Dale (2005) and Richardson et. al. (2007). In order to perform this analysis, we use a program written in Java. This program accepts the raw data extracted from Tobii with gaze timestamp and AOI information as input, and returns a scarf plot that provides information about which AOI participants looked at, when their eye gazes overlapped, and over which AOI. Figure 3.9 shows a scarf plot for a segment extracted from the eye tracking data of a single pair. In this segment the pair worked on a single geometry problem for about 210 sec. Rows 0 and 1 indicate the distribution of eye gaze of the first and second participants over the 16 AOIs respectively. Each AOI is color coded where red, purple, green and gray tones represent the first, second, third and fourth rows of the AOI matrix. Area C stands for content. This category is applied to those gaze instances where participants are not looking at some specific area on the screen, which may either happen due to excessive head movements or due to typing events (since most participants look at the keyboard while typing). In addition to this, row 2 represents the cases where gaze locations of the participants overlap or intersect in time. When there is an overlap a gray line is added that marks the beginning and end of the gaze overlap event. The plot also indicates that the total duration of gaze overlap was 17 seconds in this particular segment (see Figure 3.10). Finally the software also allows zooming in and out of the scarf plots (see Figure 3.11), which can be useful for qualitative analysis of those instances with high/low degrees of gaze overlap.

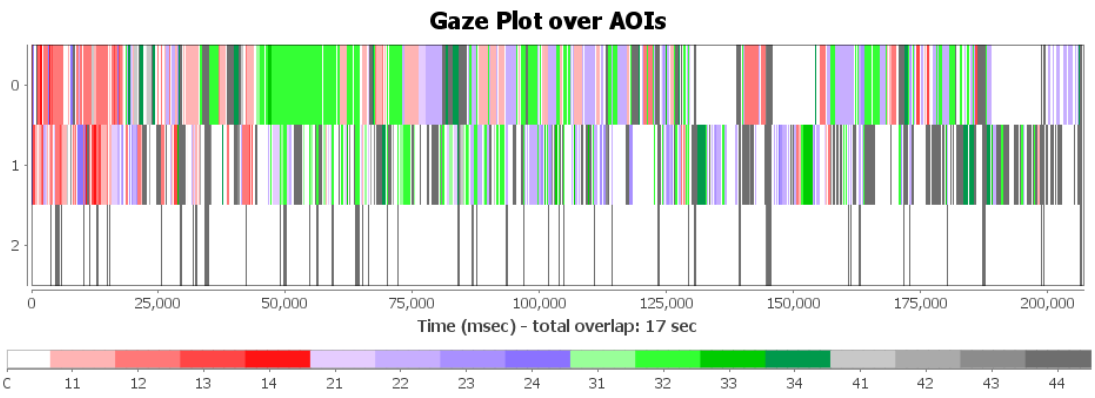

Figure 3.10 Gaze Plot over AOIs

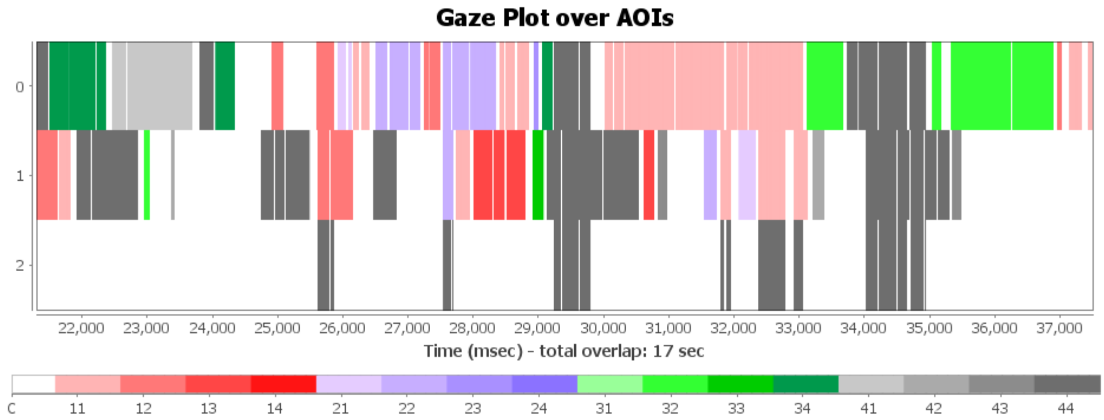

Figure 3.11 Zoom in Version of Scarf Plot

In addition to the scarf plot, the software also returns a plot that displays the gaze overlap distribution as displayed in Figure 3.12. This visualization shows the distribution of recurrence percentages among the gaze patterns of both partners with time lags ranging in between +4 and -4 seconds during the same segment. This visualization is generated by plotting the total gaze overlap duration among the participants, when participant A's gaze sequence is shifted x msec where x ranges between -4000 and 4000 msec, and is incremented in 100 msec. The values are then converted into percentage values in reference to the segment's length. The software can plot recurrence charts for any range and resolution, but obtaining a data point for every 100 msec turned out to be sufficient to observe general patterns in cross recurrence for individual pairs.

The recurrence plot also displays the recurrence percentage distribution (the blue curve in Figure 3.12) when the gaze sequences are randomly shuffled in an effort to provide a baseline for comparing against the observed recurrence distribution. Note that only the order of the gaze events is shuffled for the baseline computation, but the duration of each gaze event is not changed.

The reason why we examined the +4 and -4 seconds as time interval is based on the study of Richardson and Dale (2005). They examined the level of recurrence of speakers and listeners' eye gazes during problem solving session, and they found that the listeners' tend to look at the same location where speakers looked at a delay of 2 seconds. This finding depends on the situation of speaker-listener collaboration, but in our study communication was performed via a chat tool, so we extend the time interval from +2 and -2 seconds to +4 and -4 seconds in order to explore gaze overlap patterns peculiar to the chat case. Because the time of a partner see his/her teammate's message, and looks at where s/he mentions takes time more than 2 seconds.

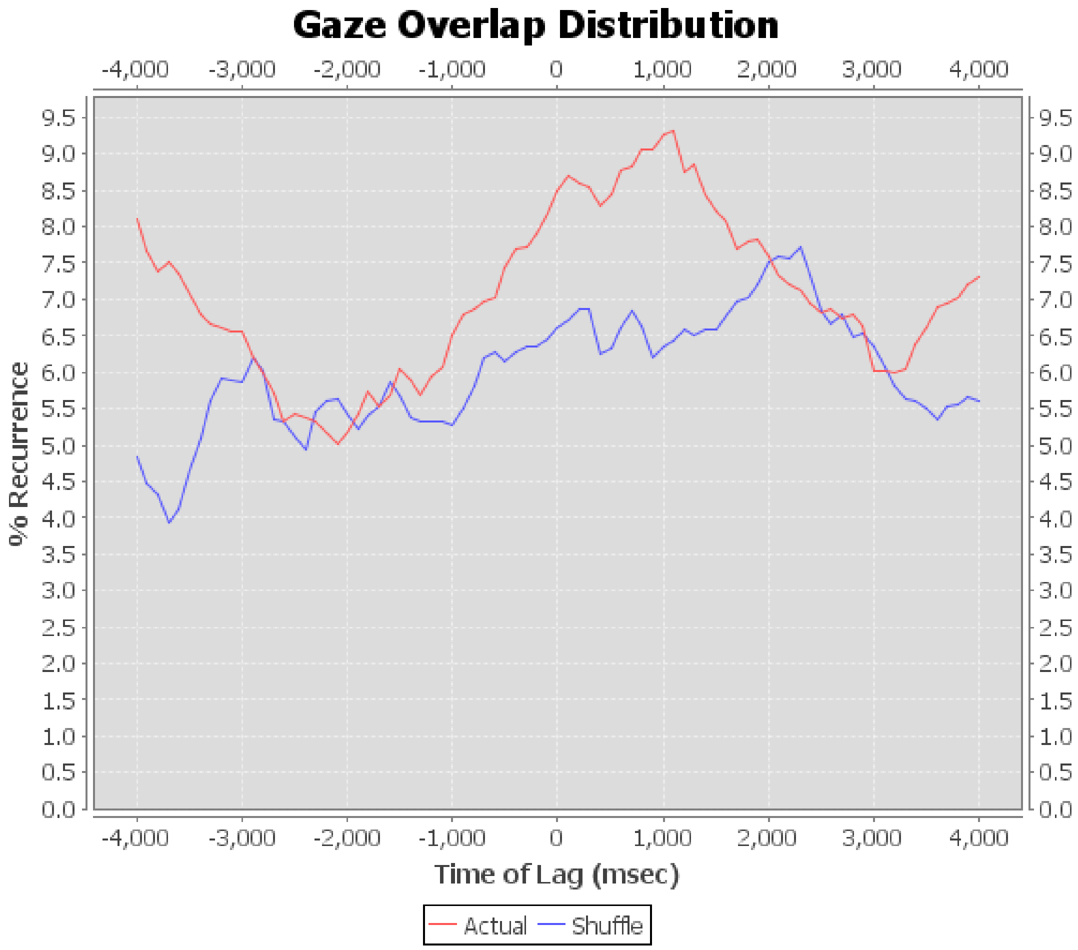

Figure 3.12 Gaze Overlap Distribution

The graph shows the cross-recurrences of a pair in time duration of 4 seconds. The additional baseline indicates a randomly shuffled AOI value from the dataset, to be able to make a comparison against a random case.

A separate recurrence graph is plotted for each session of every pair. For each pair, these plots were then combined into a single recurrence percentage plot by taking the average of all corresponding data points coming from the plots for individual segments (see Figure 4.10 for an example). This produces a summarized recurrence plot showing the gaze patterns over all problem solving segments of the pair. In the combined summary plot, data points also range from -4000 msec to +4000 msec with a 100 msec resolution. Point 0 indicates the recurrence percentage of the pairs for a precisely synchronous gaze, -200 indicates the recurrence percentage in which B gazes with a 200 msec delay with respect to A, and vice versa. The blue part shows the same info with a shuffled gaze data which is used as a baseline. The vertical lines are the standard error bars, which indicate the amount of deviation in the data for the corresponding time. These graphs are used to identify global gaze patterns for each pair. For instance, pairs that exhibit significant gaze recurrence patterns and whether the gaze following is balanced among partners or if one member tend to follow the other and vice versa can be deduced from the summary plots.

After experiments, for the second survey analysis, answers from the open ended questions were examined, and analyzed. While analyzing the data, codes were determined, and enumerated in order to find frequency of related category. According to Yıldırım and Şimşek (2000), to increase reliability of qualitative data, they should be converted into numbers.

Participants, also, filled the System Usability Scale (Likert type) and this scale was, also, analyzed descriptively. According to this scale, rating of first, third, fifth, seventh and ninth items calculated with "Rating Position-1", and rating of second, fourth, sixth, eighth and tenth calculated with "5-Rating Position". Then sum of the scores is multiplied with 2,5, so result is found between 0 and 100.

3.4 Assumption of the Study

For this study, following assumptions are pointed out:

- Participants responded accurately to open-ended questions and SUS.
- The measures employed were reliable and valid indicators of the constructs to be studied.
- The qualitative and quantitative data were accurately recorded, collected and analyzed.

3.5 Limitation of the Study

The following limitations were recognized throughout the study:

- The scope of this study is limited to 18 college students (i.e. 9 pairs).
- The two eye-trackers used in this study do not have the same sampling resolution. T120 and T1750 provide a data point for every 8 and 20 msec respectively.

CHAPTER 4

RESULTS

In this chapter, firstly the results of the questionnaire conducted before the experiments are presented. Next, the results of the analysis based on eye-tracking data are presented both quantitatively using features such as number of fixations, gaze duration, gaze overlap and recurrence, and qualitatively via interaction analysis of excerpts obtained from video recordings of VMT Chat sessions. The last part of this chapter includes a qualitative analysis of the results of the questionnaire conducted after the experiment.

4.1 Quantitative Data Results

4.1.1 Participants' Demographics

In this part, the demographics of the participants and descriptive statistics about their educational level, major, prior experience with GeoGebra, computer experience, computer skills, Internet usage (year and daily), and prior experience with drawing and chat software are presented.

18 people participated in this study. Their ages varied between 22 and 29, and their mean age was 25,2. 6 of them were male, and 12 of them were female. The distribution of the educational level of the participants is given in Table 4.1. 10 of the participants were in the Ph.D., 4 of them were in the M.Sc., and 4 of them were in the B.S. degree programs at METU respectively. The distribution of the participants' departments is, also, given in Table 4.2.

Table 4.1 Educational Level

	B.S.	M.Sc.	Ph.D.
Educational Level	4	4	10
%	22.22	22.22	55.56

Table 4.2 Distribution of the Participants' Major

Department	Elementary Science and Mathematics Education	Elementary Mathematics Education	Medical Informatics	IS	CEIT
Frequency	2	4	1	2	9
%	11.11	22.22	5.56	55.56	50.00

4 of the participants indicated that they had used the GeoGebra program before, and their usage frequency is rare (Less than 2 or 3 months). The distribution of the frequency of computer usage is given in Table 4.3. 10 of the participants have been using computers for 10 years or above, 6 of them between 7 to 9 years, and 2 of them between 4 and 6 years respectively. 4 of the subjects rated their computer usage skills as very good, 11 of them as good, and 3 of them as average respectively, which is summarized in Table 4.4.

Table 4.3 Computer Usage

	4-6 years	7-9 years	>10 years
Computer Usage	2	6	10
%	11.11	33.33	55.56

Table 4.4 Computer Usage Skills

	Average	Good	Very Good
Computer Usage Skills	3	11	4
%	16.67	61.11	22.22

The distribution of the time period of Internet usage is given in Table 4.5. As shown in table, 5 participants have been using the Internet for 10 years and above, 8 of them for 7 to 9 years, 4 of them for 4 to 6 years, and 1 participant for 1 to 3 years respectively. The distribution of the daily usage of Internet given in Table 4.6 indicates that only 1 participant reportedly uses the Internet more than 8 hours in a day. 5 participants use the Internet between 6 and 8 hours in a day, whereas 10 participants reported usage between 4 and 6 hours, 1 participant between 2 and 4 hours, and 1 participant less than 2 hours a day respectively.

Table 4.5 Internet Usage (Year)

	1-3 years	4-6 years	7-9 years	>10 years
Internet Usage	1	4	8	5
%	5.56	22.22	44.44	27.78

Table 4.6 Internet Usage (Daily)

	<2 hours	2-4 hours	4-6 hours	6-8 hours	>8 hours
Internet Usage	1	1	10	5	1
%	5.56	5.56	55.56	27.78	5.56

As far as previous experience with drawing software is concerned, 10 of the participants replied that they have used a drawing program before, and 8 of them reported that they have never used such a program. Participants who reported prior experience with drawing programs all mentioned that they used Adobe Photoshop. In addition to this, some participants mentioned other drawing programs such as Corel Draw, Paint, MS Expression Design, and ARIS Architect.

At the last question of this questionnaire, all of the participants stated that they have used a chat program before. The distribution of the frequency of chat program use is given in Table 4.7. Programs used by participants are Windows Live Messenger, Facebook Chat, Google Talk, ICQ, WhatsApp, Skype, and Viber.

Table 4.7 Chat Program Usage

	Rarely	Sometimes	Frequently	Very Frequently
Chat Program Usage	2	1	6	9
%	11.11	5.56	33.33	50

Because VMT chat environment is design to support collaborative problem solving processes to learners whose educational level can vary between secondary school and university, so studying with students from different degree and different STEM departments is appropriate for this study. Furthermore, questions contain elementary geometry concepts. The sample is, also, appropriate for this study, because participants have a familiarity to chat, use computer and Internet, and drawing program.

4.1.2 System Usability Scale Results

System Usability Scale (SUS) is used for calculating the participants' satisfaction level. All of the participants' scores are given in Table 4.8. The highest score belongs to AB from Pair-5 and TA from Pair-7, and the lowest score belongs to SD from Pair-6. The average of all participants' score is, also, given in this table.

Table 4.8 Participants' SUS Score

	SUS Score (bilgi_islem)	SUS Score (bote_ceit)
Pair-1 (GP-GÇ)	65	65
Pair-2 (SB-IHB)	65	40
Pair-3 (TK-SK)	32,5	67,5
Pair-4 (MD-AB)	33	26
Pair-5 (AB-FU)	80	72,5
Pair-6 (MD-SD)	47,5	15
Pair-7 (TA-ST)	80	23
Pair-8 (BE-HK)	72,5	32
Pair-9 (DFC-AE)	52,5	72,5
Average	52,30	

4.1.3 Descriptive Results

In this part, the quantitative data are presented. In Table 4.9, the numbers of messages written by participants are indicated. The first letters of pairs states the participants who used "bilgi_islem" user name, and used eye-tracker in Computer Center. The second letters states the participants who used "bilgi_islem" user name, and used eye-tracker in the TELLAB at the Department of Computer Education and Instructional Technology. These letters are the abbreviation of the participants' names and surnames.

Table 4.9 Number of Messages Written by Participants

	Number of Messages (bilgi_islem)	Number of Messages (bote_ceit)
Pair-1 (GP-GÇ)	82	111
Pair-2 (SB-IHB)	133	119
Pair-3 (TK-SK)	154	219

Pair-4 (MD-AB)	187	152
Pair-5 (AB-FU)	247	171
Pair-6 (MD-SD)	121	133
Pair-7 (TA-ST)	116	121
Pair-8 (BE-HK)	117	185
Pair-9 (DFC-AE)	124	130

In Table 4.10, the total time of the experiment for each group is presented. As shown, just pair-1 finished the experiment approximately 45 minutes, but others wanted to continue although we said that 45 minutes is over.

Table 4.10 Total Experiment Time for Each Pair

	Total Time
Pair-1 (GP-GÇ)	47 mins 23 seconds
Pair-2 (SB-IHB)	54 mins 58 seconds
Pair-3 (TK-SK)	59 mins 42 seconds
Pair-4 (MD-AB)	1 hour 6 mins 5 seconds
Pair-5 (AB-FU)	1 hour 10 mins 22 seconds
Pair-6 (MD-SD)	52 mins 24 seconds
Pair-7 (TA-ST)	1 hour 13 mins 33 seconds
Pair-8 (BE-HK)	1 hour 10 mins 6 seconds
Pair-9 (DFC-AE)	52 mins 20 seconds

Table 4.11 represents the spent time on each question. In addition to this, green color represents the questions correctly solved by participants. Red cells represent cases where participants attempted the problem but arrived at an incorrect solution. Blue colored cells indicate cases where pairs tried to solve the problem, but they gave up before reaching a final answer. Finally yellow cells show those questions which participants did not attempt.

Table 4.11 Spent Times on Each Question

	Q1	Q2	Q3	Q4	Q5	Q6	Q7	Q8	Q9	Q10
Pair-1 (GP-GÇ)	5 mins 36 seconds	8 mins 4 seconds	11 mins 46 seconds	8 mins 18 seconds	6 mins 41 seconds	7 mins 27 seconds				
Pair-2 (SB-IHB)	11 mins 31 seconds	5 mins 24 seconds	3 mins 27 seconds	7 mins 31 seconds	7 mins 40 seconds	14 mins 38 seconds	16 mins 19 second			
Pair-3 (TK-SK)	13 mins 42 seconds	8 mins 16 seconds	4 mins 36 seconds	4 mins 43 seconds	4 mins 26 seconds	13 mins 7 seconds	5 mins 33 seconds			
Pair-4 (MD-AB)	5 mins 44 seconds	5 mins 31 seconds	4 mins 42 seconds	2 mins 47 seconds	3 mins 14 seconds	4 mins 27 seconds	14 mins 28 seconds	5 mins 7 seconds	10 mins 10 seconds	
Pair-5 (AB-FU)	11 mins 22 seconds	10 mins 12 seconds	11 mins 18 seconds	8 mins 26 seconds	7 mins 22 seconds	9 mins 27 second		7 mins 32 seconds		
Pair-6 (MD-SD)	7 mins 44 seconds	9 mins 20 seconds	6 mins 20 seconds	9 mins 13 seconds	7 mins 17 seconds	7 mins 38 seconds				
Pair-7 (TA-ST)	14 mins 46 seconds	22 mins 24 seconds	7 mins 29 seconds		10 mins 35 seconds					
Pair-8 (BE-HK)	4 mins 49 seconds	6 mins 5 seconds	7 mins 47 seconds	10 mins 21 seconds	5 mins 14 seconds	11 mins 31 seconds		11 mins 10 seconds		
Pair-9 (DFC-AE)	23 mins 13 seconds	26 mins 57 seconds								

In Figure 4.1, the numbers of operations for each participant of Pair-1 are shown. Generally, GÇ solved the problem, but sometimes GP made contribution to solving phase.

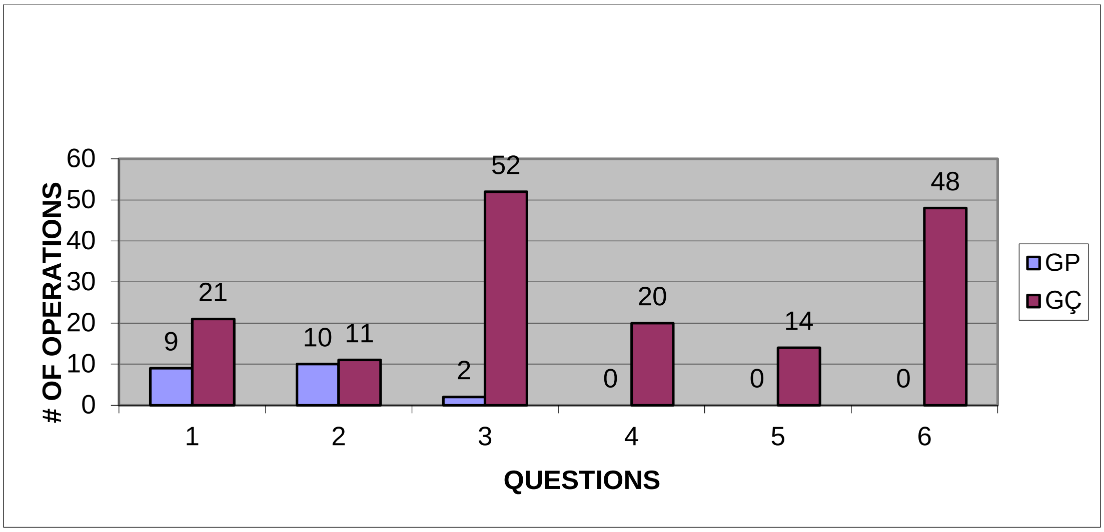

Figure 4.1 Number of Each Participant's Operations for Pair-1

In Figure 4.2, the numbers of operations for each participant of Pair-2 are shown. In the first question, IHB tried to solve, but he was not successful. Then SI took control, and solved it. During the experiment, SI continued to solve the questions and IHB just followed his action, and wrote the answers.

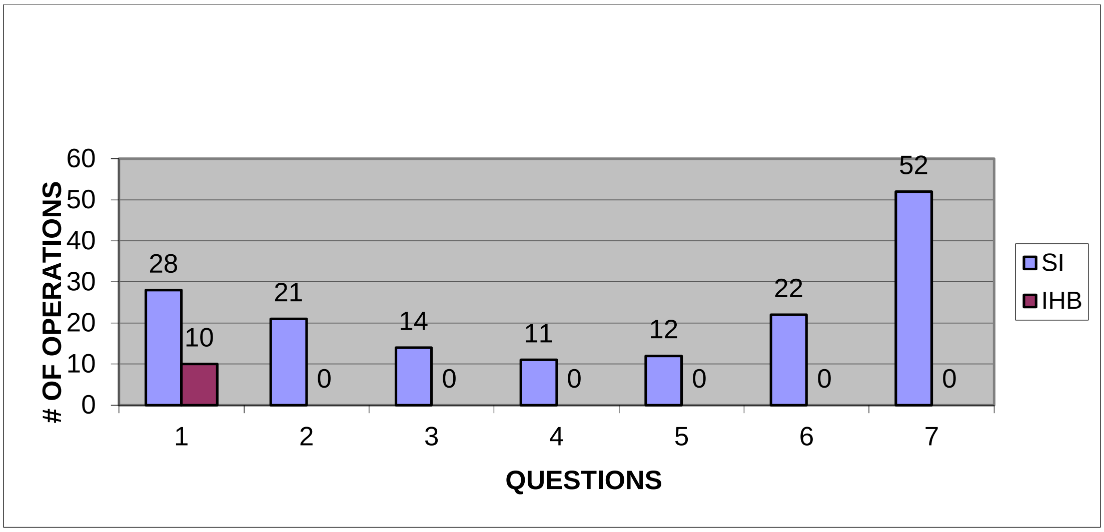

Figure 4.2 Number of Each Participant's Operations for Pair-2

In Figure 4.3, the numbers of operations for each participant of Pair-3 are shown. Except question 3, both participants made contributions to the questions. But in question 2 and question 6, SK made more contributions.

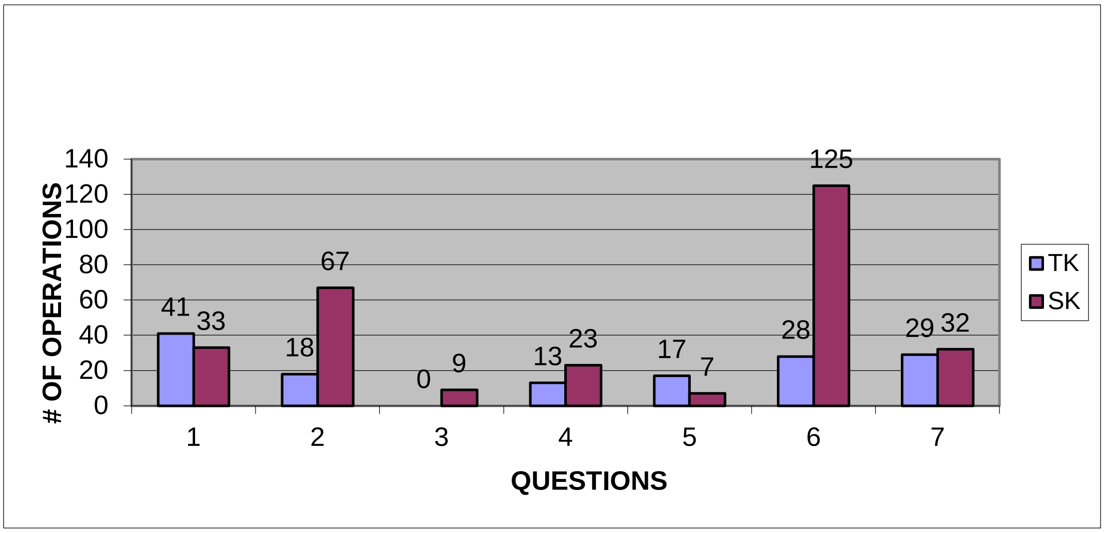

Figure 4.3 Number of Each Participant's Operations for Pair-3

In Figure 4.4, the numbers of operations for each participant of Pair-4 are presented. As shown in the figure, MD contributed more than AB.

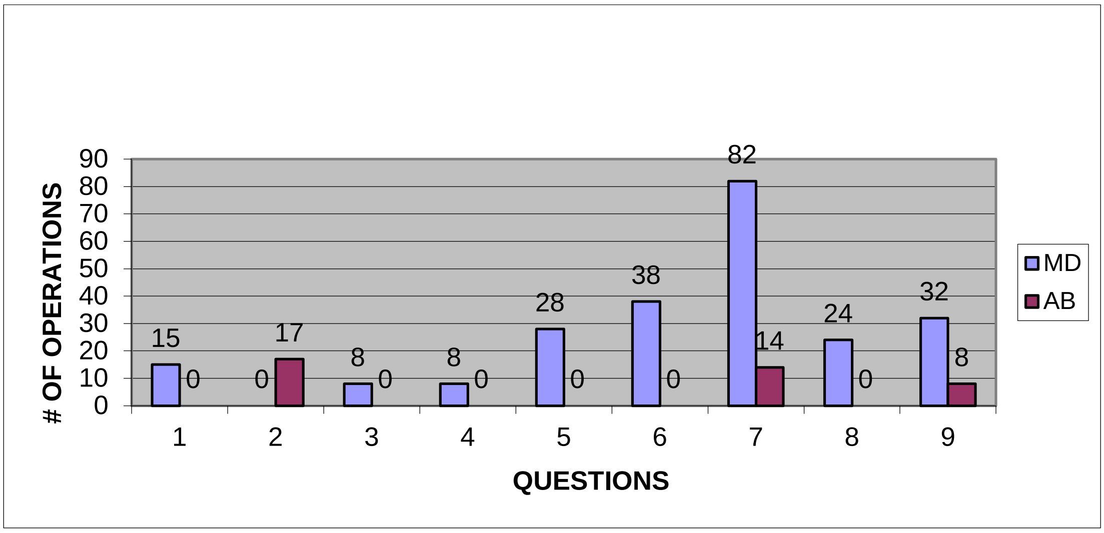

Figure 4.4 Number of Each Participant's Operations for Pair-4

In Figure 4.5, the numbers of operations for each participant of Pair-5 are shown. Both of them contributed to the five questions, and AB solved 2 questions on his own.

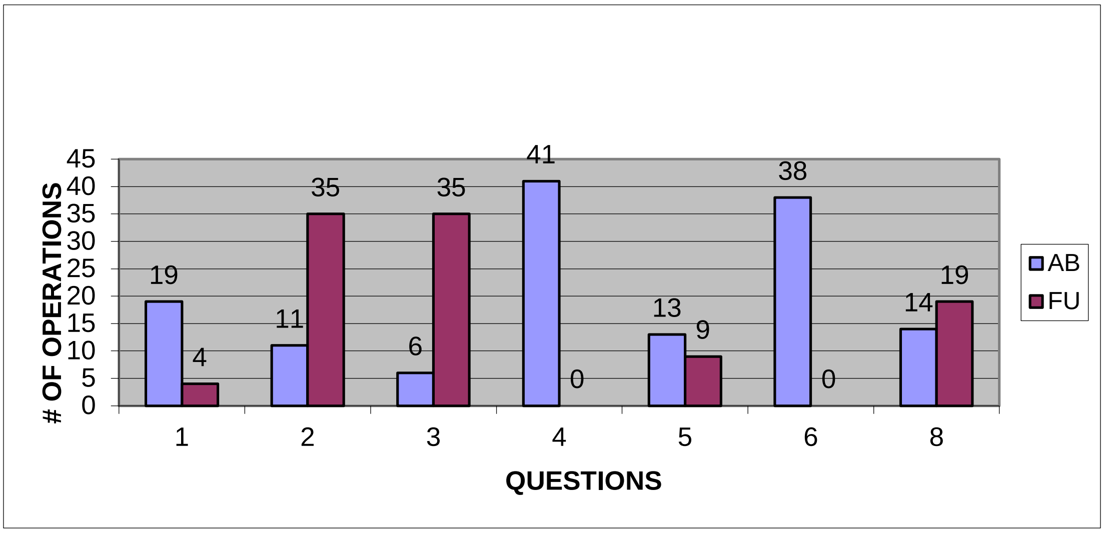

Figure 4.5 Number of Each Participant's Operations for Pair-5

In Figure 4.6, the numbers of operations for each participant of Pair-6 are shown. Except question 6, both of the participants made contribution to the questions. But MD performed more operations than SD.

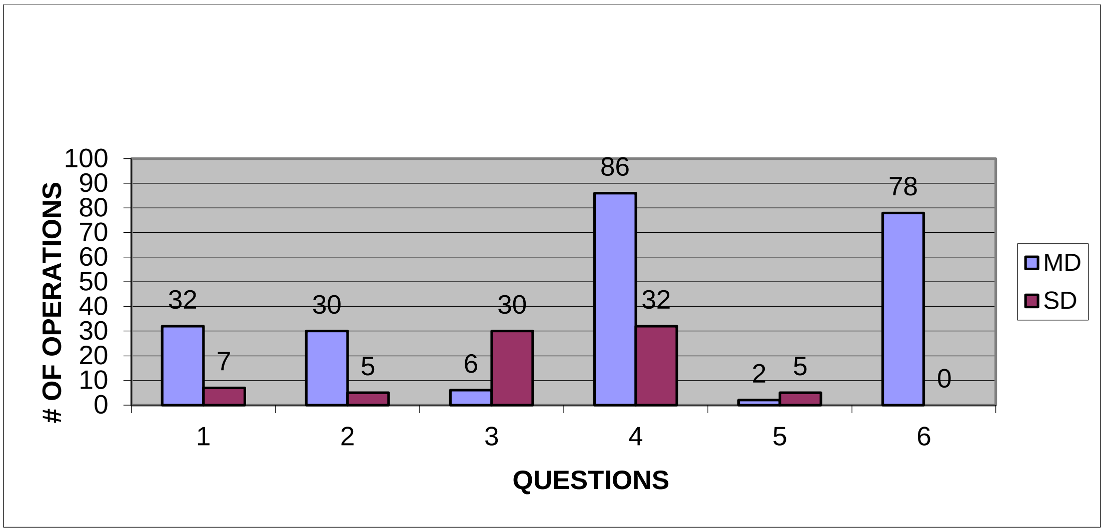

Figure 4.6 Number of Each Participant's Operations for Pair-6

In Figure 4.7, the numbers of operations for each participant of Pair-7 are presented. As shown, ST performed more operations than TA.

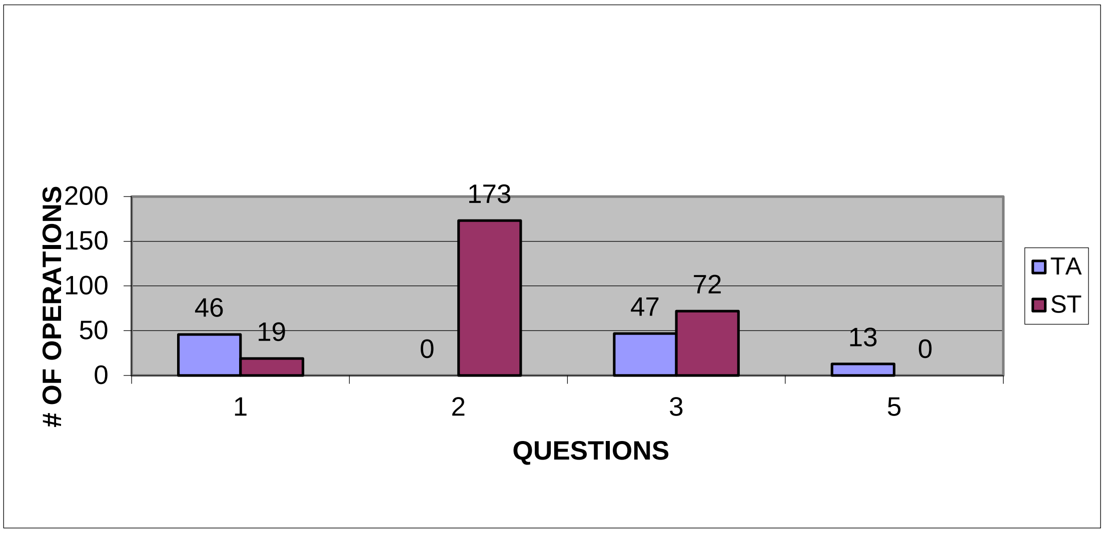

Figure 4.7 Number of Each Participant's Operations for Pair-7

In Figure 4.8, the numbers of operations for each participant of Pair-8 are presented. As shown, whereas BE solved the question 1, question3 and Question 5 by her own, HK just solved question 2 by his own. But he made more contributions in question 4 and question 8 than BE. On the contrary, BE made more contribution in question 6 than HK.

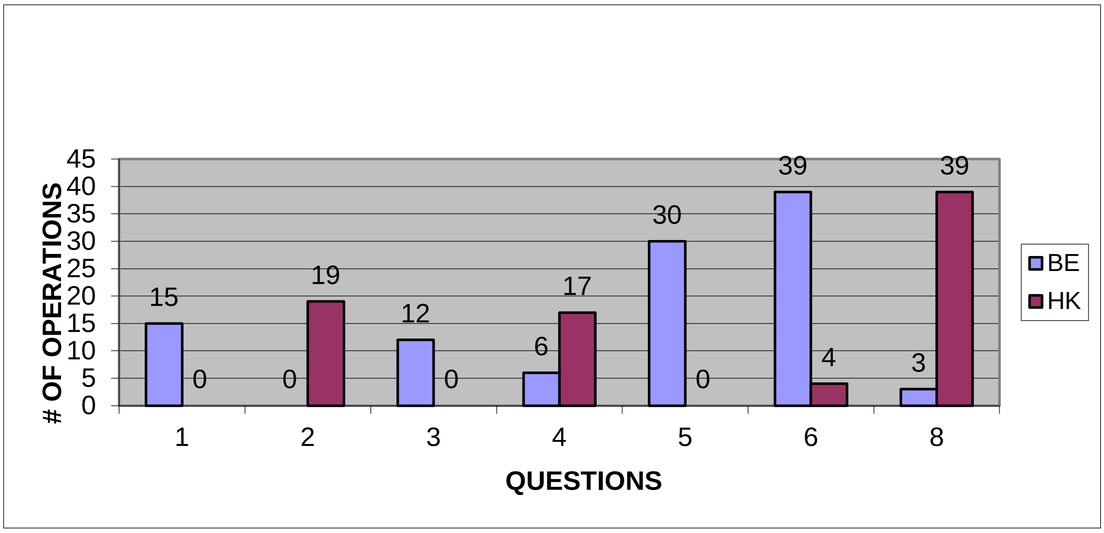

Figure 4.8 Number of Each Participant's Operations for Pair-8

In Figure 4.9, the numbers of operations for each participant of Pair-9 are shown. Both of them contributed to the questions, but DFC did more.

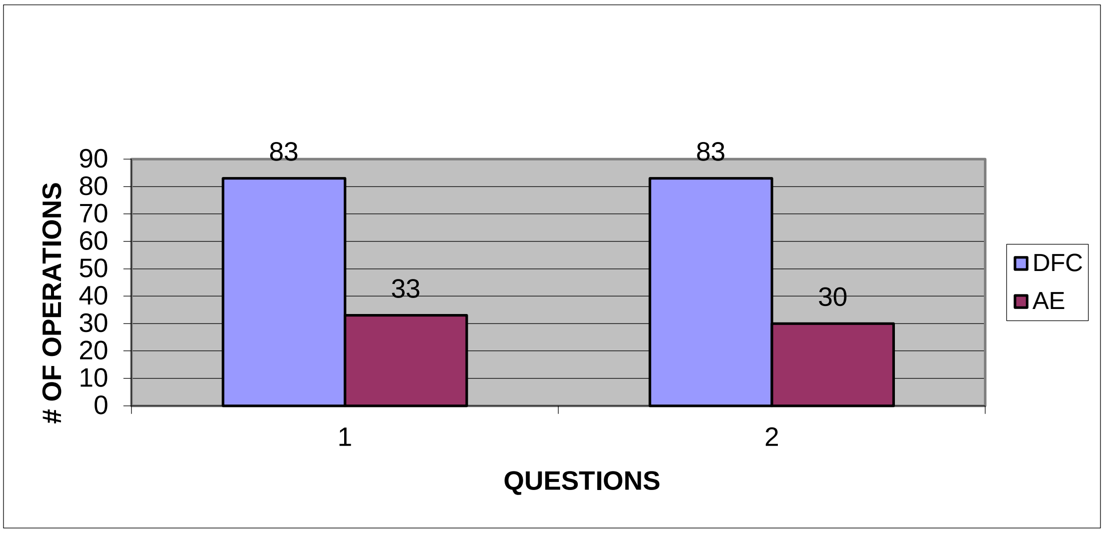

Figure 4.9 Number of Each Participant's Operations for Pair-9

4.1.4 Eye-tracker Data

In this part, the recurrence graphs for each pair are presented. While calculating the percentage of recurrence, each data point shows the overlap in the specified time lag value. 0 point indicates no lag; it is calculated as the duration the both participants gaze over the same AOI simultaneously, divided by the overall time of the segment.

Then the gaze data of one of the participants is shifted 100 msec and gaze overlap is recalculated. This identifies the occurrences of B gazing at the same point as A with a 100 msec delay. The duration is divided by segment length, and recorded as -100 msec data point.

A curvilinear graph is obtained when each value between -4000 msec and +4000 msec (with 100 msec resolution) is recorded. The overall curve of the pair is then calculated through the mean values of every question for 80 data points between -4000 and +4000. This forms the graph above.

The graphs can be interpreted as:

- If the percentage of recurrence shown as red circle is far from, and has higher percent than the random baseline shown as blue triangle, this pair has significant level of gaze coordination.
- If there is symmetry around the 0 msec, partners follow each other's actions equivalently.
- If there is a skew to the right of the 0 msec, the person whose eye-movement data are chosen firstly follows the second person more. If there is a skew to the left of the 0 msec, the person whose eye-movement data are chosen firstly is followed by the second person more.
  When examining Figure 4.10, because of percentage of recurrence and random baseline is close to each other and the convergency occurs at some points, we can interpret this graph as the level of following to each other's actions is not high.

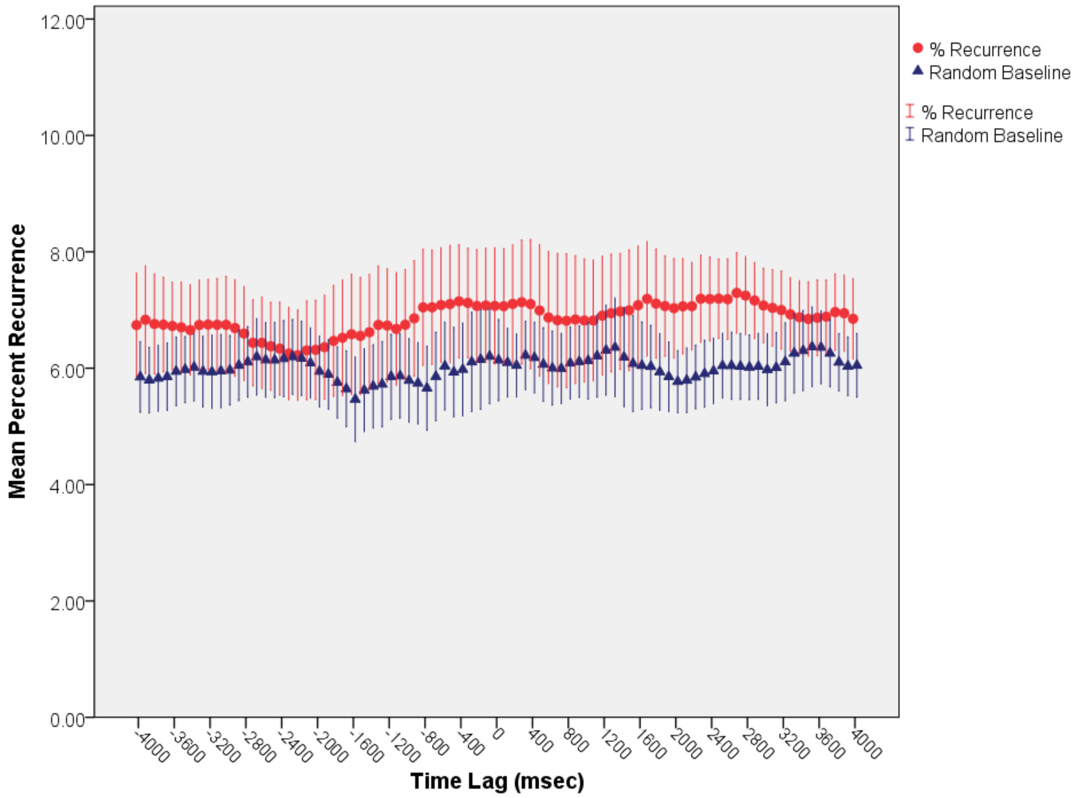

Figure 4.10 Recurrence Graph of Pair-1

When examining the graph of Pair-2, the percentage of recurrence and random baseline are very close to each other, and overlap occurs at some points even. Thus, we can interpret this graph as the level of following to each other's actions is low.

When additional information on this session about the number of each participant's operations per question is considered, the numbers of SI's operations are much more than the number of IHB's operations. So, one can infer that the collaboration level of this pair is low.

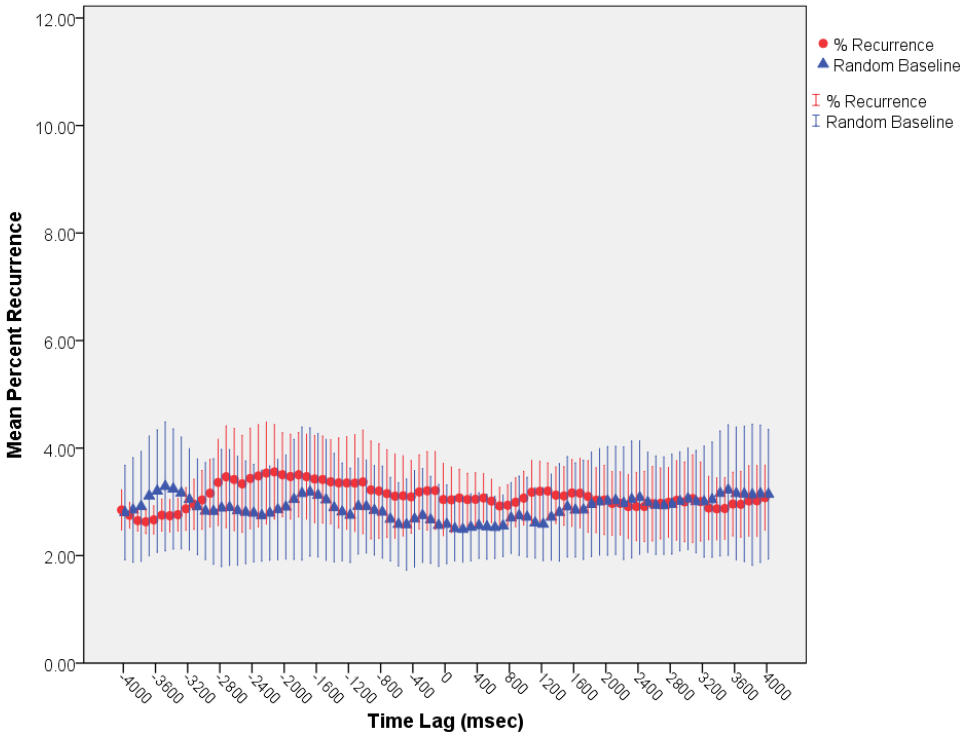

Figure 4.11 Recurrence Graph of Pair-2

Pair 3's plot can be interpreted in a similar way like Pair-2. The percentage of recurrence and random baseline are very close to each other, the convergence occurs at some points, and the recurrence distribution is rather flat and even. The percentage of recurrence even stays lower than the random baseline at some points. Thus, we can interpret this graph as the recurrence level is low, because the levels of following to each other's actions are low.

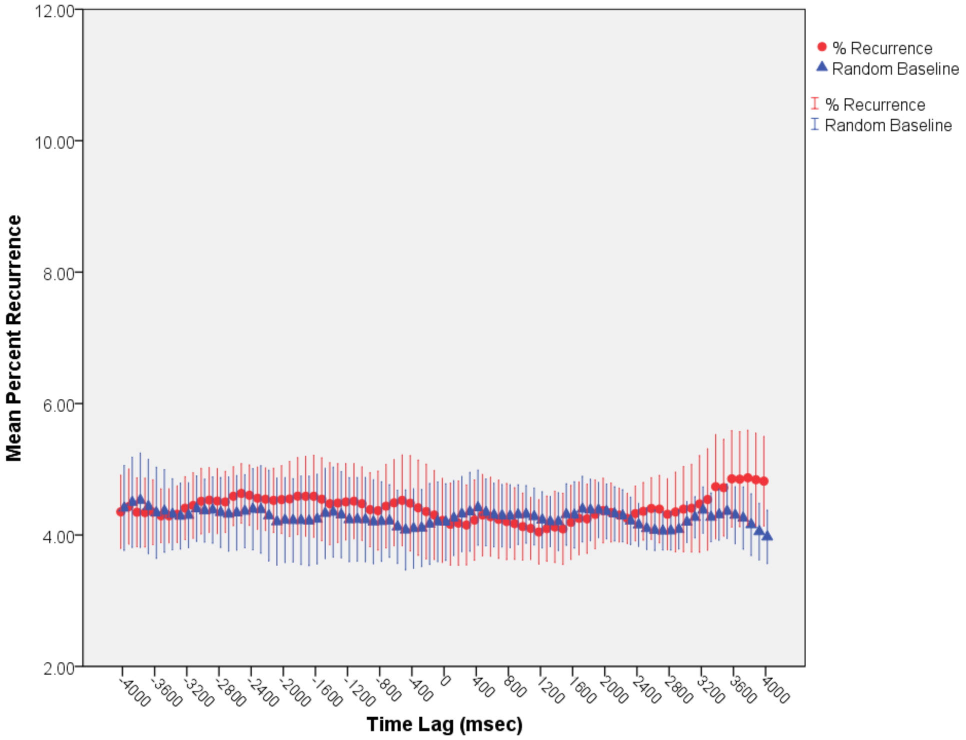

Figure 4.12 Recurrence Graph of Pair-3

When we look at the graph of Pair-4, the least percentage recurrence level observed in our sample can be seen. And generally, the two lines are very close to each other, and intersect. Since the recurrence level is overall quite low, we can deduce that these participants did not quite follow each others' actions.

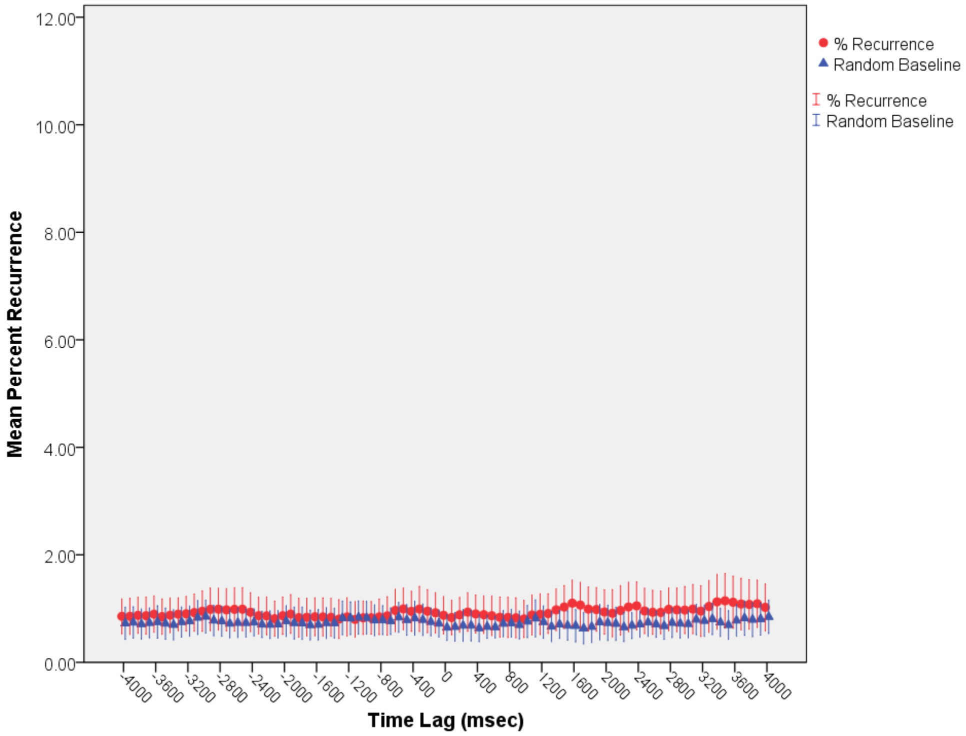

Figure 4.13 Recurrence Graph of Pair-4

The graph of pair-5 shows us that AB follows the FU's action more, because there is a skew on the right side of the 0 point.

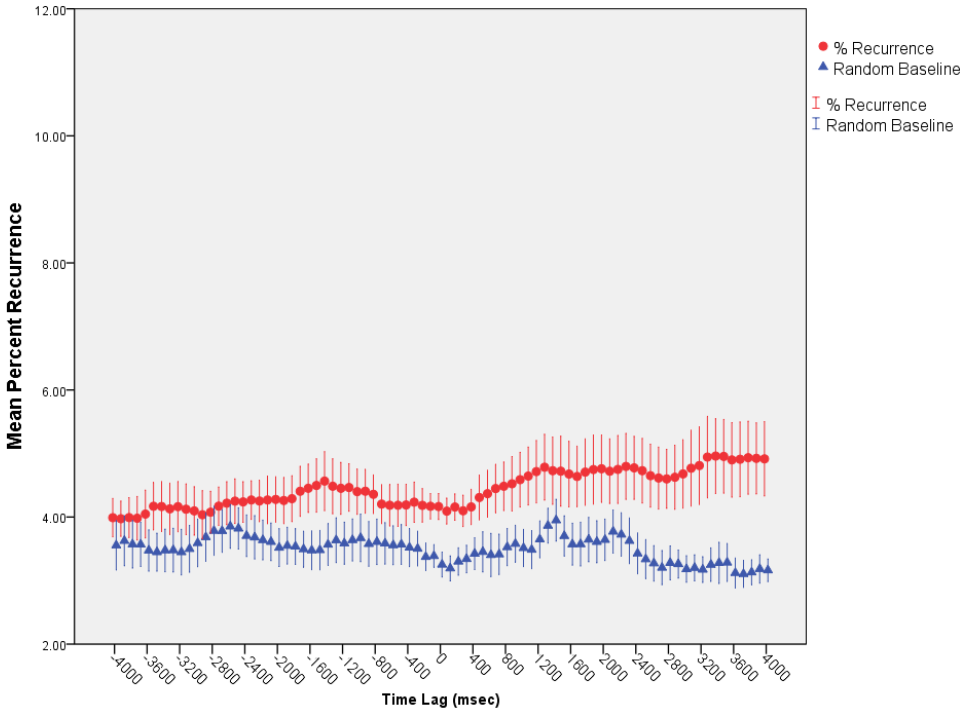

Figure 4.14 Recurrence Graph of Pair-5

The graph of Pair-6 shows that partners follow their actions between the time lag interval -2000 and +1600 equivalently. But the SE is high, so the data points has high variability, which is manifested in relatively longer standard error bars that overlap with those of baseline measures.

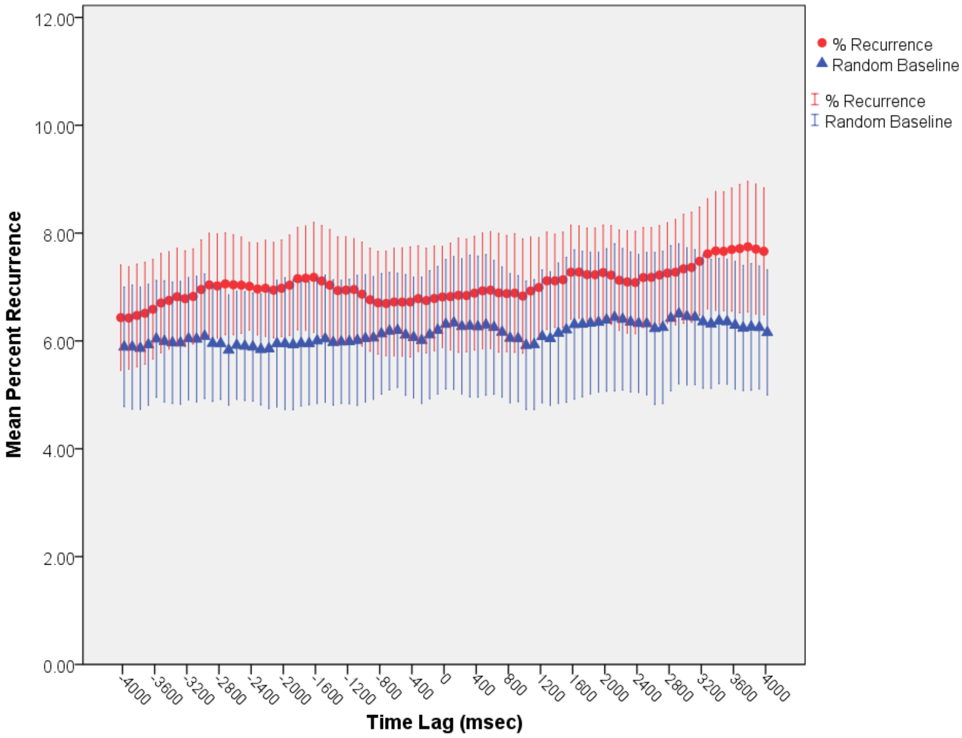

Figure 4.15 Recurrence Graph of Pair-6

Pair-7 has high percentage of recurrence, and the distance between the two lines is far. Thus there is a significant recurrence. Furthermore the time lag -800 and +800 are approximately symmetric in reference to 0, so that partners follow their actions between the time lag interval -800 and +800 msec equivalently.

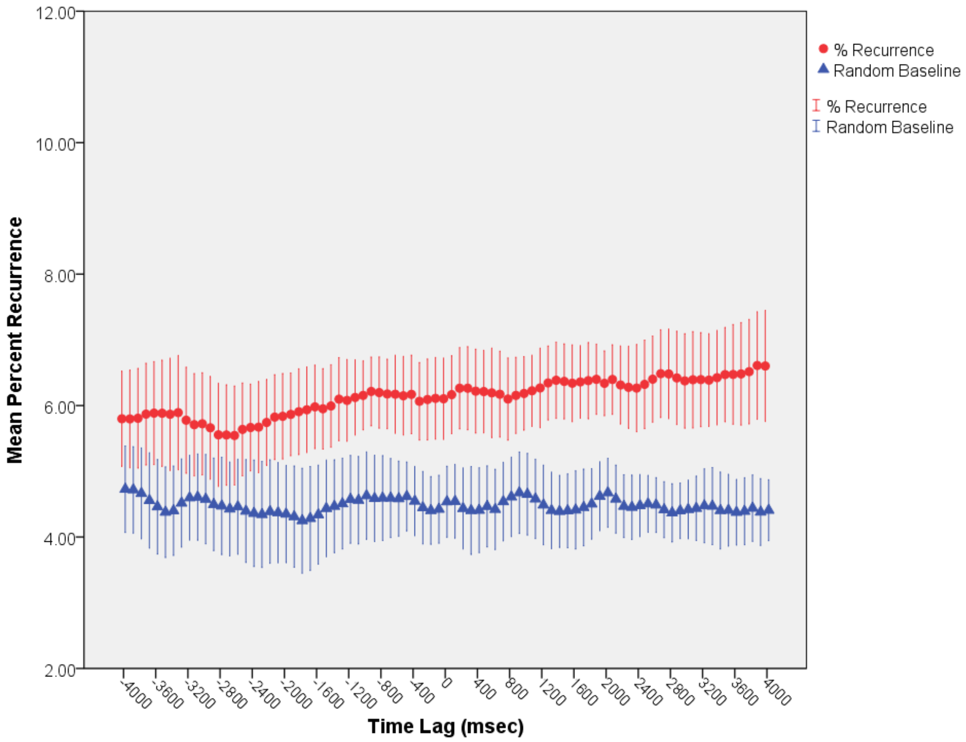

Figure 4.16 Recurrence Graph of Pair-7

Pair-8 has the highest percentage of recurrence among all pairs in our sample. Both of the partners seem to follow the other's actions at a similar level. Between the -2400 msec and +2800 time lag interval, the distance between the percentage of recurrence line and the random baseline increases. Thus this pair is very successful to follow each other considering the graph.

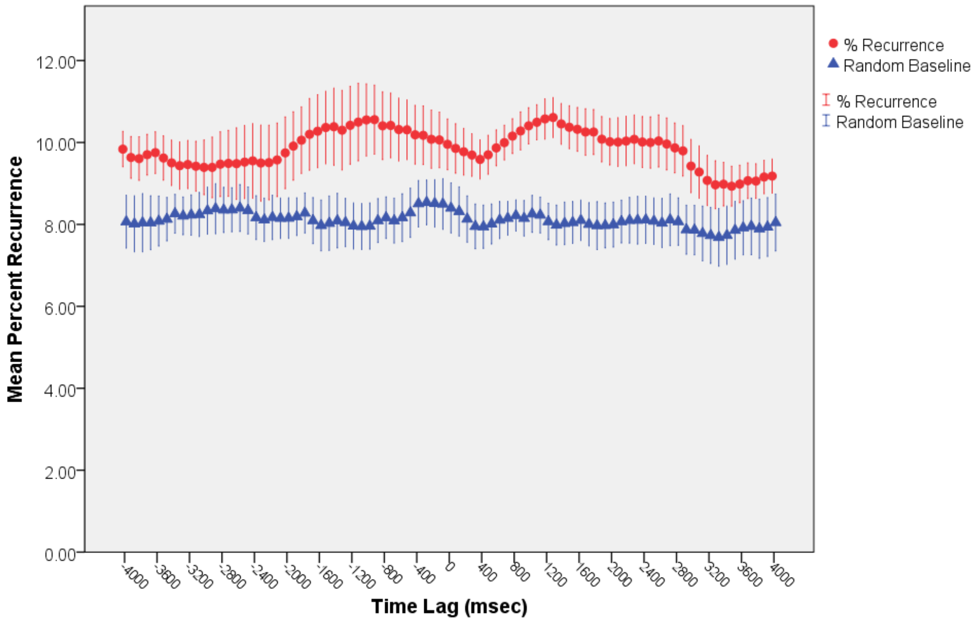

Figure 4.17 Recurrence Graph of Pair-8

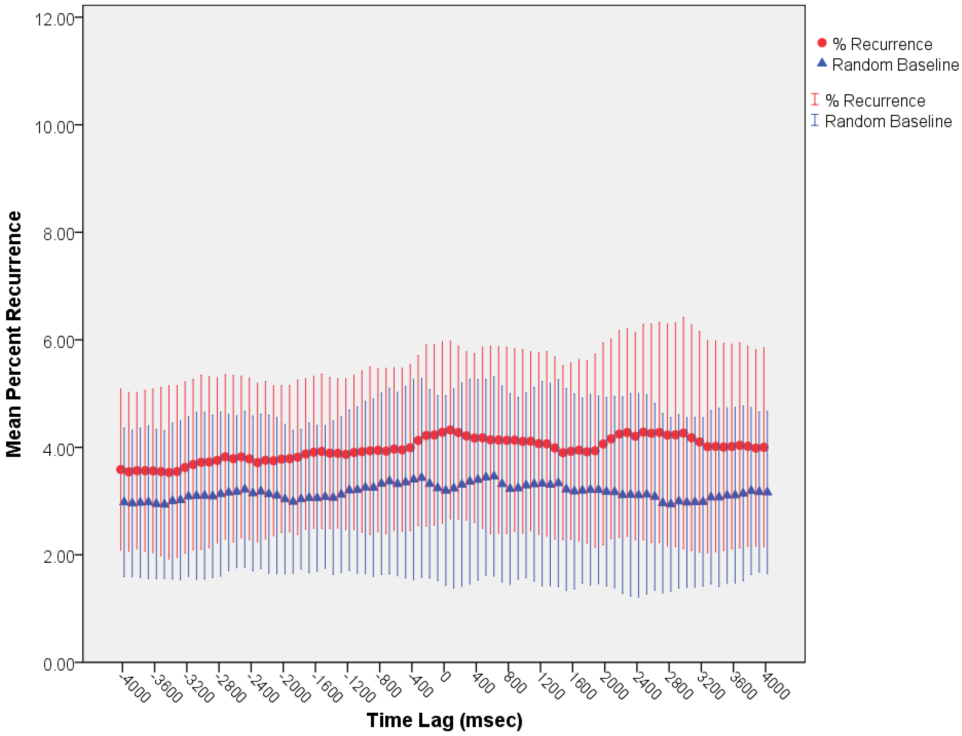

Figure 4.18 Recurrence Graph of Pair-9

In addition to these analyses, 9 pairs were split into 3 groups in terms of the level of achievement and quality of collaboration they displayed in their chat logs and videos. Based on the qualitative analysis of their logs and videos, pairs 5, 7 and 8 were selected as the high achievement group since they exhibited the anticipatory gazes, suggesting solution strategy, and contributing equal approximately. Pairs 2 and 4 were selected as the low achievement group because they did not follow their actions frequently, and when one drawn the shapes, the other one wrote solutions. Furthermore, they did not help each other; one of them solved whole questions. Finally, pairs 1, 3, 6 and 9 were selected as the medium achievement group since while one constructed the solution; the other partner followed his/her actions. In these pairs anticipatory gazes, and suggesting solutions performed, but less than the high achievement groups.

The degree of gaze overlap observed during each session was used as an indicator of the level of joint attention achieved by each group. Previous studies conducted with voice enabled computer mediated communication found that participants took on average approximately 2 seconds to focus their attention on an object after it was mentioned by his/her partner (Richardson & Dale, 2005). In the present study the communication among partners is mediated by a chat and a shared drawing tool. Reading a chat utterance and then allocating one's attention to the referred object on the drawing board often takes more than two seconds. However, the gaze recurrence plots with various lag combinations indicated that highest degrees of gaze overlap occurs within a similar time window in this chat environment. Therefore, those instances in which one subject looks at the same area of the screen that his partner looked at within two second were treated as gaze overlap cases.

The bar chart in Figure 4.19 indicates that the high achievement group exhibited on average 31% gaze overlap, which is followed by the medium and low achievement groups with 24% and 13% gaze overlap respectively. A one-way ANOVA[1] conducted over gaze overlap values indicated that this difference is statistically significant, $F(2) = 11.917$, $p<0.001$, $\eta^2 = 0.341$. Levene's test indicated that group variances are not equal, so the ANOVA is followed by Games-Howell post hoc tests that compared each pair of achievement level without assuming equal variances. Post hoc tests found a significant difference between low achievement and medium achievement groups (MD=-12.32, $p<0.05$), as well as low achievement and high achievement groups (MD=-20.19, $p<0.01$). The difference between medium and high achievement groups was not significant at the $\alpha=0.05$ level. Thus, higher achieving groups exhibited significantly more gaze coordination during collaborative problem solving sessions.

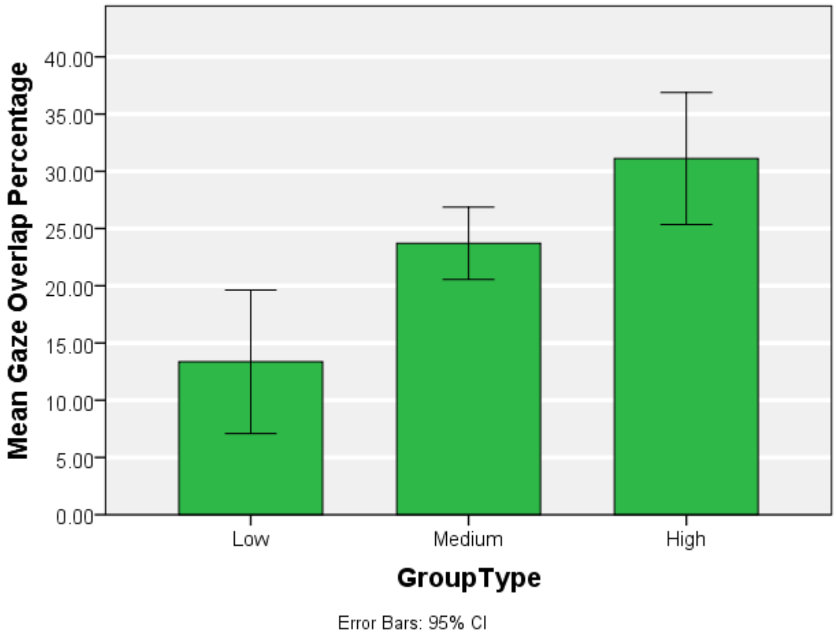

Figure 4.19 Percentage of Mean Gaze Overlap

4.2 Qualitative Data Results

In this part, we present our findings into two categories. In the first category, some excerpts are presented with screenshots from the exported videos. These videos were exported from Tobii Studio Software, and examined with the Transana Transcription and Analysis Software. In the second category, the results of the open-ended questions are presented with the some excerpts of the participants' answers.

4.2.1 Interaction Analysis Results

In this part, we provide some excerpts from chat session to seek for qualitative evidence for whether pairs follow each other's actions during problem solving process or not, and support the interpretation of our quantitative findings. Furthermore, in some sessions we observed

[1] Shapiro-Wilks test indicated that gaze overlap values are normally distributed, S-W(49) = 0.968, $p>0.05$.

anticipatory actions, where gaze overlaid video recording indicate that some participants estimate the location of next possible action of the team member before s/he performs. Such instances can be considered as a strong evidence for the achievement of common ground and mutual understanding. Finally, qualitative analysis of session logs also revealed cases where there was no indication of gaze coordination. Through interaction analysis of such cases we aimed to identify underlying reasons for low gaze coordination. For instance, one typical case involves situations while one partner was writing the answers on the Sonuçlar (i.e. results) tab, the other started to work on the next question. Gaze overlapping either did not occur in those cases or occurred by chance, because participants could not follow their actions as they were working on different tabs in VMT. In short, by closely analyzing and contrasting gaze patterns in well coordinated and poorly coordinated episodes of interaction, we aim to support the interpretations we developed over the cross recurrence plots summarizing the entire collaborative work of a team.

PAIR-5 (AB [bilgi_islem]-FU [bote_ceit])

This pair is very successful in terms of following each other's actions, and performing anticipatory actions as evidenced in the video recordings exported from Tobii Studio Software with overlaid gaze information. We present some excerpts from a few questions they solve.

Question-1: Firstly, following messages were written, both participants read the first question on "Sorular" tab, and passed the "GeoGebra" tab.

> **bote_ceit:** 1. soruya bakalım. *(Let's look at the first question.)*
> **bilgi_islem:** Hadi başlayalım. *(Let's start.)*

After they read the question1, following conversation occurred, and they reasoned together.

> **bilgi_islem:** Kare yapacağız. *(We are going to construct a square.)*
> **bote_ceit:** Nasıl yapalım? Dik ve eşit uzunlukta doğru parçalarıyla oluşturabiliriz. *(How do we do?We can construct using perpendicular and same length lines.)*
> **bilgi_islem:** Evet. *(Yes)*
> **bote_ceit:** Deneyelim mi? *(Should we try?)*
> **bilgi_islem:** Nokta oluşturup, doğru parçası, sonra paralel ve dik doğrular kullanabiliriz. *(We can create point for line segment, and then use the parallel and perpendicular lines)*
> **bote_ceit:** Olur istersen başla sen, gerektiğinde ben gireyim. *(OK, if you want, start. I interfere when needed.)*

Then bilgi_islem constructed the solution. While bilgi_islem constructed the square (Figure 4.20), bote_ceit looked at what he drew at the construction area (Figure 4.21).

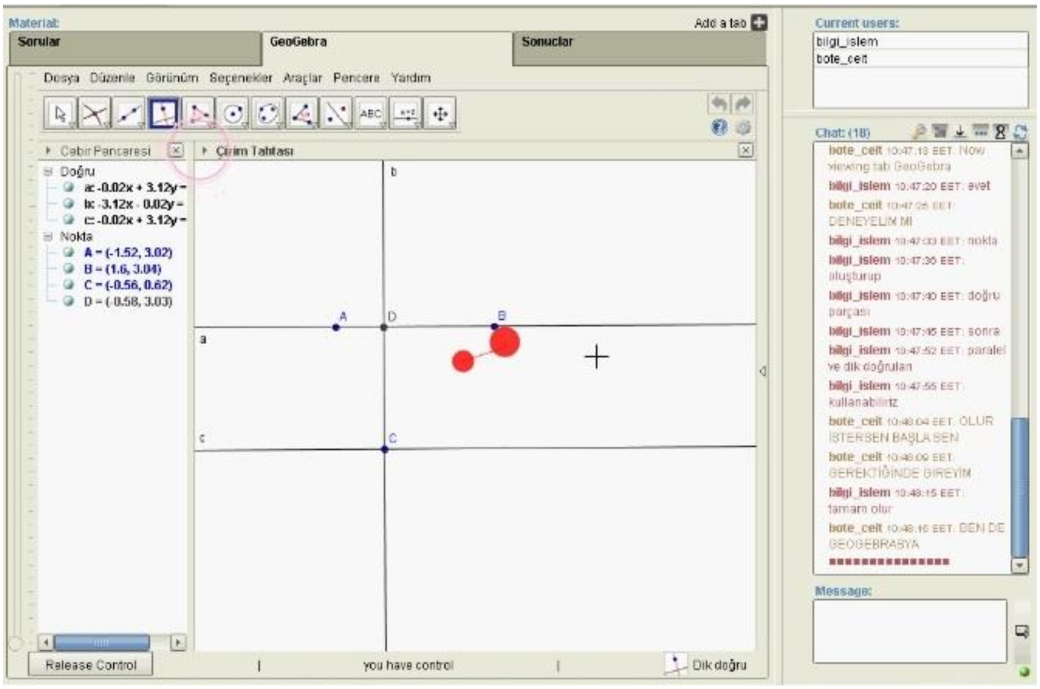

Figure 4.20 Eye Movements of AB (bilgi_islem) from Pair-5 for Question 1

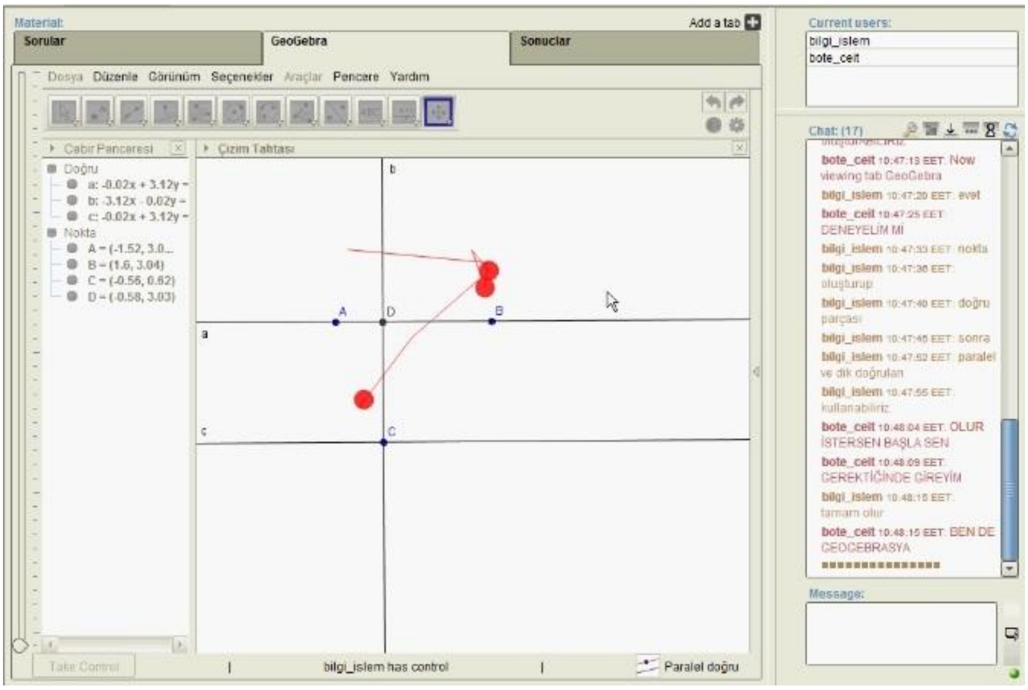

Figure 4.21 Eye Movements of FU (bote_ceit) from Pair-5 for Question 1

While constructing the solution, bote_ceit suggested a part of solution.

> **bote_ceit:** Kenarların eşit uzunluk olayını da sağlayalım. *(Let's make the edges of equal length.)*
> **bilgi_islem:** Evet, onu unuttum, onu yapalım. *(Yes, I forgot it. Let's do it.)*
> **bote_ceit:** Bu haliyle paralelkenar veya dikdörtgen olur. Onu nasıl yapalım? *(In this situation, it is a parallelogram or rectangle. How do we do?)*

bilgi_islem: CD uzunluğu kadar bir uzunluk yapmamız lazım.

While bilgi_islem was typing the message "CD uzunluğu kadar bir uzunluk yapmamız lazım (*We need to do a length with same length of CD.*)", bote_ceit read this message, and looked at the CD length (Figure 4.22).

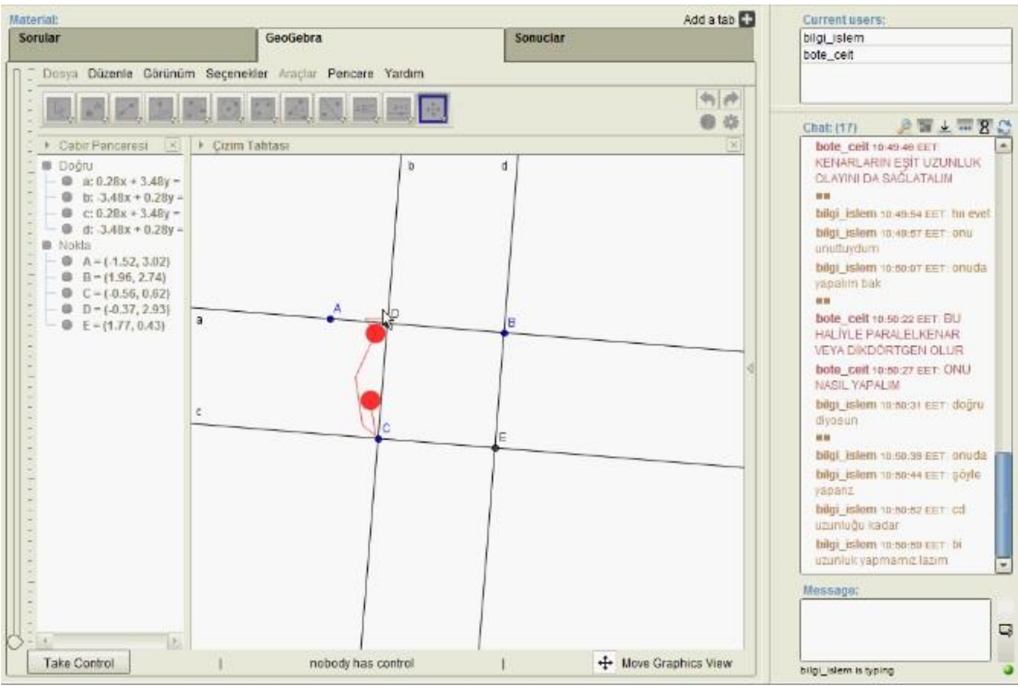

Figure 4.22 Eye Movements of FU (bote_ceit) from Pair-5 for Question 1

bilgi_islem: ab doğrusunda o noktayı belirleyip yapabiliriz. *(We can identify that point in ab line.)*

bote_ceit read the message, looked at a, and b lines (Figure 4.23).

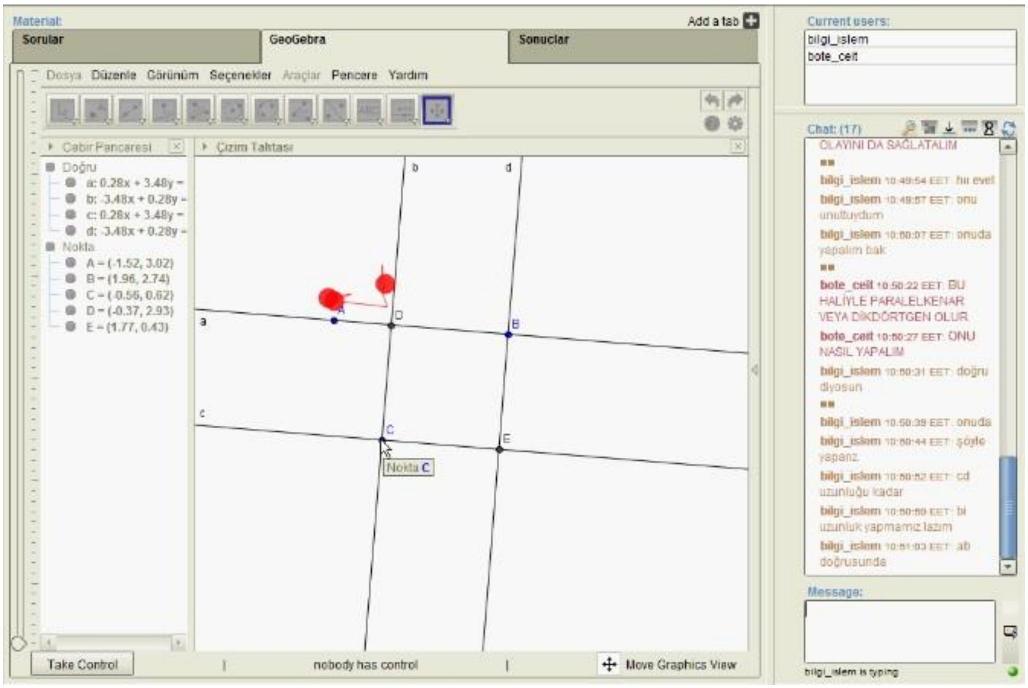

Figure 4.23 Eye Movements of FU (bote_ceit) from Pair-5 for Question 1

> **bilgi_islem:** D merkezli cd yarıçaplı çember işimizi görür. (*D-centered circle with the cd radius will do.)*
> **bote_ceit:** Olur. *(OK!)*

bote_ceit firstly looked at the point D (Figure 4.24).

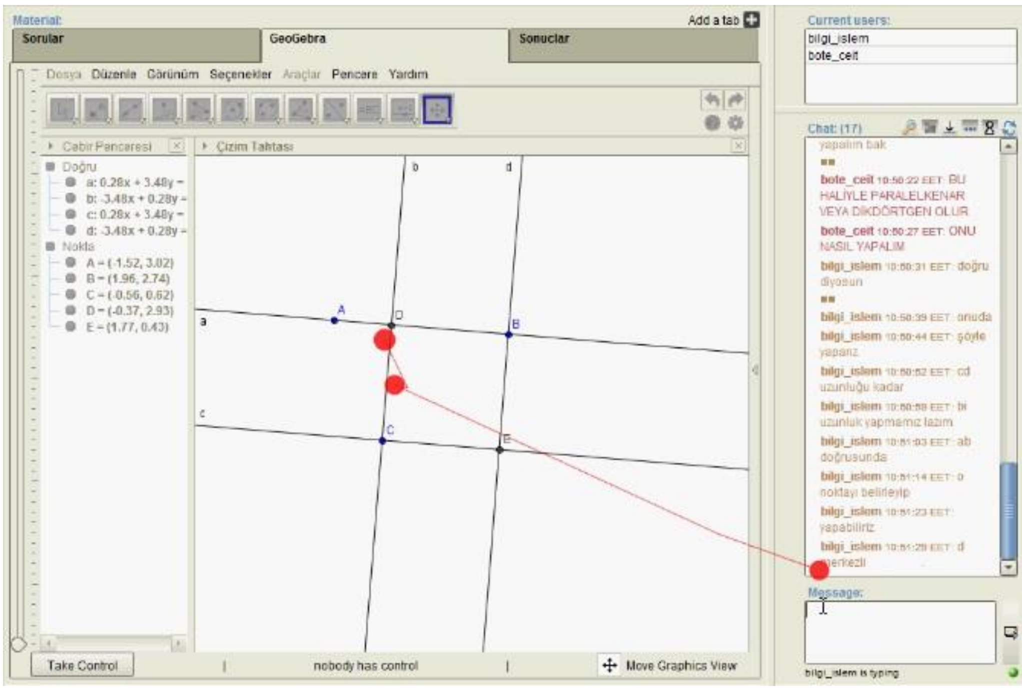

Figure 4.24 Eye Movements of FU (bote_ceit) from Pair-5 for Question 1

bilgi_islem drew a D-centered circle. Before he drew the F-centered circle (Figure 4.25), bote_ceit started looking at the near F point, and located the mouse cursor on F point (Figure 4.26).

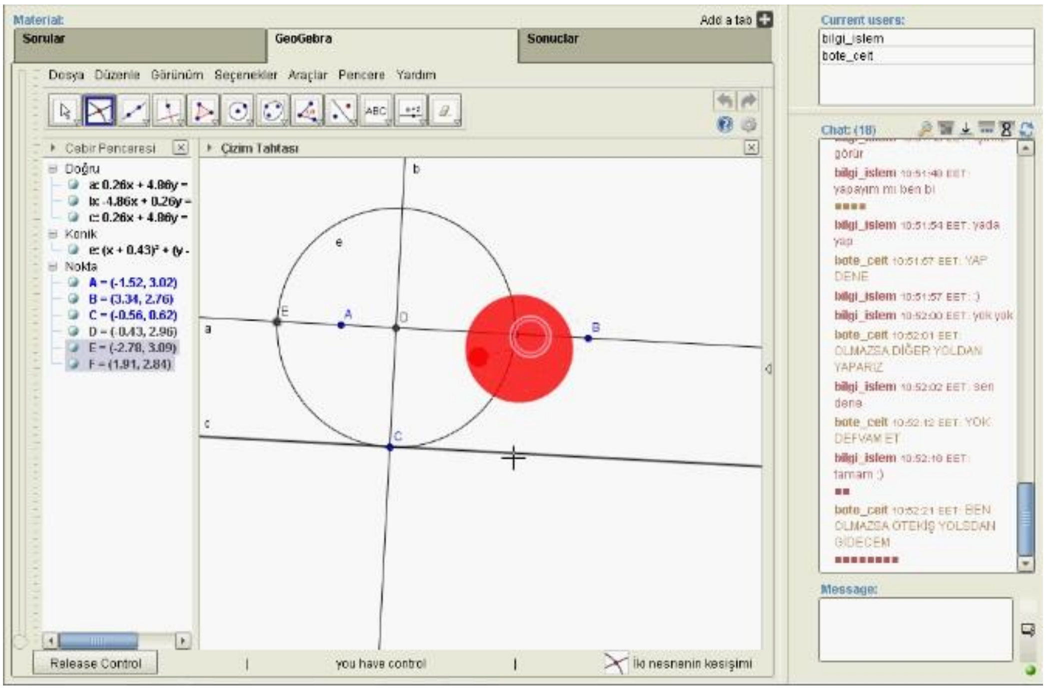

Figure 4.25 Eye Movements of AB (bilgi_islem) from Pair-5 for Question 1

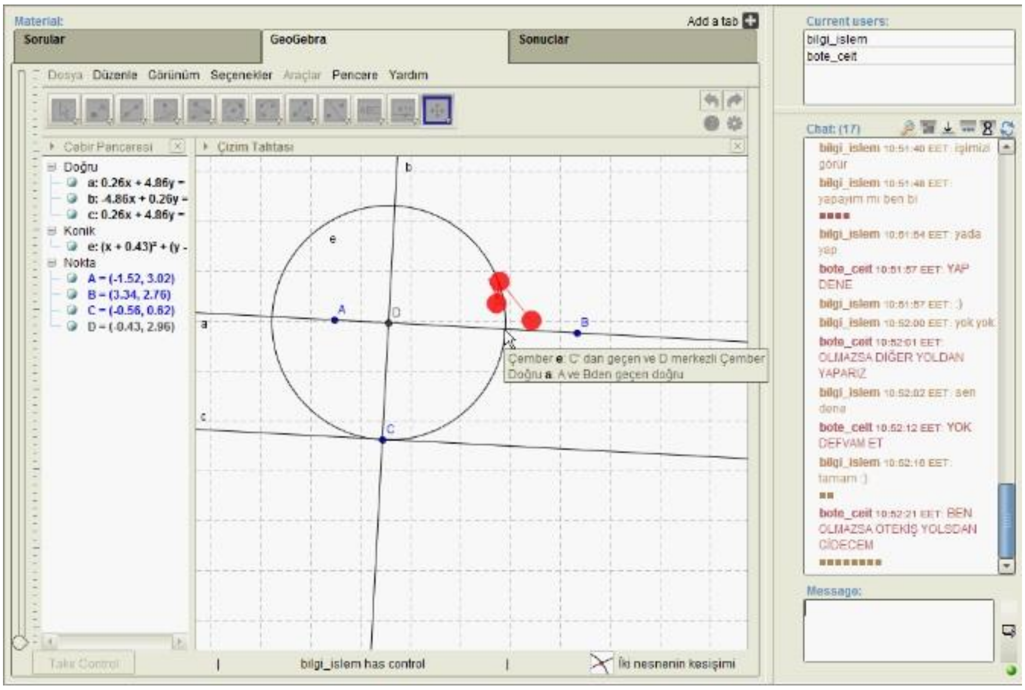

Figure 4.26 Eye Movements of FU (bote_ceit) from Pair-5 for Question 1

Before bilgi_islem created an intersection point at the fourth corner of the square (Figure 4.27), bote_ceit started looking at near the point, and located the mouse cursor on that point (Figure 4.28).

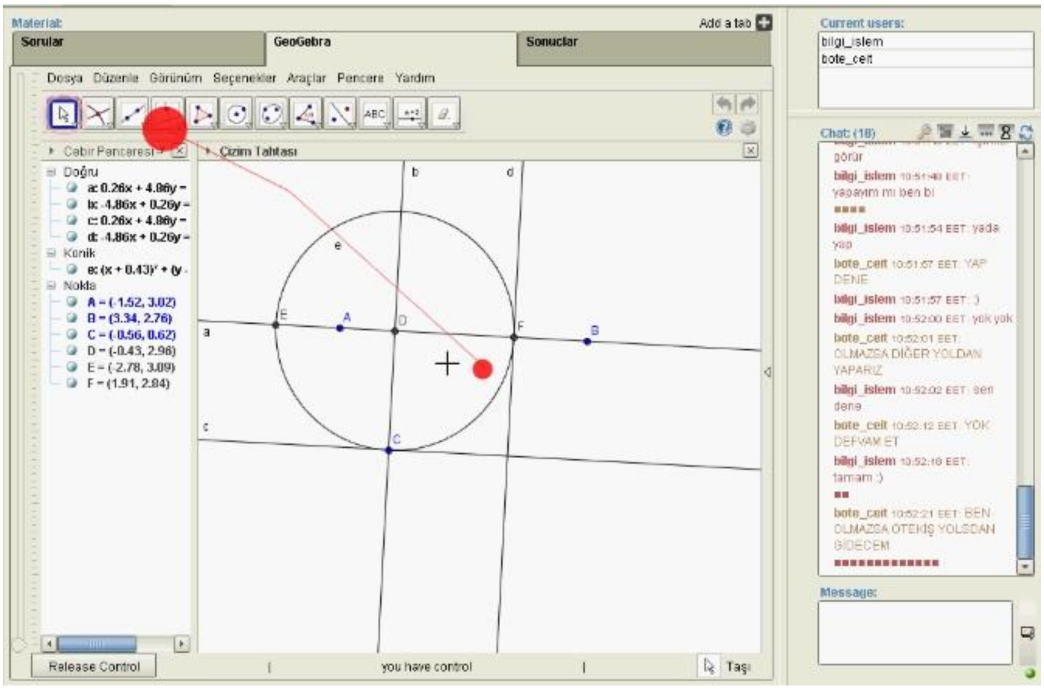

Figure 4.27 Eye Movements of AB (bilgi_islem) from Pair-5 for Question 1

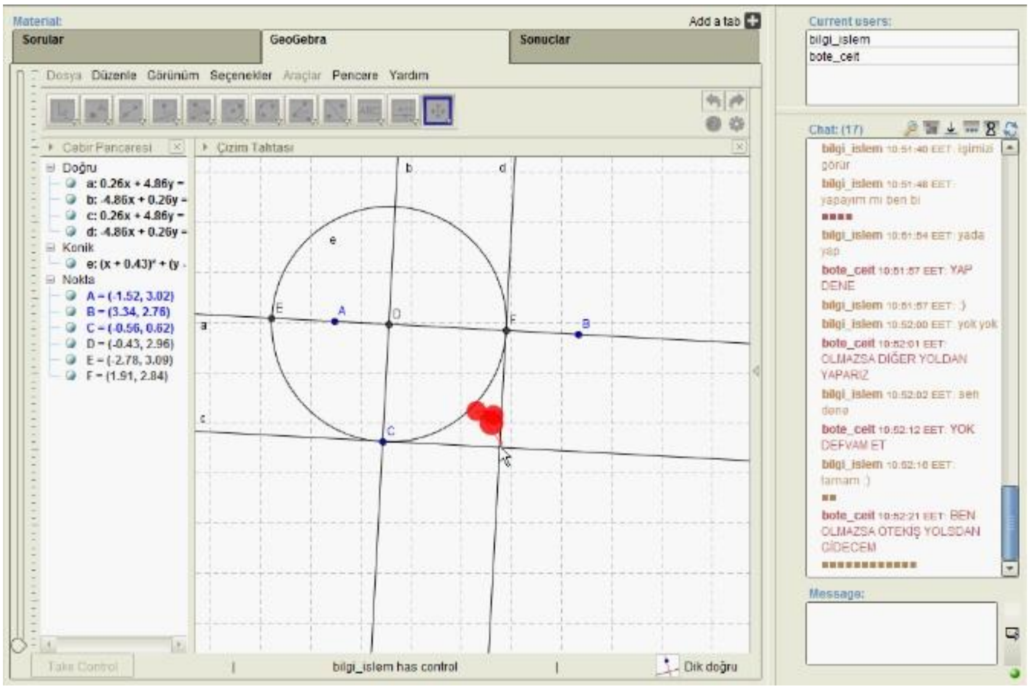

Figure 4.28 Eye Movements of FU (bote_ceit) from Pair-5 for Question 1

bote_ceit took the control, and controlled the dependency of drawing.

> **bilgi_islem:** Şimdi oldu di mi? *(It is OK, isn't it?)*
> **bote_ceit:** Oldu, dinamiklik katınca bozulmuyor. *(OK, it does not get spoiled when you have dynamics.)*
> **bilgi_islem:** Tamamdır. *(OK)*

bote_ceit: Yaptığımızı anlatalım bence hemen. *(I think, we explain what we do right now.)*

Then she passed the Results tab.

bilgi_islem: Evet hadi anlatalım. *(Yes, let's tell it.)*

Then bilgi_islem passed the Results tab, too, and bote_ceit wrote answer.

bilgi_islem: Tamam :) *(OK :))*
bote_ceit: Tamamdır, gerekli yeri istersen düzelt. *(OK, if you want, correct the required parts.)*
bilgi_islem: Bence iyi, sıkıntı yok. *(I think it is good, there is no problem.)*

Question-3: In this question, participants read the question, and discussed how they can solve the problem, so they reasoned together again. Then they solved the problem. bote_ceit took control, and constructed a circle, and a triangle. But she realized that this solution was not correct, and said:

bote_ceit: Yalnız bu bozuldu olmadı. *(This one has been faulty.)*

After that, bilgi_islem suggested a different solution.

bilgi_islem: Aklıma bir de başka bir şey de geldi. *(I found a different solution to this.)*
bote_ceit: Onu deneyelim *(Let's try that!)*
bilgi_islem: Dur bir de, şöyle yapalım, iki çember ikisi de aynı yarıçaplı. *(Hold on, let's try it with two circles with the same radii.)*
Dur çizeyim bi ben. *(Wait, let me draw it.)*
bote_ceit: Evet öyle olur. *(Yes, that would work.)*

Then bilgi_islem took the control, and started to construct. After he constructed two circles, he hesitated to draw anything. Meanwhile bote_ceit looked at the point A, point B and the top intersection of circle A and circle B (Figure 4.29), because she expected bilgi_islem to draw a triangle with these points.

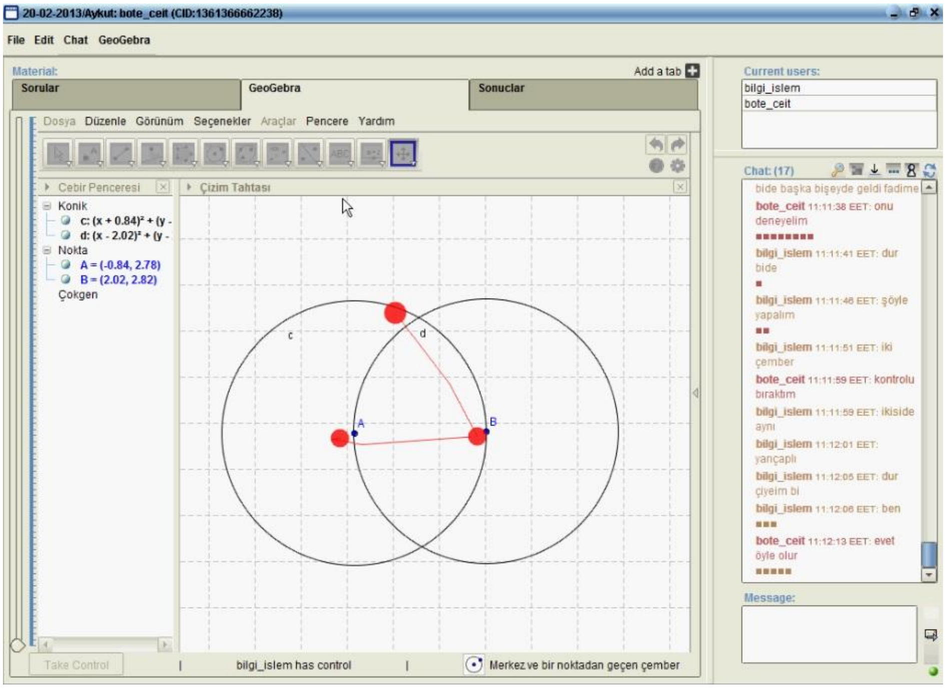

Figure 4.29 Eye Movements of FU (bote_ceit) from Pair-5 for Question 3

Then bilgi_islem united the point A and point B using segment tool, and bote_ceit looked at the top intersection of circle A and circle B, again (Figure 4.30).

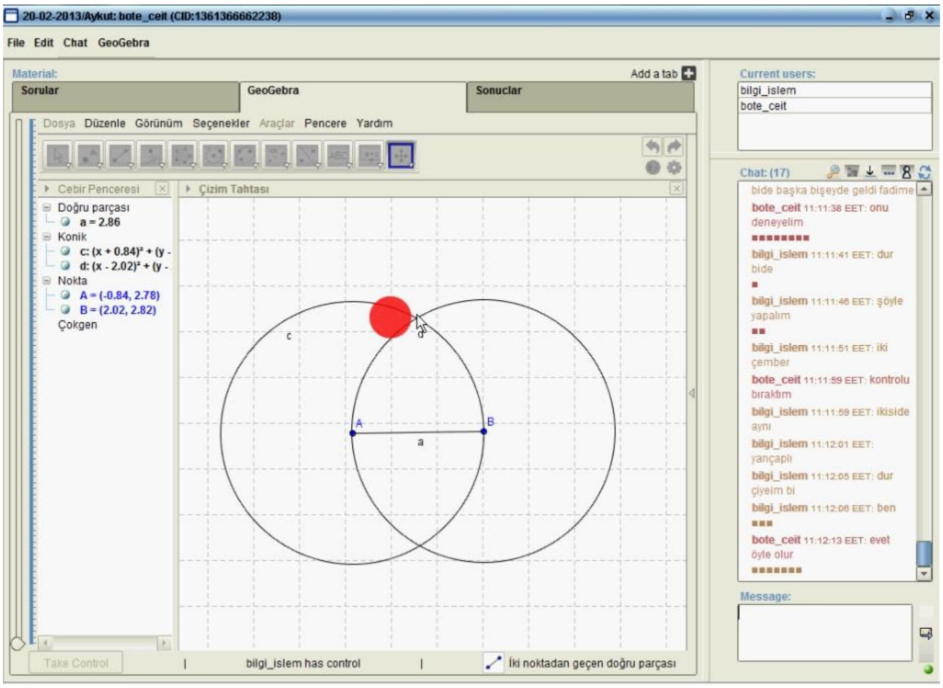

Figure 4.30 Eye Movements of FU (bote_ceit) from Pair-5 for Question 3

Then she wrote:

> **bote_ceit:** Kesişim noktaları ile a yı veya b yi birleştirince de olur. *(You could also have joined a or b with the intersection points.)*

bilgi_islem: Bunun kesişimi eşkenar üçgen olmaz mı? *(Wouldn't the intersection of this be an equilateral triangle?)*

bote_ceit took the control, and drew the shapes. Meanwhile bilgi_islem looked at the intersection points of the circles (Figure 4.31), before bote_ceit united the intersection points and centers of the circles (Figure 4.32).

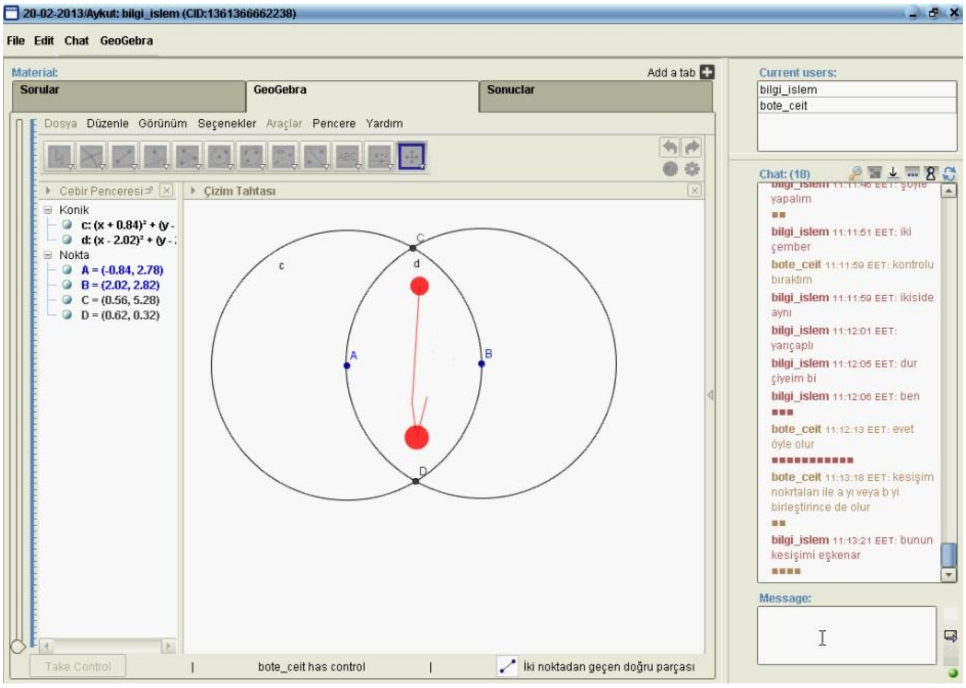

Figure 4.31 Eye Movements of AB (bilgi_islem) from Pair-5 for Question 3

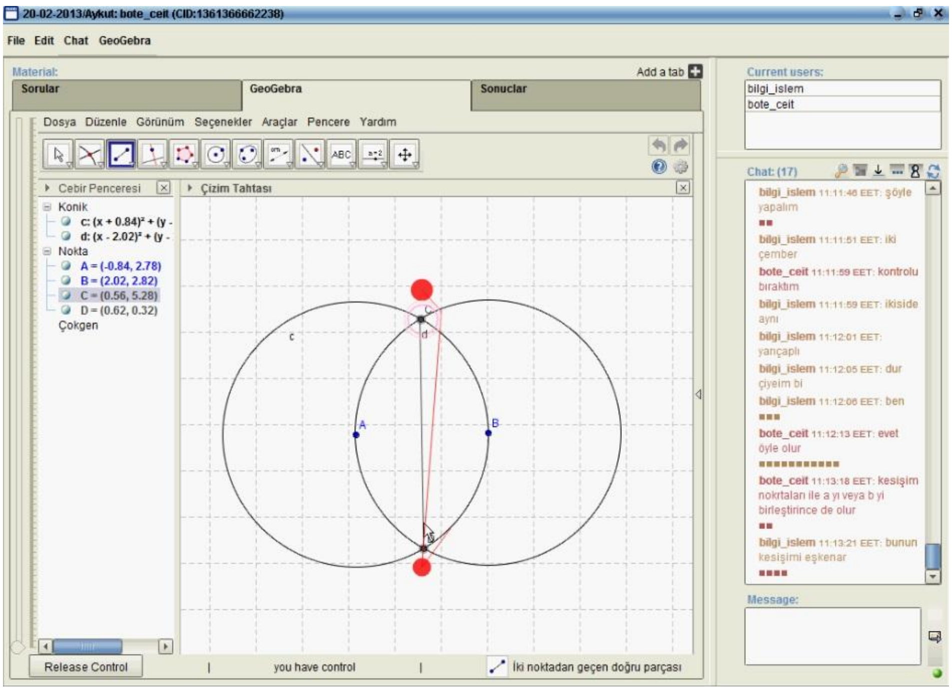

Figure 4.32 Eye Movements of FU (bote_ceit) from Pair-5 for Question 3

bote_ceit: Bu olmaz mı? *(Won't this do?)*

bote_ceit changed the rotation, and controlled dependency. Also she checked length and angles.

bilgi_islem: Aaaa evet oldu galiba. b ve e eşit. *(I guess this did work. b and e are equal.)*
Tamam bence, bir de iç açılarını gösterelim. *(It's alright I think, let's also show the internal angles.)*
bote_ceit: Bir dolu yolu vardır bunun bu bence biri. *(There are many ways to do it, this is one.)*
bilgi_islem: Evet evet, ben de 3. çemberle düşündüm. Bu daha kolay oldu. *(Yes yes, I also thought of it with 3. circle. This has been easier.)*

After bilgi_islem said "b and e has equal size", bote_ceit read this message, and looked at these lengths (Figure 4.33).

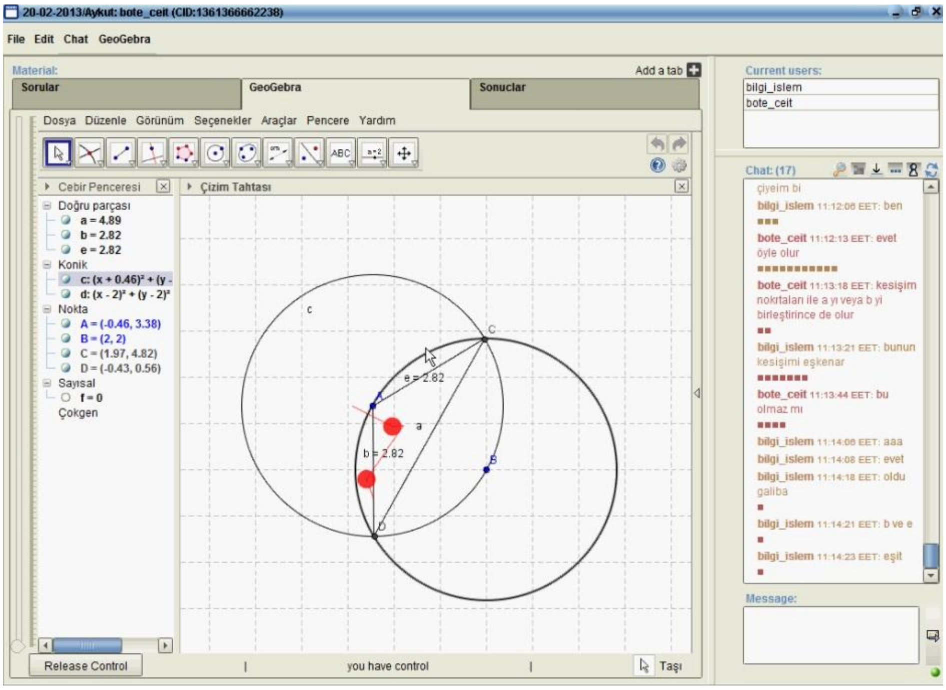

Figure 4.33 Eye Movements of FU (bote_ceit) from Pair-5 for Question 3

Question-4: Firstly, they read the question-4, and they reasoned together.

bilgi_islem: Gene çemberlerden mi yapsak? (*Shall we do it using circles again?)*
bote_ceit: OK benim aklıma da o geldi. Sen başla. (*OK I think so. Start.)*
bilgi_islem: Tamam. (*OK*)

bilgi_islem constructed drawings, and bote_ceit looked at what he did. While bilgi_islem constructed the circle, bote_ceit followed his actions. After bilgi_islem constructed two angles of the triangle (Figure 4.34), bote_ceit started to look at the third angle of the triangle not formed yet (Figure 4.35), so anticipatory gazes occurred again.

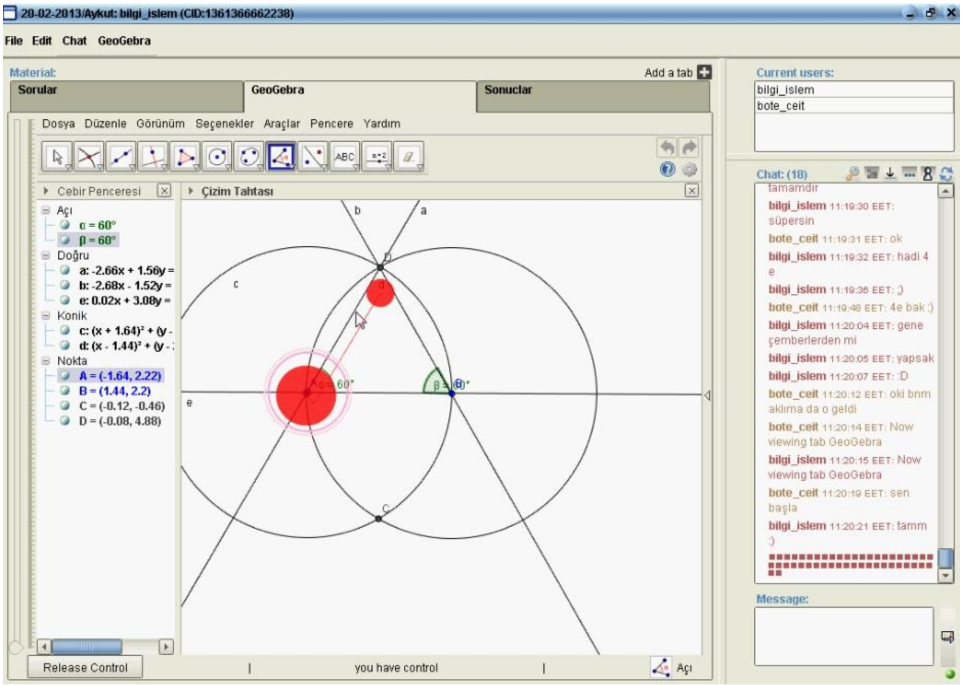

Figure 4.34 Eye Movements of AB (bilgi_islem) from Pair-5 for Question 4

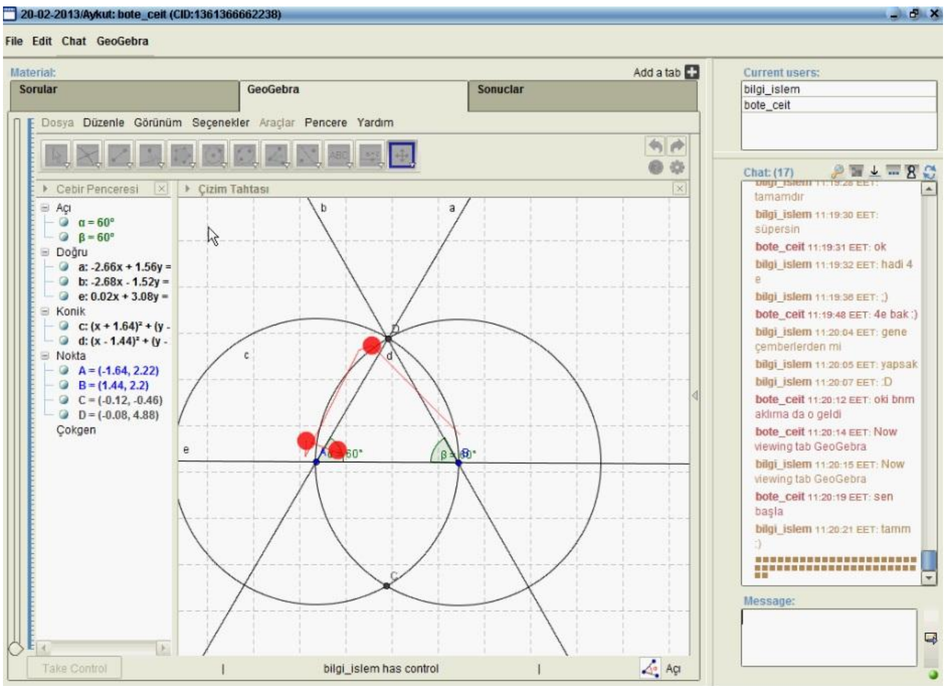

Figure 4.35 Eye Movements of FU (bote_ceit) from Pair-5 for Question 4

Before bilgi_islem marked the center of the triangle, bote_ceit started to look at the center, and located the mouse cursor on center (Figure 4.36), so anticipatory gazes occurred in this instance as well.

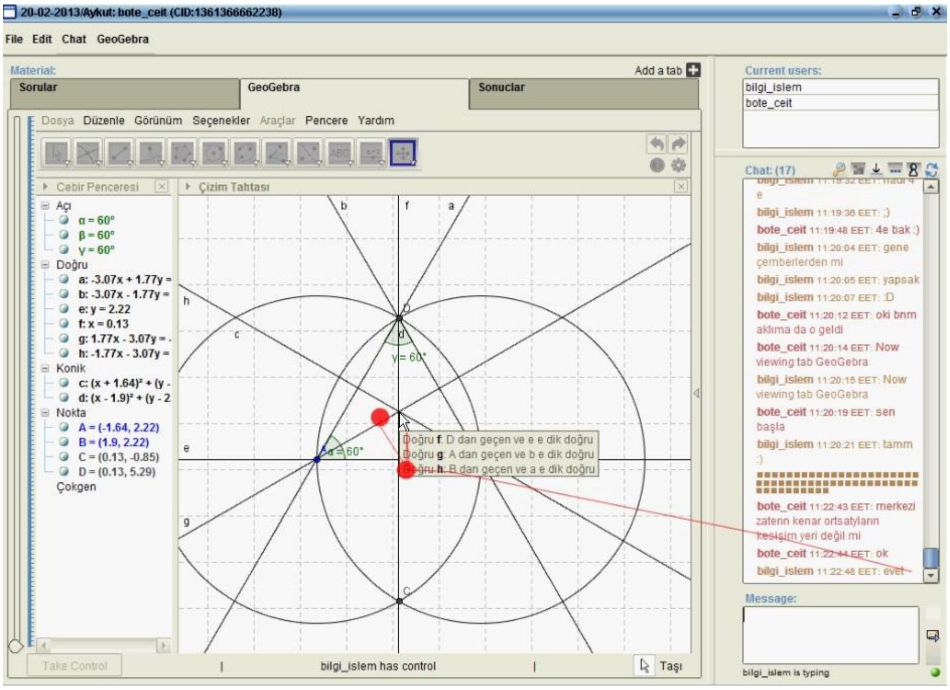

Figure 4.36 Eye Movements of FU (bote_ceit) from Pair-5 for Question 4

Question-8: They read the question-8, and discussed how they could solve.

> **bote_ceit:** İçteğet çemberin merkezi açıortayların kesim noktası olacak. (*The centre of the inner tangent circle will be the intersection of the angle bisectors.)*
> **bilgi_islem:** Evet. (*Yes*)
> **bote_ceit:** Açı ortay nasıl çiziyorduk? (*How do we draw the angle bisector?)*
> **bilgi_islem:** Önce onu bulmamız lazım, açıortay toolu var. (*Firstly we must find it; there is an angle bisector tool.*)

After this conversation, bote_ceit started to draw triangle, and its bisectors. Before she stated the intersections between bisectors and triangle, and the intersection of the bisectors, bilgi_islem started to look at those points. But the circles she drew were not correct, and she wrote her partner to solicit her help:

> **bote_ceit:** Çember olmadı mı ne? Bi de sen bak. *(Isn't that a proper circle? You take a look at it.)*
> **bilgi_islem:** Dikmelerin kenardaki noktaları oluyor yarıçap. Ben bakıyım mı? *(Radius is the points of perpendiculars at the edges. Shall I check it?)*
> **bote_ceit:** Bak tabi. *(Sure.)*

So bote_ceit wanted help from her partner, and bilgi_islem offered a solution in chat and then proposed to take over the construction work to carry out his proposed solution.

After this conversation, bilgi_islem took the control, and completed the solution. bilgi_islem drew perpendicular lines passing through point D which is the centre of the circle to the edges of the triangle. Then he stated the intersection points. Before he stated the J point (Figure 4.37), bote_ceit started to look at this point (Figure 4.38). The reason why these anticipatory gazes frequently occur in this group could be related to the way this pair organized their work. This group tended to reason together in chat about what they should do before they began drawing the solution, so bote_ceit could anticipate bilgi_islem's next actions based on their prior discussion. This can also be treated as a strong indicator of mutual understanding among group members regarding what was stated in chat. The chat messages project a certain organization of drawing actions, and one partner demonstrates his understanding by executing the drawing actions, whereas the other demonstrates her understanding by looking at next relevant locations at each step (from time to time this partner even moved the mouse to where he considers the next relevant drawing should appear).

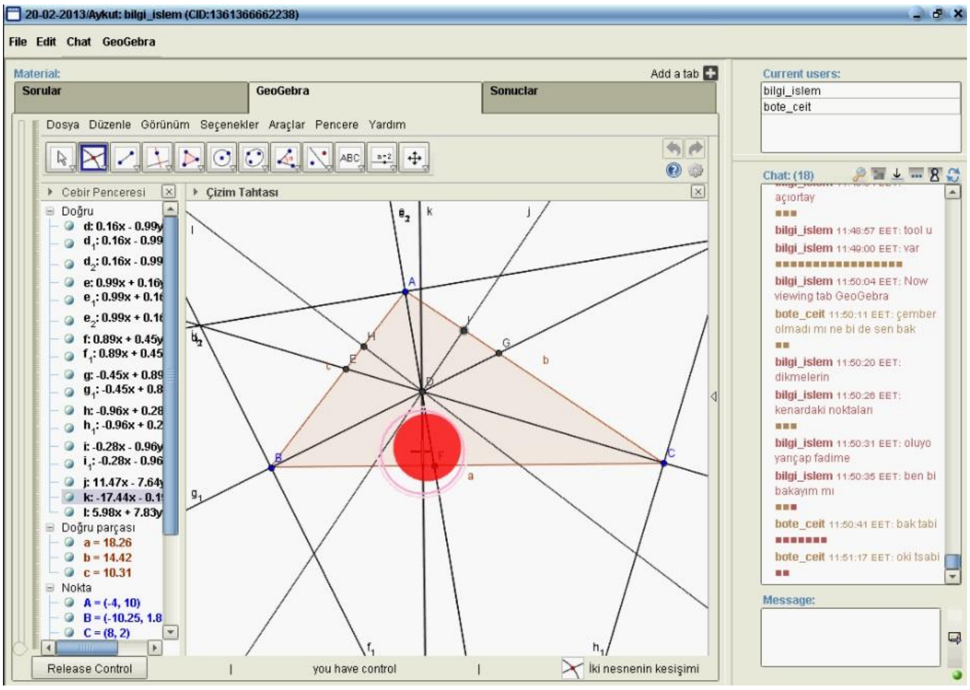

Figure 4.37 Eye Movements of AB (bilgi_islem) from Pair-5 for Question 8

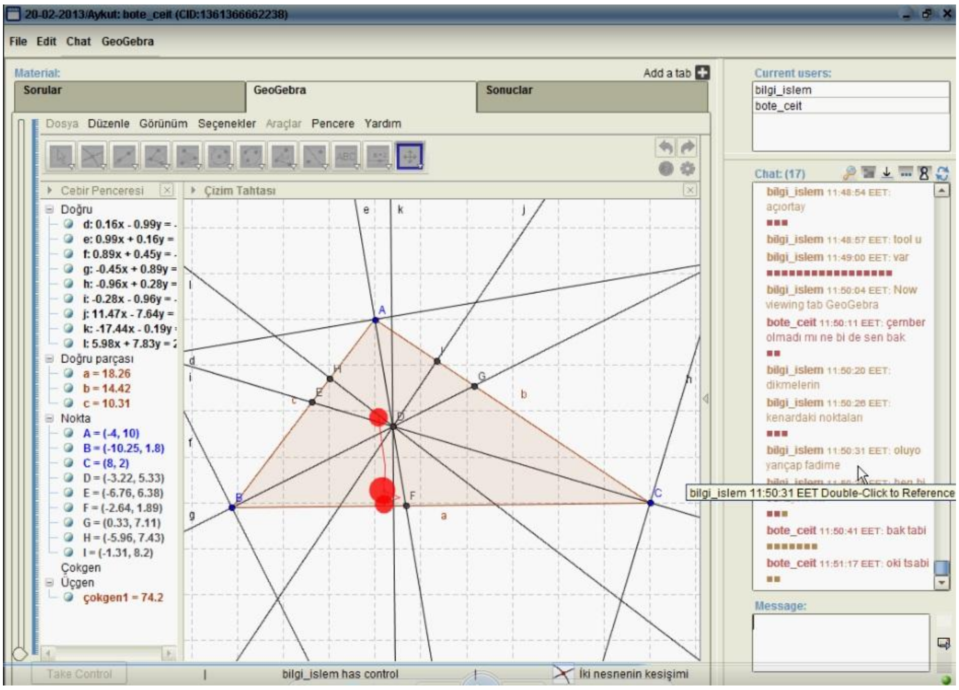

Figure 4.38 Eye Movements of FU (bote_ceit) from Pair-5 for Question 8

bilgi_islem stated the angles, and controlled dependency between shapes. While bilgi_islem stated the angles, bote_ceit looked at those angles. Before bilgi_islem formed the angle DHA (Figure 4.39), she started looking at this angle, and located the mouse cursor on it (Figure 4.40). The reason why this anticipatory gaze occurred is that bilgi_islem stated the two angles, so bote_ceit anticipated that bilgi_islem will state the third angle, so anticipatory gazes occurred because of the sequential and same actions.

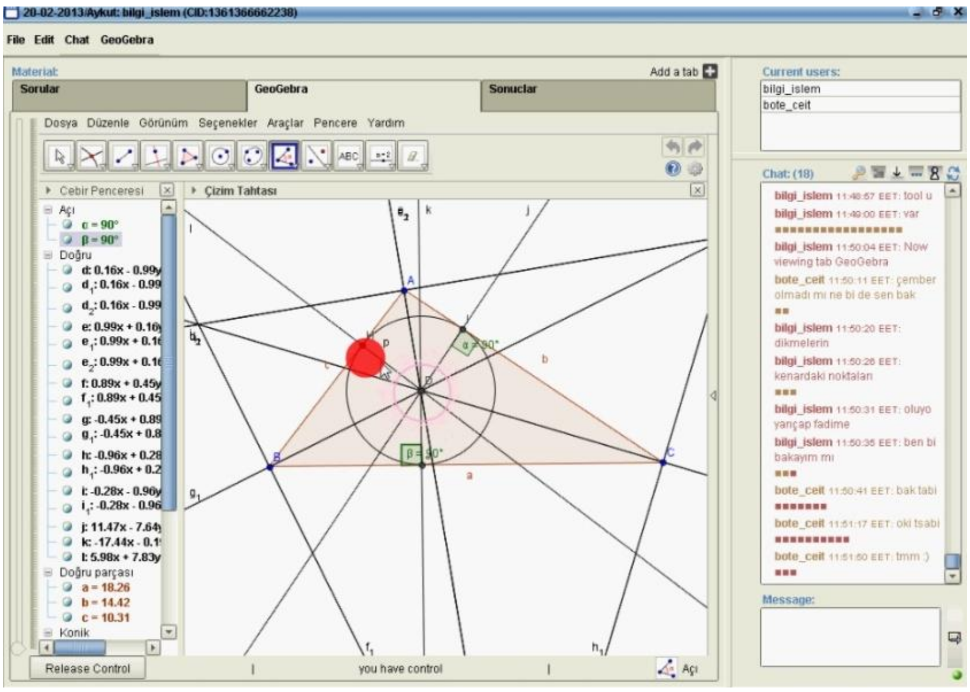

Figure 4.39 Eye Movements of AB (bilgi_islem) from Pair-5 for Question 8

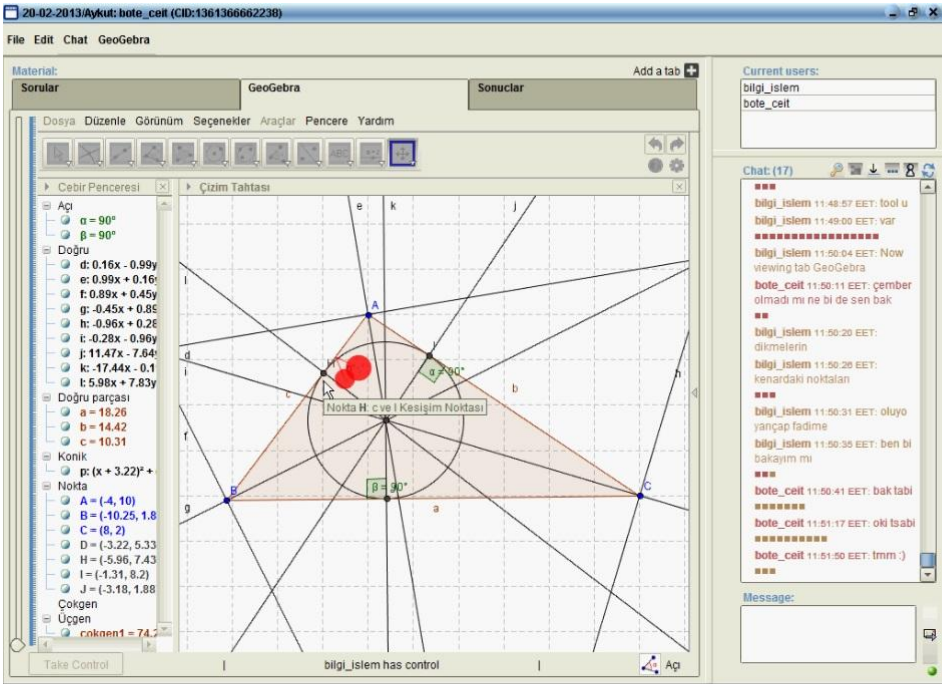

Figure 4.40 Eye Movements of FU (bote_ceit) from Pair-5 for Question 8

Considering the overall process, Pair-5 solved seven questions in total, and we presented several excerpts from their chat session. Both participants actively contributed to the problem solving and writing solutions. When one of the partners got stuck with a problem while attempting a solution, the other partner provided guidance for him/her. They helped, and directed each other, reasoned together, and proposed ideas. Furthermore anticipatory gazes occurred frequently, where before one partner constructed something on the board at a specific location, the other partner started to fixate on that area.

Analysis of the excerpts suggests several factors underlying the occurrence of anticipatory eye gaze sequences. First one is about reasoning together before constructing the solution. For each question they solved, pair-5 discussed how they can solve the given problem before they constructed the solution, so while one constructed the solution, the other anticipated the next action of his/her partner. The second reason of anticipatory gazes is about sequential and same actions. For instance, one started stating three angles, and after s/he stated two of them, his/her partner started looking at the area of third angle. This type of anticipatory gazes is, also, related with the level of reasoning together, because if they know the solution strategy, they can follow, and anticipate the other's actions. The third reason of anticipatory gazes relates with the level of helping each other, and suggesting solutions. Partners helped each other, or suggested a different solution when one could not solve. Before applying different solution strategy, one partner suggesting a different solution first explained the proposed solution, and then solve problem. So his/her partner understood his/her strategy, could follow actions, and anticipated next actions of his/her partner. In addition to these, they could follow their actions using some VMT features. For example, in chat area, an awareness message (… viewing GeoGebra tab) appears when one changes the tab, so partners can follow their actions, see which tab his/her partner views, and coordinate their actions according to his/her partner. Participants from pair-5 used this feature of VMT environment frequently, so they can follow each other, and looked close areas. Furthermore, VMT provides users with one more awareness feature to follow each other. When users type a message, "… is typing" awareness message appears under the chat area. Participants considered this feature in order to follow their partners' messages, so they could coordinate their actions using this feature. Finally, another important awareness feature of VMT that seemed to have helped this team coordinate their eye gazes is that the tool makes the details of the drawing and manipulation processes visible to both partners (including the dragging of objects), which allows the other partner to fully monitor the steps of the construction.

Because of these reasons, this pair’s eye gazes overlapped frequently during the course of their online session. When comparing the videos and quantitative data, we can say that they are consistent with each other. Peers followed each other's actions and suggestions, and reasoned together, so their eye gazes overlapped.

PAIR-8 (BE [bilgi_islem]-HK [bote_ceit])

This pair is, also, very successful in terms of following each other's actions, and anticipatory actions. We present some excerpts from a few questions they solve.

Question-4: Before constructing the solution, they read the question, and reasoned together briefly.

> **bote_ceit:** direk mi çizcez eşkenar üçgeni *(Will we draw the equileteral triangle directly?)*
> **bilgi_islem:** nasıl buluruz ağırlık merkezini (*How do we find the centre?)*
> çizelim bakalım (*Let's draw.)*
> **bote_ceit:** kenarortay indiririz. (*We draw a perpendicular bisector.)*
> **bilgi_islem:** sen al kontrolü bi başla bakalım (*Take control, and start*)

bote_ceit took control, and drew an equilateral triangle using equilateral polygon tool. VMT offers a feature that shows the last used GeoGebra tool, so users can see which tool to be used, and follow each other’s actions. Pair-8 used this feature in this question. bote_ceit stated the midpoints of all edges (Figure 4.41). Meanwhile, bilgi_islem saw the tool that bote_ceit's used, and looked at the midpoints' of the edges (Figure 4.42).

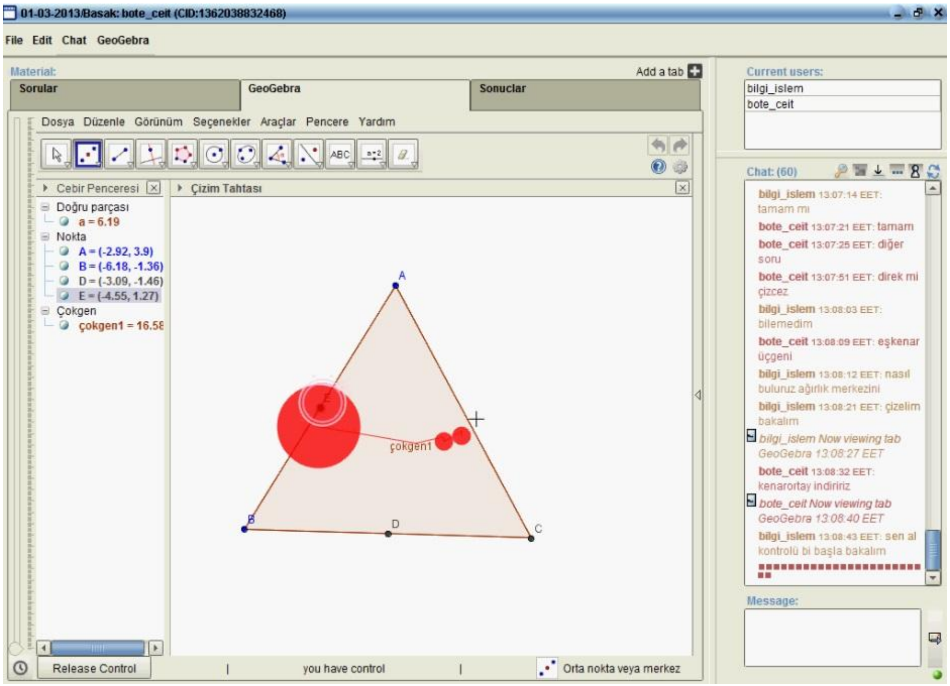

Figure 4.41 Eye Movements of HK (bote_ceit) from Pair-8 for Question 4

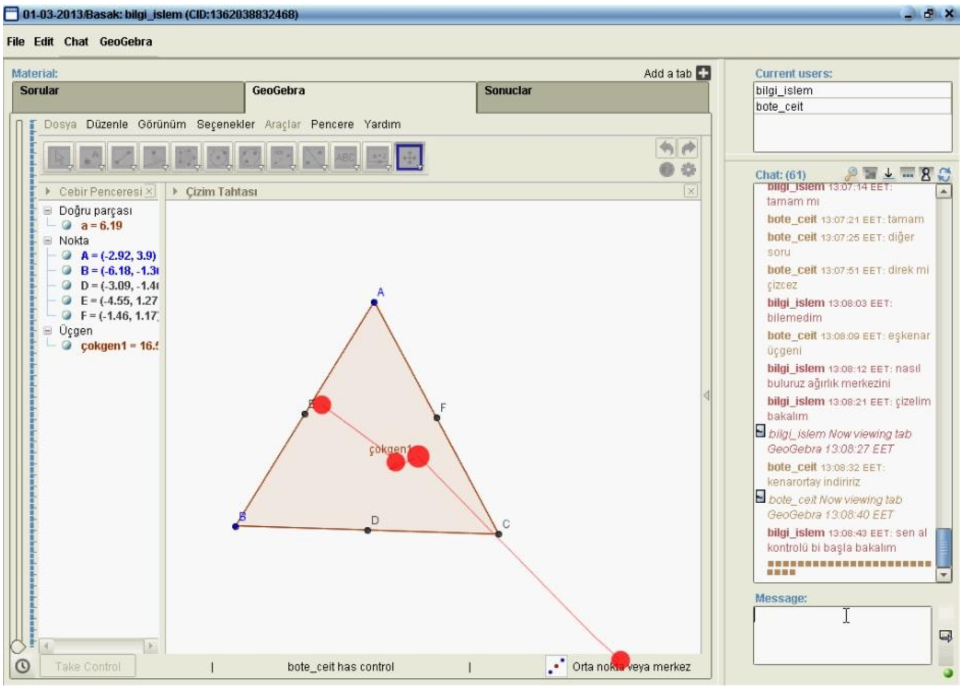

Figure 4.42 Eye Movements of BE (bilgi_islem) from Pair-8 for Question 4

Before bote_ceit stated the center point (G) (Figure 4.43), bilgi_islem looked at this location (Figure 4.44). Anticipatory gazes occurred, because bote_ceit said the solution strategy before constructing the solution, so bilgi_islem anticipated his action.

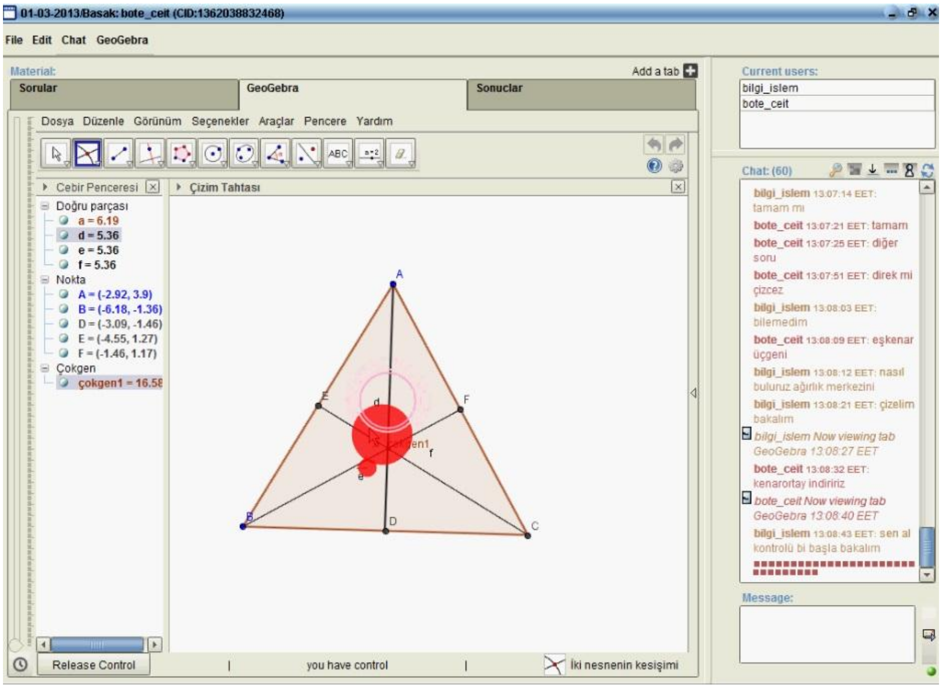

Figure 4.43 Eye Movements of HK (bote_ceit) from Pair-8 for Question 4

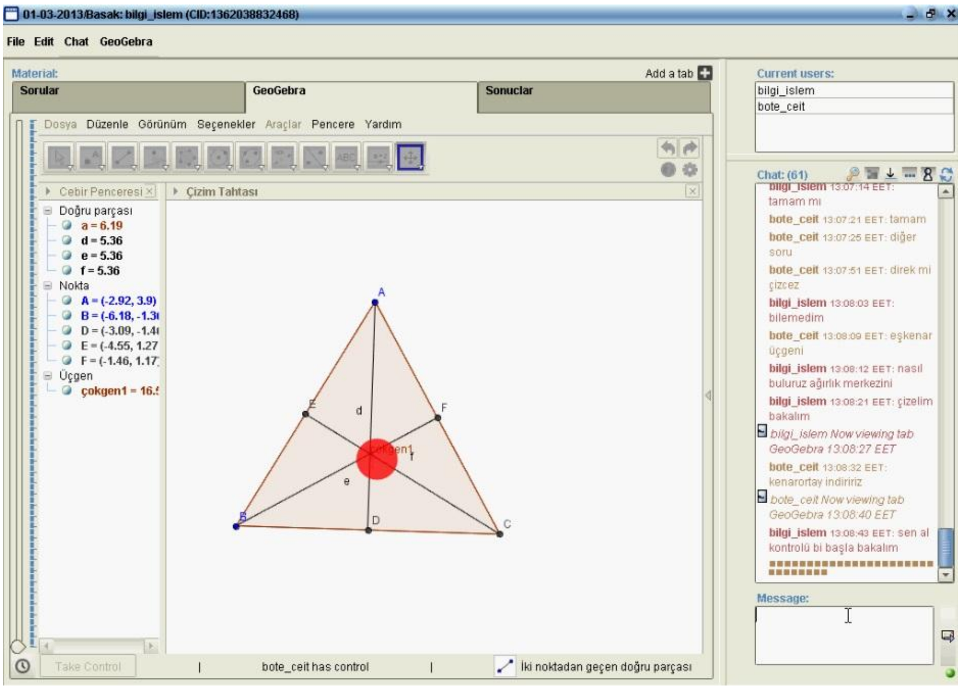

Figure 4.44 Eye Movements of BE (bilgi_islem) from Pair-8 for Question 4

During this session, bilgi_islem followed bote_ceit's action, and looked at algebra window frequently.

Question-6: During this phase, bote_ceit followed bilgi_islem's action, and they looked at chat section frequently. bilgi_islem took control, and drew a circle. But then she did not do anything, and wrote a message to bote_ceit:

bilgi_islem: bilemedim nasıl yaparız *(I couldn't figure out how to do it.)*
açı kullancaktım ama yok *(I would use angles, but no...)*
bote_ceit: düşünelim *(Let's think.)*
yukarda 3 kenar olcak aşağıda da *(There should be 3 edges at the top and the bottom.)*
nasıl buluruz *(How could we find it?)*
eşkenar üçgen oluştursan *(Try and form an equilateral triangle?)*

So bote_ceit suggested a solution, and bilgi_islem tried to do what bote_ceit said. Before bilgi_islem stated the top of the intersection of two circles (Figure 4.45), bote_ceit started to look at this area (Figure 4.46). This anticipatory gaze occurred, possibly due to the shared understanding team members developed with respect to the suggested solution strategy.

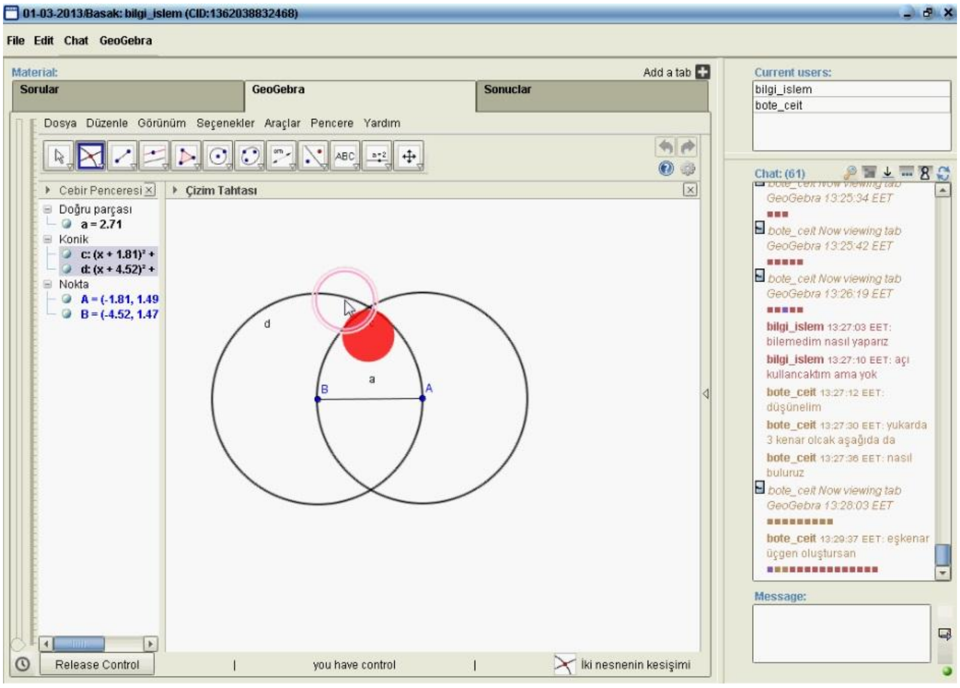

Figure 4.45 Eye Movements of BE (bilgi_islem) from Pair-8 for Question 6

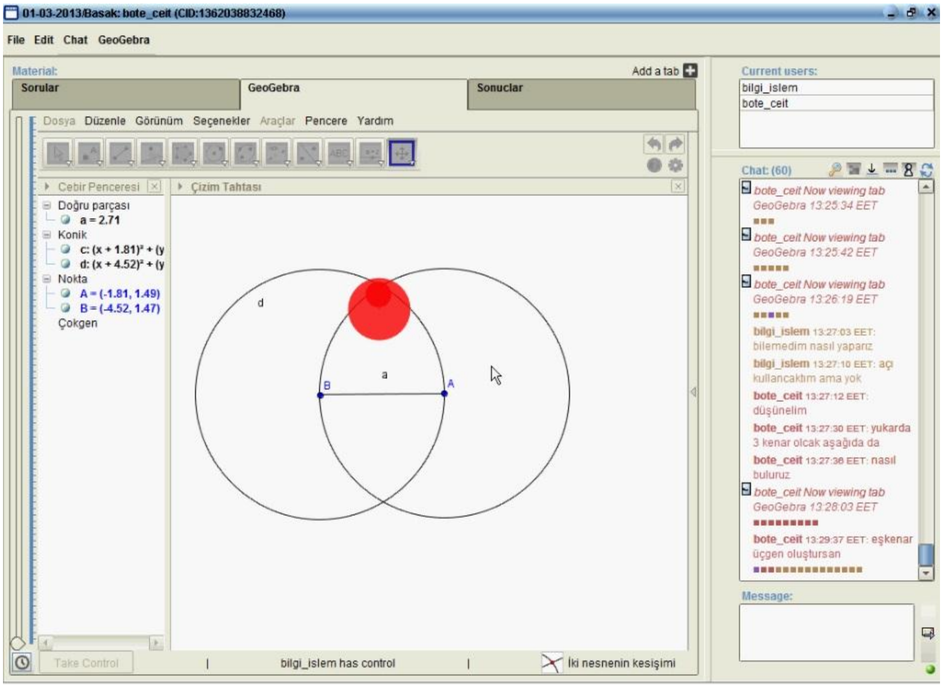

Figure 4.46 Eye Movements of HK (bote_ceit) from Pair-8 for Question 6

> **bote_ceit:** aynısını diğer tarafa da yap *(Do the same to the other side.)*

bilgi_islem did what he said, but then she gave up this strategy, and drew 4 circles. Then she united the intersection points, and constructed an equilateral hexagon.

Question-8: bote_ceit took control, and drew a circle. He searched tangent tool, but he could not find. Then bote_ceit said;

> **bote_ceit:** teğeti unuttum *(I forgot the tangent line.)*
> **bilgi_islem:** 4. tabda teğet aracı var işine yarar belki *(There's a tangent tool at the 4th tab that could work.)*

So bilgi_islem helped bote_ceit to find the right tool. After bote_ceit read bilgi_islem's message, he directly looked at tab4 (Figure 4.47).

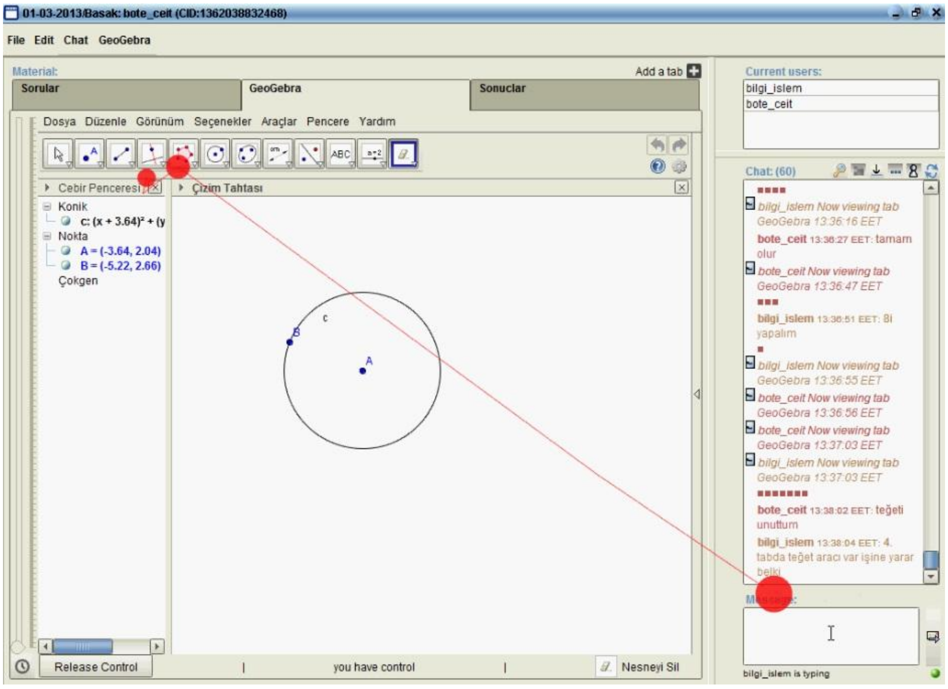

Figure 4.47 Eye Movements of HK (bote_ceit) from Pair-8 for Question 8

> **bilgi_islem:** a dan b ye doğru çiz *(Draw that from a to b.)*
> sonra b noktasından ona dik çek *(Then take a perpendicular from point b to that.)*

So bilgi_islem suggested a solution strategy. After bote_ceit read those messages, he looked at point A, then point B. Then he formed a perpendicular line. Then bote_ceit deleted the perpendicular line.

> **bilgi_islem:** kontrolü bi versene *(Could you hand me the control?)*

Then bilgi_islem tried to formed tangent, but she could not. Meanwhile bote_ceit said:

> **bote_ceit:** iç açıortay bulcaz *(We'll find the bisector.)*
> kesim noktası *(Intersection point...)*
> üçgen çiz tamam mı? *(Draw a triangle alright?)*
> **bilgi_islem:** sen al kontrolü *(You take the control.)*

So bote_ceit suggested a solution strategy, took control, and deleted everything. Then he drew a triangle using polygon tool, and stated the inner angle bisectors. After that he intersected the bisectors named as point D. Before he stated the point D (Figure 4.48), bilgi_islem looked at this point (Point 4.49). The reason why this anticipatory gaze occurred is that they had common knowledge, and bote_ceit stated the solution before he done.

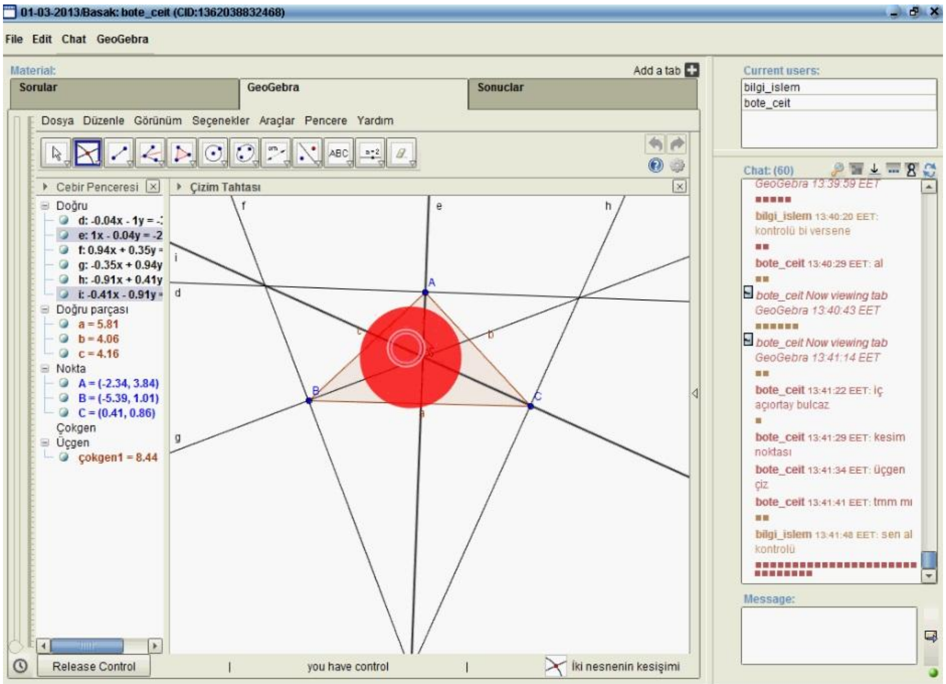

Figure 4.48 Eye Movements of HK (bote_ceit) from Pair-8 for Question 8

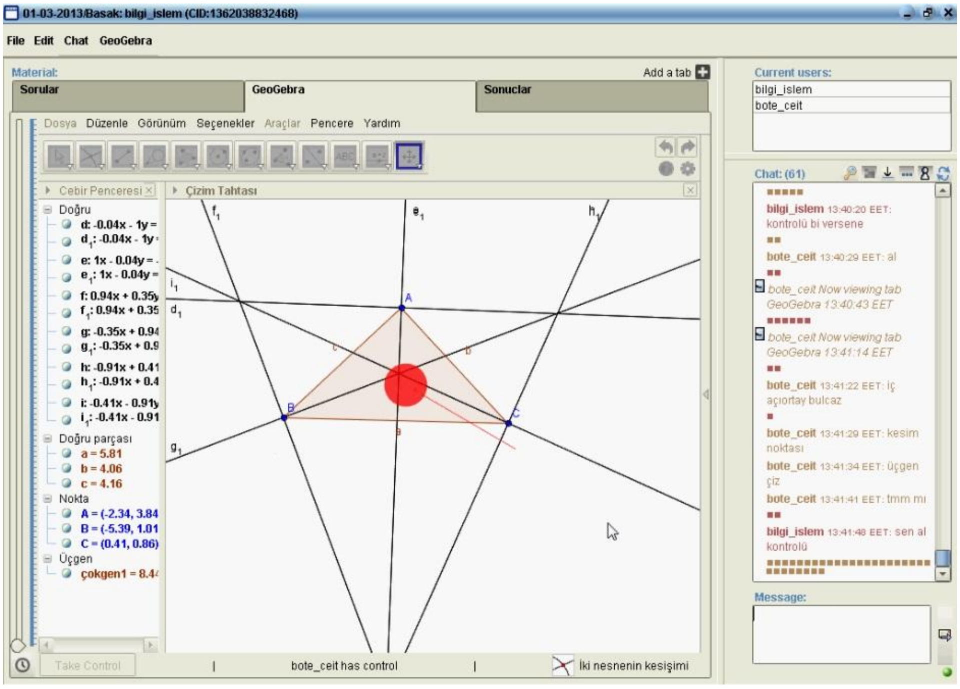

Figure 4.49 Eye Movements of BE (bilgi_islem) from Pair-8 for Question 8

Then he formed perpendicular line from point D to edges of triangle, and stated those intersected points named as E, F, and G. Finally, he drew a circle using circle passing 3 points tool.

Pair-8 solved seven questions, and we present some excerpts from their processes. Both of them contributed to the problem solving and writing solutions. When one of them tried to solve, but could not achieve, the other one made suggestions for him/her. They helped, and directed each other, reasoned together, and gave advice. Because of these reasons, the anticipatory gazes occurred, so before one constructed something, the other one started to look at this area. This pair, also, used VMT chat features to coordinate their actions such as "… viewing … tab" or "… is typing" like pair-5, as evidenced in the fixations that fall over such awareness messages. Participants used this feature in order to follow their partners' messages, so they could coordinate their actions using this feature. In short, the eye gazes of partners overlapped frequently during the course of the chat session. When comparing the videos and quantitative data, we can say that they are consistent with each other.

PAIR-2 (SI [bilgi_islem]-IHB [bote_ceit])

This pair is considered not successful in terms of collaboration, because they worked rather cooperatively. For instance, in several occasions while one partner was solving the problem, the other was writing the solution in the summary tab. So there was asynchronization among their gaze patterns. During rare cases in which gaze sequences were synchronized, generally SI (bilgi_islem) was solving the problem, and IHB (bote_ceit) was just following his actions. There was no reasoning together. The excerpt provided below is an example of asynchronous situation.

Question-4: In this question, while bilgi_islem was solving the fourth question (Figure 4.50), bote_ceit wrote the solution of third question (Figure 4.51).

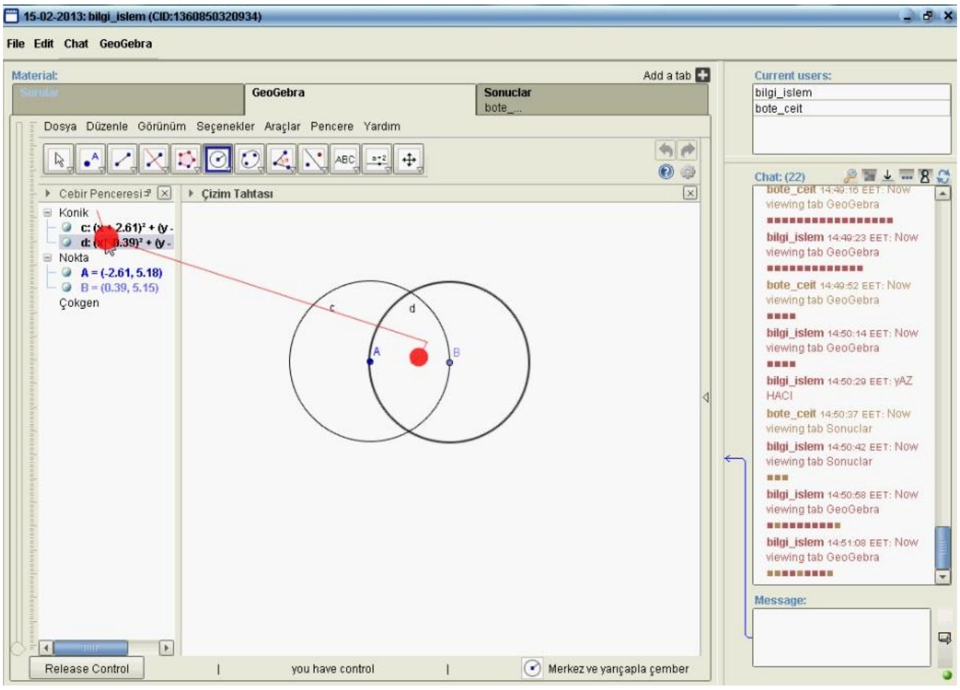

Figure 4.50 Eye Movements of SI (bilgi_islem) from Pair-2 for Question 4

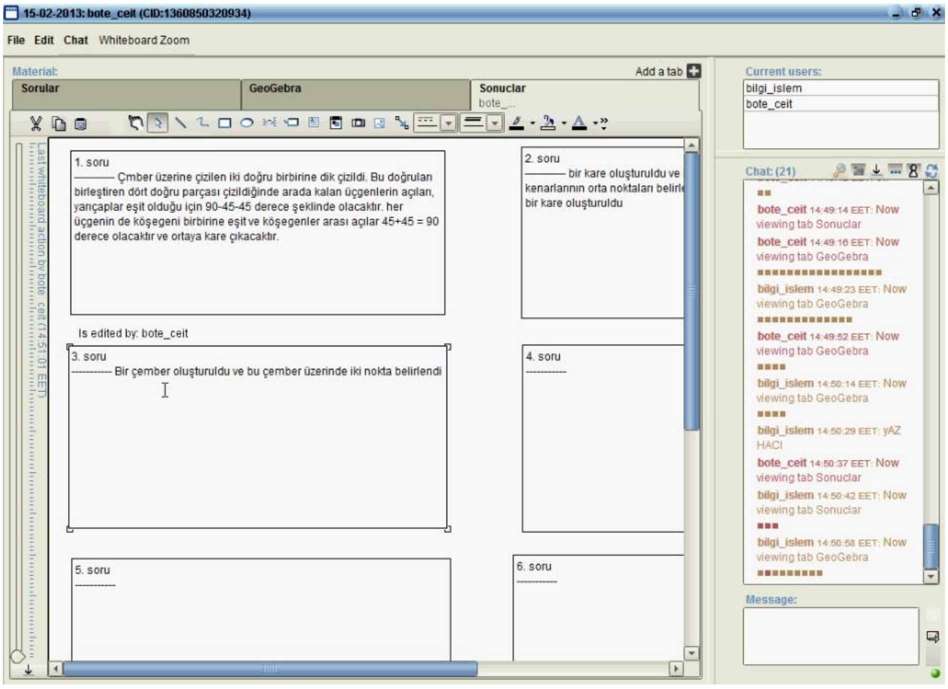

Figure 4.51 Eye Movements of IHB (bote_ceit) from Pair-2 for Question 4

They solved seven questions in total, and this asynchronized mode of operation started to occur since the third question. While IHB (bote_ceit) was writing the solution on Sonuclar tab, SI (bilgi_islem) attempted the next question. In this excerpt, bilgi_islem constructed the solution while bote_ceit wrote the solution of the third question. Then conversation presented below occurred.

> **bilgi_islem:** İspatla şimdi bunu. *(Prove this.)*
> **bote_ceit:** Tamam. (OK)
> **bilgi_islem:** Altına diğer soruyu yapıyorum. *(I'm doing other question under this one.)*
> **bote_ceit:** Tamam. *(OK)*
> bilgi_islem**:** Öncekini siliyorum. *(I'm deleting previous one.)*
> **bote_ceit:** Şu an hangisini yapıyorsun? *(Which one are you doing now?)*
> **bilgi_islem:** 5e geçtim. Siliyim mi diğerini? *(I'm doing fifth question. Do I delete other one?)*
> **bote_ceit:** Dur ya ben buna ne yazcam? O çizdiklerin kenar ortay mı? *(Wait. What do I write for fourth one? Are they perpendicular bisectors?)*
> **bilgi_islem:** Kenarortaylara köşelerden doğru parçası çizince kesiştikleri yer merkez olur kuralıdır falan de. (*Write the rule that when segments are drawn to perpendicular bisectors from the corners, the intersection point is the centre.)*
> **bote_ceit:** Tamam yazıyorum ben, sen devam et. *(Ok I write. Continue.)*
> **bilgi_islem:** Öncekini siliyorum karışmasın. (*I'm deleting previous one.)*
> **bote_ceit:** OK

Considering this conversation, bilgi_islem was like a leader, and bote_ceit was like a follower, because bilgi_islem solved the problems, bote_ceit just followed his actions, and sometimes could not follow. Because of this reason bote_ceit could not understand the solution, and BI had to explain the solution strategy.

Mainly they did not consult each other, or give suggestion, because they split the work as constructing the solution and writing the solution. While bilgi_islem was constructing, bote_ceit wrote the previous question answer. Because of this reason, bote_ceit got confused about the solution. Because of these asynchronize cases, their gazes did not overlap. And the analyzed videos support the quantitative data.

PAIR-4 (MD [bilgi_islem]-AB [bote_ceit])

This pair is not successful in terms of collaboration, because they work cooperatively like pair-2. They split the work, and while one was solving the problem, the other wrote the solution, so sometimes asynchronization on gaze overlapping occurred. The cases which with synchronization, generally MD (bilgi_islem) solved the problem, and AB (bote_ceit) just followed her action. There was no reasoning together. When MD (bilgi_islem) did not have idea about the solution, and asked her partner. But she did not look at her partner's message. The excerpts are provided below.

Question-8: In this question, bilgi_islem took control, and deleted everything on construction area.

bilgi_islem drew a triangle using polygon tool, then she generated angle bisectors, and stated a point where angle bisectors intersected (point D). After that she drew perpendicular lines from the point d to the edges of the triangle, and stated the points where perpendicular lines and edges intersected. Finally she drew a circle using circle through three points.
While bilgi_islem was solving eighth question (Figure 4.52), bote_ceit wrote the answer of the seventh question (Figure 4.53).

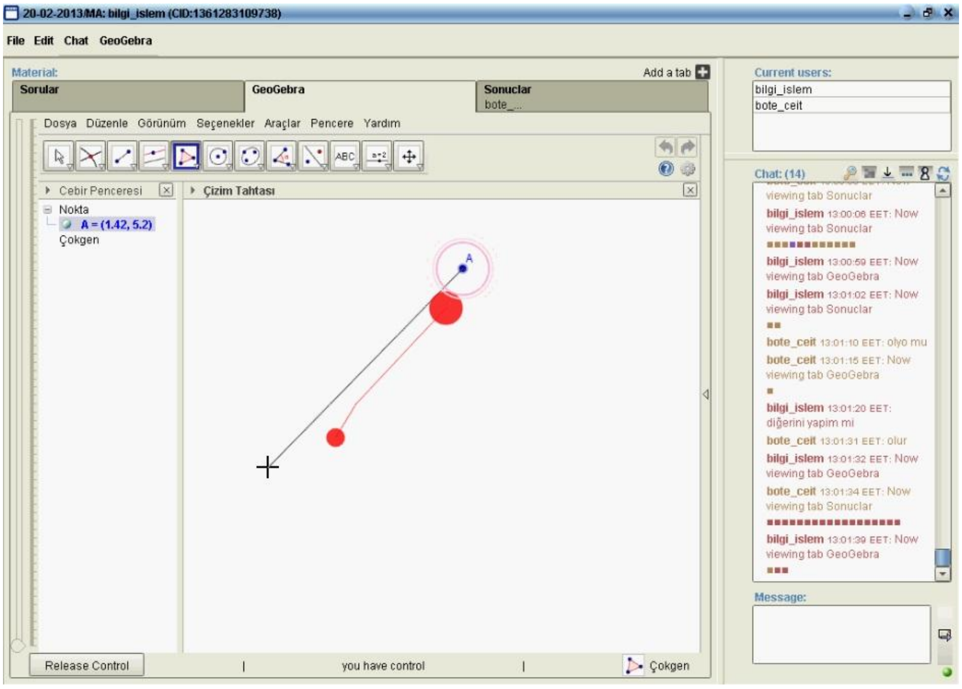

Figure 4.52 Eye Movements of MD (bilgi_islem) from Pair-4 for Question 8

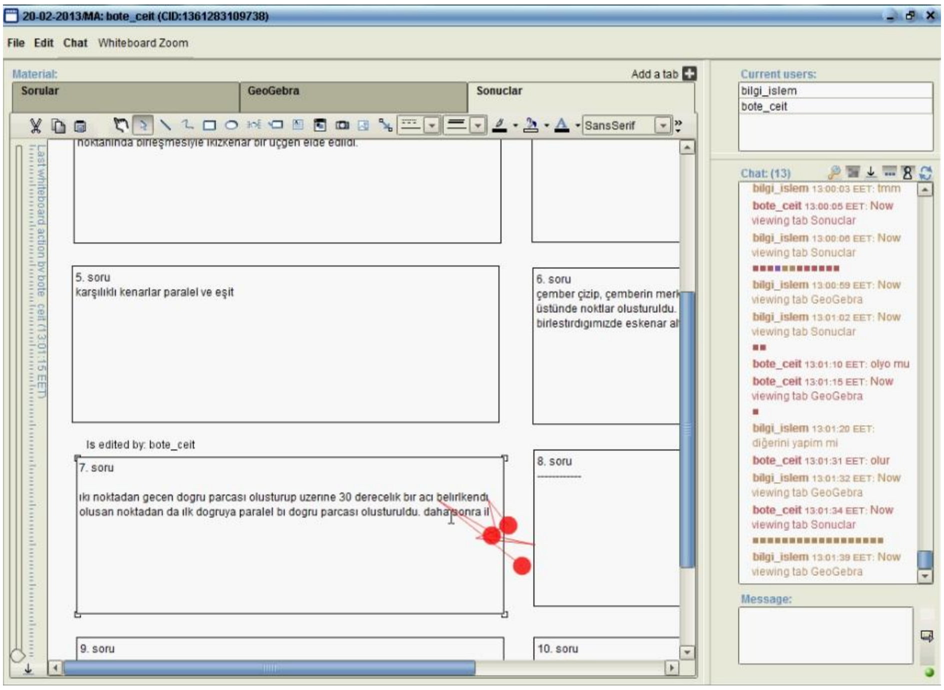

Figure 4.53 Eye Movements of AB (bote_ceit) from Pair-4 for Question 8

They solved nine questions, and this asynchronize situation started to occur as from the third question. While AB (bote_ceit) was writing the solution on Sonuclar tab, MA (bilgi_islem) solved the next question. Considering the whole process, bilgi_islem was like a leader, and bote_ceit was like a follower, because bilgi_islem solved the problems, bote_ceit just followed her actions, and sometimes could not follow, because she was busy summarizing the solution of the previous question. Furthermore, bote_ceit could not understand the solution, and bilgi_islem had to explain the solution strategy.

Mainly they did not consult each other, or give suggestions, because they split the work as constructing the solution and writing the solution. While bilgi_islem was constructing, bote_ceit wrote the previous question answer. Because of this reason, bote_ceit got confused about the solution. Their gazes did not overlap because of these reasons. And the analyzed videos support the quantitative data.

When we compare the scarf plot of pair-8 having the most gaze recurrence level and pair-4 having the least gaze recurrence level, we see the difference exactly. In Figure 4.54, the scarf plot of pair-8 for question 6 is presented. The total recurrence time is 59 seconds. When examining closely, gaze recurrences occur in chat area, and construction area.

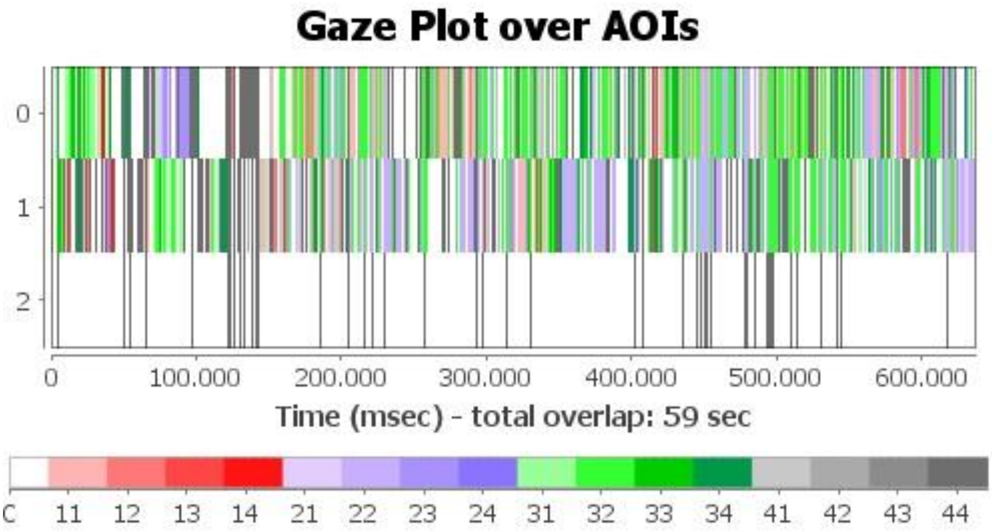

Figure 4.54 The Scarf Plot of Pair-8 for Question 6

In Figure 4.55, the scarf plot of pair-4 for question 2 is presented. The total recurrence time is 9 seconds, and this is the maximum recurrence level for pair-2. When looking at closely, gaze recurrences occur in the chat section mostly. And we can say that 0 (AB) did not look at the geogebra screen, because she was writing the answer on the summary tab. But 1 (MA) looked at the screen and different AOIs mostly, because she was attempting to solve the problem.

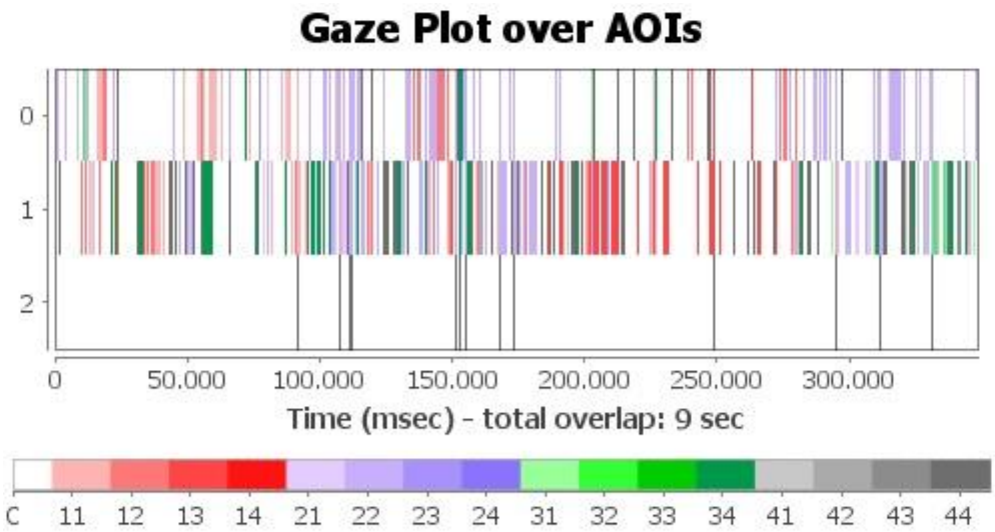

Figure 4.55 The Scarf Plot of Pair-4 for Question 2

Overall, the scarf plots and recurrence graphs are consistent with the interaction analysis.

4.2.2 Open-Ended Questions Results

To understand the participants' experiences, and their ideas about VMT Chat rooms, the answers of open-ended questions were examined. In the highlight of these data, the positive and negative features of VMT environment, suggestions of participants about VMT, and the processes of collaboration at VMT environment are mentioned below.

Question-1: **What are the positive features or features that you like in VMT environment? Please explain why you like or find positive those features.**

For this question, nine participants mentioned chat tool and communication as an advantage. They mainly stated that communicating with chat tool is beneficial for solving problem together.

From pair-5, participant AB stated that:

> "Chat odasında karşılıklı bireylerin yazabilmesi, işlem sürecinden o bireylere ait kutucukların yer alması felan çok güzeldi."
>
> "It was nice to have ability to type mutually in the chat room and have boxes belonging to participants from the operation process."

From pair-7, ST said that:

> "...sistemi kullanırken aynı zamanda chat yapmaya olanak sağlanması hoşuma gitti."
>
> "I like the way I am able to chat while using the system…"

In addition to these comments, from pair-1, GÇ indicated that;

> "Karşımdaki insanla uzakta olmasına rağmen sürekli iletişim halindeydim bu soruları çözerken çok büyük bir kolaylık sağladı."
>
> "I was able to stay in touch with person I was in contact although he/she is well away from me and that really provided great comfort while dealing with the problems."

From pair-4, AB stated that;

> "Soruları çözerken arkadaşınızla karşılıklı sohbet halinde kalabiliyorsun...Öğrenciler ilerde soruları karşılıklı etkileşim halinde çözebilirler bu sistemle."
>
> "While solving the problems, at the same time, you can chat with your friend… Students can solve the problems in interaction with each other thanks to that system."

Another advantage participants stated of this system is to provide users with collaboration. Six participants stated that solving the problems together is an advantage, because when one of the pair can not solve the problem, the other one can help, or direct him/her.

From pair-6, AB stated that;

> "… ve işbirliği kullanarak uygulanan eğitim öğretim sürecine çok faydası olduğunu düşünüyorum. Özellikle chat odası kısmı çok güzel düşünülmüş. Bu sayede uzaktan eğitim imkanı gibi uzaktan işbirliğiyle öğrenme süreçleri oluşturulabilir."
>
> "…and I think it serves for education process in which collaboration is used. Especially, chat room part was thought well. Thus, distant collaborative learning processes can be formed such as distance education."

From pair-3, TK indicated that;

> “Ek olarak dersi sevdirme amaçlı olarak kullanılabileceğini ve kullanılması gerektiğini düşünüyorum. İletişime olanak sağlaması işbirlikçi öğrenmeye katkıda bulunduğundan dolayı hoşuma gitti.”

> “Additionally, it can be used to help students enjoy the classes and it should be used for that purpose. I like it because it helps communication and contributes to collaborative learning.”

The other advantage of the system which is mentioned is to provide users with different tools. Four participants stated it.

From pair-3, TK stated that:

> “Farklı özelliklerini kullanarak farklı şekilleri çizmeyi denemek örneğin yaratıcı düşünme açısından da katkıda bulunabilir.”

> “Drawing different shapes by using different features contributes to, for example, creative thinking as well.”

In addition to this, from pair-7, TA indicated that:

> “İlk başta biraz zorlandım ancak sistemin sağladığı araçların kullanışlı olması sayesinde kolayca adapte olabildim. Bu şekilde problem çözmek çok hoşuma gitti. Menülerde yer alan araçlar (açı ölçme, kenar uzunluğu ölçme, nokta, doğru parçası vs.) problemin çözümünde düşünülen basamakları uygulamada yardımcı oldu.”

> “At first, I had difficulty to get used to it but then I could easily adapt to it thanks to useful tools provided by the system. I loved solving problems in that way. Tools placed in the menu (measuring angle, measuring edge length, point, line segment etc.) were very beneficial in following the steps of the solution of the problem.”

Three participants indicated that take control feature is very useful, because it prevented the confusion on the construction area.

From pair-8, BE stated that:

> “Bence ‘take control’ özelliği de güzeldi. Kontrol tek kişide kalıyor ve diğerine sormadan kontrolü alamıyor. Bu iki kişinin aynı anda çizim yapmaya çalışmasını ve karmaşa oluşmasını önlüyor.”

> “I think “take control” feature was also fine. Only one mate can take the control and cannot take the control without the permission of the other. That avoids drawing simultaneously and prevents the chaos.”

From pair-6, AB, also, mentioned:

> “bir kullanıcı işlem yaparken bir diğerinin sisteme müdahale edememesi ve o süreci görebilmek olumlu özellikler. Bu sayede karışıklık önlenmiş oluyor.”

> “While one user processing on the system, the other one cannot invervene it and you can observe that process. These all are positive qualities. That way confusion is not permitted.”

Two participants mentioned that this system provides users with visuality, so solving the problem visually motivates the participants. Furthermore, from pair-4, MD states that:

> “Geometride birçok öğrencinin anlamakta zorlandığı konuların görsel olarak ispatının yapılabilmesi öğrenmeyi kolaylaştırabilir.”

> “Visually proving though topics of the geometry many students having difficulty to comprehend eases learning it.”

Two participants indicated that this system helps users with practical and creative examples. From pair-7, TA indicated that:

> "Sistem geometride biraz ezber şeklinde öğrendiğimiz bilgileri uygulamalı olarak kullanmamızı sağladı."

> "System provides us with applied usage of information we have learned in the form of memorization."

From pair-3, TK said that:

> "Ortam yaratıcı örneklerde yaratmaya ve sunmaya olanak sağlıyor."

> “The system provided us to use information we had to memorize in geometry in more practical way.”

Finally, four participants mentioned that having different tabs is fine in the system. From pair-6, AB stated that:

> "Ayrıca bu uygulama geogebra kullandık ve hepsi farklı sekmelerdeydi yani sorular, çözüm bölümü ve cevabın yazıldığı bölüm bu da koordinasyon açısından çok iyiydi."

> “Moreover, we have used geogebra in this application and all are in different tabs; in other words, questions, answers and solution part are all apart. This served for coordination well.”

To sum up, for this question, participants mentioned chat tool, collaboration feature, different drawing tools, take control feature, providing users with visuality of geometry and creative examples as advantages of the system.

Question-2: **What are the negative features or features that you do not like in VMT environment? Please explain why you do not like or find negative those features.**

For this question, four participants mentioned the difficulty about usage of GeoGebra tools as a disadvantage, and the aim of some of the GeoGebra tools are not clear. From pair-1, GP said that:

> "Araç çubuğundaki bazı düğmelerin işlevleri düşündüğümden farklıydı bu benim için biraz şaşırtıcı oldu. Bunların işlevini çözmeye çalışırken biraz zorlandım."

> "Some buttons on the toolbar had different functions than I thought. That was surprised me a bit. I had difficulty while I was trying to understand functions of them."

In addition to this, from pair-7, ST indicated that:

> "bazı tool ların çiziminin elle çizime göre daha zor olması da bir dezavantaj (örn: doğru parçası)".

> "Drawing some shapes via tool is more difficult than drawing them manually like "line segment". That is one disadvantage."

Three participants stated that the design of the interface is not attractive, and it does not motivate us. Three participants indicated that sometimes the environment has interruptions. Two participants wrote that the moving GeoGebra construction area causes confusion. From pair-8, BE stated that:

> "GeoGebra da taşıma yaptığımda ya da ekranı küçülttüğümde karmaşa oluyordu, bundan hoşlanmadım."

> "When I move shapes in GeoGebra or minimize the screen, things get confused and I did not like it."

From pair-6, MS said that:

> "Gördüğümüz alanı kaydırdığımızda karşımızdaki arkadaşımızda da ekran kaymalı. Kaymadığından dolayı çalışırken aynı yeri göremedik."

> "When one mate move the area we both view, the area the other mate view should also move. Since it did not, we were not able to view the same area while studying."

Generally, participants stated the difficulty of usage of GeoGebra tools, and the interface design as a disadvantage.

Question-3: What are the difficulties that you encounter while solving problems?

For this question, seven participants mentioned the difficulty about the usage of GeoGebra tools. While drawing, participants who have not used GeoGebra before have difficulties, and sometimes they could not achieve to construct drawing although they explore, and know how to solve problem. From pair-7, TA stated that:

> "Sistemde yer alan araçların ne işe yaradığını ve nasıl kullanıldığını bazen hatırlamakta zorlandım (Örneğin açı ölçme aracının saat yönünde ya da saat yönünün tersinde kullanıldığında farklı işlevinin olması gibi). Bu da soru çözerken zaman kaybına sebep oldu. Uygulamada zaman sıkıntısı olmasa da problem çözerken zaman kaybetmemek benim için önemliydi. Araçlara tamamen adapte olmak ve etkin kullanmak için daha fazla alıştıma yapmanın şart olduğunu anladım."

> "Sometimes, I had difficulty in memorizing what functions of the tools in the system serve for and how they are used. For example, the tool measuring angle has different functions depending of its use either by clockwise or counter clockwise. This caused

time loss during solving the problems. Even though there was no time issue in the application, it was important for me not lose time. I understood that I should make much more practice to be able to adapt to the tools better and use them effectively.”

From pair-6, SD indicated that:

"Şekilleri çizmekte zorlandım. Çizim ortamı benim için uygulama anlamında zordu"

“I had difficulty in drawing shapes. Drawing medium was though for practice.”

The other difficulty participants face with was to communicate each other with chat tool, because sometimes misunderstanding and difficulties occurred during collaboration processes. Two participants mentioned this difficulty. From pair-5, FU stated that:

"sözel iletişim kuramamak bir sure sonar sıkıcı gibi geldi."

“It became boring not to communicate verbally after a while.”

From pair-7, TA indicated that:

"sohbet aracının metin tabanlı olması hem işlem ekranını hem de sohbet ekranını takip etmeyi zorlaştırdı. Ekip arkadaşımın yazdıklarından bazılarını görmediğim durumlar oldu. Bu durum işbirlikli çalışmayı zorlaştırdı."

“It was hard to follow both process screen and chat screen since the chatting tool was based on text. Sometimes, I could not notice some of what my teammate wrote to me. That made collaborative study harder.”

Finally, from pair-2, SI said that:

"Yanlış yaptığımı düşündüğüm şekilleri geri alamadığım için seçip silmek zorunda kaldım ve çizim alanı dolu olduğunda bu biraz zaman kaybettirdi."

“Since I could not undo shapes that I thought I had drawn wrong, I had to select each one then delete them. Since my drawing space was full of these shapes, I had lost some time.”

For this question, most of the participants indicated that the usage of GeoGebra tools is difficult. Because of this difficulty, some of them could not draw although they know the solution. The other difficulty participants confronted is to communicate chat tool, because chat tool has limitations, causes some misunderstandings and time loss.

Question-4: What are your suggestions about the system?

The answers given for this question is mainly about the interface design, and GeoGebra tools. Three participants suggested that the interface must be redesign, because it is not attractive, and the colors are dull. From pair-2, IHB stated that

"Chat kısmında renklendirme kısmı daha seçici olmalı ve donuk renkler kullanılmamalı. Ayrıca yapılan her işi mesela tablar arası geliş gidişlerin chat kısmına yansıyacaksa bile farklı bir renklendirme ile yapılmalı."

"In chat part, coloring scheme should be more distinctive and use of undertone should be avoided. Moreover, if each work to be performed during transition among tabs is reflected to chat part, then, different color scheme should be used."

In addition to this, from pair-7, TA indicated that:

"Sistemin ekran tasarımında kullanılan renkler ve düzen biraz sıkıcı geldi. Öğretimsel amacı engellemeyecek ve dikkat dağıtıcı olmamak şartıyla daha ilgi çekici bir tasarım yapılabilir."

"Format and colors used in the screens of the system seems to be boring. More attractive design can be formed without causing any distraction of the participation and preventing educational purpose."

Three participants mentioned that making GeoGebra tools more easy to use. Two participants suggested that communicating with voice is more efficient. From pair-1, GÇ stated that:

"Bence karşıdaki insanla olan iletişim webcam kullanılarak yüz yüze yapılmalı böylece yazmakla zaman kaybedilmez ve yanlış anlamalar en aza indirilebilinir."

"I think communication with the teammate should be established face-to-face via webcam; thus, time loss and misunderstandings can be minimized."

From pair-5, AB, also, suggested that:

"Karşıdaki kullanıcının mouse hareketlerini, seçtiği tool ları, inşa sürecini görebilsek çok daha iyi olur."

"Visualization of movement of the mouse of the other mate, tools he/she selects and building process would be very beneficial."

Participants mainly made some suggestions about the interface design, and GeoGebra tools. In addition to these, communicating via webcam and visualization of movements of the mouse cursor of other mate are different suggestions from participants.

Question-5: What was level of cooperation with your team member in the process of problem solving? Please explain your collaboration process. How was your contribution to the problem solving processes? What was the contribution of your teammate? What was the contribution of cooperation in the system? Can you tell about the positive and negative aspects of solving the questions with your teammate?

All of the participants stated that communicating with his/her partner, and solving problem together is very important to provide collaboration. 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. In the excerpts provided below, participants told their collaboration experiences:

From pair-5, AB:

“Sistem işbirliği süreci, katkısı açısından mükemmeldi bence. Soruları çözerken ilk başta beraber soruyu okuyup anlamaya çalıştık. Daha sonra çözümü nasıl yapabileceğimizi düşündük. Sonra çözüm penceresine geçip kafamızdakileri uygulamaya çalıştık. Birimiz çözümü gerçekleştirirken diğerimiz onu yönlendirdi. Bazı sorularda çözüme ulaşamadığımızda diğer kullanıcı aklına bişey geldiğinde hemen o devraldı ve çözümü gerçekleştirdi. Bir soruda çözümü arkadaşım bi yoldan başlattı ama tam bulamadı o yolu görünce benim aklıma başka bir çözüm geldi ve onu uyguladım ama kafamda birşey takıldı orda partnerim devreye girdi ve çözümü gerçekleştirdik. Bir başka soruda partnerim çözüm sürecini gerçekleştirirken ben de yönlendirerek ekstra dörtgende bulunması gereken özellikleri söyledim ve onları da bulduk. Ekip arkadaşım çok uyumlu bir çalışma sağladı onun aklının takıldığı yerde ben devreye girdim benim aklımın takıldığı yerde o devreye girdi. Sistemin chat odası işbirliğimi arttırdı. Ayrıca aynı kağıt üzerinde aynı sayfa üzerinde birlikte çalışmak işbirliğini sağladı ikimizde ayrı yerlerde çalışıp sonuçları karşılaştırsaydık işbirliğimiz tam olarak gerçekleşmezdi. Aynı sayfada ekip arkadaşımında sürecini görmek çok daha pozitif etkiledi.”

“The process of system collaboration was perfect in terms of its contribution. While solving the problems, at first, we had read the question and tried to understand it. Then, we thought on how we could reach the solution. Then, we moved to solution window and tried to practice what we thought. While one of us tried to reach the solution, the other one took the lead. When having trouble to reach to the solution, the other mate took the control if I cross something in his/her mind and solved the problem. In one question, my friend started to solution but could not go further at some point. Looking at his/her way, an idea stroke in my mind, then I proceeded but I am also stuck at some point, then my mate get into charge, then we finally reached the solution. In another question, while my mate was dealing with the solution part, I was guiding my friend about what attributes a rectangle should have and we found out these attributes. My teammate studied with me in harmony; when we were stuck, I helped him/her and vice versa. Chat tool of the system increased our collaboration. Moreover, studying on the same shared working paper on the home page increased our collaboration. If we worked on different papers and compared our results, we would not collaborate effectively. Viewing my mate’s process at same page has positively affected it.”

From pair-8, BE:

“Kolay sorularda zaten kontrolü birimiz alıyor ve çözümü tamamlıyorduk. Zor olanlarda da nasıl bir yol izleyeceğimizi konuşup sonra çözüme geçiyorduk. Benim takıldığım yerlerde arkadaşım şöyle bir şey vardı, şu yöntemi deneyebilirsin şeklinde hatırlatmalarla bana yardımcı oldu. Birbirimizin çizimlerini gördüğümüz için anında müdahale edebiliyorduk ve şimdi şunu kullan bunu yap şeklinde yardımcı olabiliyorduk. Birimizin göremediğini diğeri görüyordu.”

“In easy tasks, one of us was already taking the control and completing the solution. In tough ones, we first decide on what to do then move to the solution part. When I had difficulty at some point, my mate helped me by suggesting some methods. When we view drawings of each other, we could intervene and suggest things immediately. When one of us could not notice some aspect, the other one could."

From pair-7, TA:

"Ekip arkadaşımla olan işbirliğimiz yüksek düzeydeydi. Öncelikle soruları okuyup fikir yürütmeye çalıştık. Soruya karar verdikten sonra çözümle ilgili fikirlerimizi paylaştık. Gönüllülük esasına göe kimin sistem araçlarını kullanarak çizim yapacağına karar verdik. Sorunun çözümünü tam olarak bilemesek de yaptığımız yorumlar karşılıklı olarak çözüm yolu geliştirmemize yardımcı oldu. Bazı sorularda ben soruyu çözmede kullanabileceğimiz yöntemi anlatmaya çalıştım o da araçları kullanarak benim fikirlerim ve kendi fikirlerini birleştirip çizim yaparak çözümü sağladı. Benim kesin fikirlerim olduğunda ise o fikirleriyle yardımcı oldu ve çözümlerle ilgili çizimleri ben gerçekleştirdim. Çözüm sürecini açıklamamız gerektiğinde yaptıklarımızı tekrar ederek birbirimize yardım ettik ve kanıtların yazımını sağladık. Birimiz çizim araçlarını kullandığında diğerimiz sorunun çözüm yollarını kanıtlarıyla yazdı. Çözüm yollarımızı ve yazdıklarımızı birlikte kontrol ederek hata yapmamaya çalıştık."

"We had higher collaboration with my teammate. First, we read the questions and tried to have an idea. After deciding the question, we shared our ideas about the solution with each other. Based on volunteerism, we decided on who is going to draw by using system tools. Even though, we could not figure out exactly how to precede the solution, interactive comments on issued helped us to develop some solution method. In some questions, I tried to explain which method to use and my mate provided the solution by making drawing by combining my ideas with his/her ideas. When I had certain ideas, my mate helped me with his/her own ideas and I made the drawings with these ideas. When we try to explain solution process, we repeated what we did and documented the proofs by helping each other. While one of us using drawing tools, the other one was documenting solution methods with their proofs. We tried not to make mistakes by controlling solution methods and writings of each other."

From pair-9, DFC:

"Ekip arkadaşımla güzel bir çalışma gerçekleştirdiğimizi düşünüyorum. Arkadaşımın takıldığını hissettiğimde veya aklıma bir fikir geldiğinde kontrolü hemen almak istedim ve arkadaşım da bunu olumlu bir şekilde karşılayarak kontrol hakkını bana verdi. Bu zaman kaybımızı azalttı diye düşünüyorum. Ekip arkadaşımda problemi çözmek için gerekli eforu harcadığını düşünüyorum.Problemi beraber çözmek aklıma gelmeyen noktaları düşünmem açısından önemliydi. Benim düşünemediğim noktaları arkadaşım hatırlattı. Örneğin kareyi doğrulamak için köşelerin 90 derece olduğunu ispatlamamız gibi. Bu benim aklıma gelmemişti. Ekip arkadaşımın problem çözme hakkına sahipken ben problem üzerinde değişiklik yapamıyordum. Ama bu durum benim için iyi oldu diye düşünüyorum. Çünkü arkadaşım problem üzerinde uğraşırken problem hakkında düşünme süresi bulabildim."

"I think I was good work we had performed with my teammate. When I felt that my friend was in trouble, I had the idea to take the control of the work and my teammate welcomed this situation. I think this reduced our time loss. I think I have spent the effort required to solve the problem with my teammate. Solving the problems together was important to think points which I could not cross my mind alone. My friend reminded me the points I could not image alone. For example, validating a square by proving each angle should be 90 degrees. That had never crossed my mind. While my friend had the right to solve the problem, I could not make any change on the problem. However, I think that was good for me because I had the opportunity to think a while on the problem while my friend was dealing with it."

Although all participants have a positive opinion about this process, three of them stated that VMT environment has some limitations. Two of them indicated that chat tool has some limitations affecting the collaboration process. For example, they could not see some messages, or they misunderstood each other, and chatting causes time loss. From pair-6, BA stated this situation in the excerpt provided below:

> "Bazen sorunun çözümüne kendimi kaptırıp arkadaşımın sorularını göz ardı ettiğim ya da yeterince açıklamadığım oluyordu. Bence bu yüzyüze olmamanın bir sonucu. Yazışırken bütün detayları yazmıyorum ama karşımda olsa ve anlatıyor olsam bütün detayları açıklardım."

> "Sometimes I was indulging to the solution of the problem resulting in disregarding the questions of my friend or not providing enough explanation to them. I think this was because we were not face to face. While typing I am not providing all the details but if I had her in front of my eyes, I would explain all the details."

In addition to this, from pair-7, TA indicated her experiences as:

> "Sistemde sohbet aracının olması işbirliği sürecimizi katkı sağlamakla birlikte sınırlılıkları da vardı. Metin tabanlı olması yönüyle bazen soru çözümüne odaklanıp sohbet aracına yazılanları görmediğimiz oldu."

> "Although there was a chat tool contributing to our collaboration process, there were some limitations either. Since it was text-based, sometimes we were focusing on the solution of the problem causing disregarding unconsiously what was written on the chat tool."

For this question, all participants stated their positive ideas about collaborative problem solving processes, directing and helping each other. But three participants mentioned some limitations of VMT environment such as misunderstanding and time loss.

4.3 Summary of the Results

In this part, the summary of the obtained results in relation to the research questions is presented.

For the first question, we observed that some VMT features help users with the coordination of joint attention. The chat tool could be considered as the first such feature of VMT. Participants used this tool to communicate with each other, and while solving the problems, they directed each other by exchanging text messages. Especially, while one was writing a message, the message such as "… is typing" was seen under the chat tool. Eye tracking videos indicate that these messages also help users with facilitating joint attention exceedingly. Moreover, the construction area makes the evolution of the ongoing construction visible to all users. Thus, gaze overlaps typically occur while constructing, and typing to each other. The second feature facilitating joint attention is the awareness message announcing the changing of tabs. When a participant changes the tab, there is an awareness message "… viewing tab GeoGebra" in the chat. Participants who saw this message knew where their partner was looking at, and often changed their tab accordingly. This feature is important; because it helped participants follow each other easily without needing to type messages such as "where are you looking at?" But participants see their own tab actions in the same way, and it causes the chat unnecessarily crowded. The third feature is the take control button, and the message about "you have control" or "… has control". When a participant took control, and constructed the solution, the other participant saw this message and the dimmed appearance of take control button (i.e. it becomes not clickable). Then s/he looked at the construction area, because s/he knew that his/her partner is about to start a construction. Thus this feature, also, helps facilitating the joint attention. The fourth feature is located at the bottom right of the construction area, which shows the tool that is currently selected by the person who is in control. This tool is potentially important for pairs to coordinate their actions and eye gaze in purposeful ways, because when a user realizes the tool which is currently selected, then s/he can better follow the ongoing construction and even perhaps anticipate the next action by searching for the relevant area that tool might be used. Such cases may help peers better understand each other, and gradually build a shared understanding of their constructions. Namely, if this feature can be designed to better communicate the currently selected drawing tool, then it may enable users to understand each other, coordinate their actions, and create shared understanding; in other words perform better collaboration.

Briefly, participants coordinated their actions across the construction area and the chat by using features of chat tool. When one could not solve the problem, s/he looked at chat area in order to see whether his/her partner suggested a solution or not. Additionally, "… typing" message was used for coordinating action across construction area and chat. While solving problem, they looked at chat area frequently, because they saw that their partner was typing a message.

For the second question, we used recurrence analysis and interaction analysis methods. Firstly, we created recurrence graphs, and observed the recurrence level for each pair. Secondly, videos of each pair were analyzed to examine the organization of the interaction, and excerpts from those videos were presented. Comparing these two analyses, we made some comments about the organization of collaboration. On one hand, pair-5, pair-7 and pair-8 were considered as successful pairs, because they could coordinate their actions. Furthermore, they could anticipate some of the next actions of their partner, because before contructing the solution, they tended to reason together, and discuss how they could approach the problem. Because peers discussed probable solution strategies in chat, they achieved a shared understanding of what should be done, which led to an increase in gaze overlapping in the drawing area. In addition to this, gaze overlapping occurred when peers followed each other's actions well, suggested solutions, helped each other, and sequencial and same actions.These three pairs were, also, successful, because they contributed to the problem solving phase approximately equally, as it is evident in the distribution of each partner's chat contributions and drawing actions for each task. Finally, they were successful because they made use of VMT features such as awareness messages frequently in order to follow each other's actions or messages, so their gazes overlapped frequently.

On the other hand, pair-2 and pair-4 are unsuccessful pairs, because they could not coordinate their action and achieve joint attention. This was mainly because while one partner was solving the problem, the other wrote the previous question's answer. Users constructing the solution were like a leader, because they figured out and constructed the solutions. Furthermore they explained the solution steps to the other user. So the other users were acting like a follower. They could not follow their peers at some points, because they were busy writing the previous question's answer. In addition to this, they did not reason together before constructing the solution, so shared understanding or anticipatory gazes did not occur frequently. Mainly, they gave suggestions at very low level while constructing the solution, and did not consult to each other, because one user solved the problem without helping. In brief, they split the work as construction and writing, so they did not work collaboratively, and their eye gazes did not overlap frequently. This was also evident in the cross-recurrence plots of these two pairs, as the curve for gaze overlap was almost identical to the randomized baseline. Thus, there is a relationship between the amount of gaze overlap and success in joint problem solving and collaboration.

For the third question, we benefited from the interaction analysis. Considering the videos exported from Tobii Studio software, we made some observations regarding factors underlying the achievement of shared understanding in interaction. An important indicator of shared understanding are anticipatory gaze patterns, where a participant starts to look at the specific area where his/her partner is about to perform an operation. Furthermore, in such cases we observed that team members followed each others' actions using VMT features, helped each other, suggested strategies to reach a solution, and discussed the probable solutions before constructing them on the geogebra tab. We gave some example excerpts that illustrate the presence and absence of these properties. Thus gaze overlaps give evidence about shared understanding, but we can not simply say that all gaze overlaps corroborate with shared understanding evidenced in interaction, because there can be unsystematic or random gaze overlapping in some cases.

For the fourth question, we used the answers of open-ended questions and videos. Participants stated that some features of VMT causes difficulties during collaboration process. Some of the participants said that it was hard to follow both construction area and chat area since the chat tool was based on text. Sometimes, they could not notice some of what their teammate wrote. That made collaborative study harder. Because of this reason, some participants suggested a communication channel based on voice instead of text-based chat. Another disadvantage of this system is that when a participant moves, zooms in or out the construction area, the other participant's screen does not change, and sometimes they were not able to view the same area while studying. The other disadvantage of VMT environment is about the chat tool. Color tones of each user's messages are very similar, and participants have difficulty in identifying which message belongs to whom, and because of this reason they often need to read the last few messages in order to find last message written by his/her partner. This affects communication negatively. The other problem is awareness message about changing tab. This property provides users with follow each other's action, and sees which tab his/her partner views, but participants see their own tab actions in the same way. Those messages make the chat unnecessarily crowded. Finally, some participants stated that VMT interface is not attractive, and boring. Considering the videos, VMT features mentioned above have some deficiencies, but provide them just enough to communicate with each other, follow their partner, and work collaboratively. VMT chat tool gives an awareness message "… is typing". Participants use this feature to follow peer's messages, and coordinate their attention across the construction and the chat area. In addition to VMT chat tool and interface, the usage of GeoGebra tool was found difficult by participants. They had difficulty while constructing the solution by using the drawing features provided by geigebra, although they knew the solution strategy.

CHAPTER 5

DISCUSSION

The aim of this thesis is to examine the processes of collaborative problem solving sessions mediated by the VMT environment. During the sessions, eye-trackers recorded the eye movements of participants. After sessions, participants filled a questionnaire containing SUS and open-ended questions. We analyzed these collected data, and tried to answer the research questions. Throughout this chapter, results are discussed in detail.

5.1 User Satisfaction

This set of data is based on SUS questionnaire evaluating to what extent users are satisfied with the environment. The average score of the SUS questionnaire is 52,30 out of 100. However, as it was mentioned earlier, this questionnaire is originally developed to evaluate environments designed for a single user, and gives limited information about the user collaboration related experiences. Understanding user's reasons and motivations underlying their adoption of collaboration tools such as team-space tools, wikis, social networking tools and etc. to the collaborative environment is still a big problem (Holtzblatt, Damianos & Weiss, 2010; Matthews, Whittaker, Moran, Yuen & Judge, 2011). Because of this reason, we complemented SUS with open-ended questions directed towards their collaborative experience with the system. Participants' answers provided detailed information about their experiences in the VMT environment and its success in effectively supporting collaboration.

Some of the participants stated that VMT environment has some limitations in terms of working collaboratively. Limitations are mainly based on communication specifically via the chat tool, because it causes time loss and misunderstandings. Furthermore participants reported that they could not see some messages due to the way the chat tool interface is designed. One of these problems is about color. The messages of different people have different color, but the used color tones are very similar. Thus, participants have difficulty in identifying which message belongs to whom, and because of this reason they often need to read the last few messages. This creates a usability problem, and affects communication negatively. Color is an important design principle affecting users' perception, and is a part of harmony (Brady & Phillips, 2003). Thus, color selection must be done correctly.

The other problem is about communication, as stated by participants, because participants sometimes focused on the construction area and drawings, so they disregarded some of the chat messages unintentionally. Since the chat is text-based, some participants could not articulate all details of their ideas or solutions. In addition to these problems, some of the awareness messages automatically generated by the system were considered distracting as they take too much space. For instance, when participants change the tab, this action is written in the chat area as “user A now viewing the tab geogebra”. This property is very useful, and supports collaboration, because thanks to this property partners can follow which tab their partner is currently monitoring. But participants see their own tab actions in the same way, as shown in Figure 5.1. Such messages make the chat unnecessarily crowded. Because of these reasons that inhibit the effectiveness of communication, participants stated that they would prefer to communicate verbally about the geometric constructions rather than exchanging text messages.

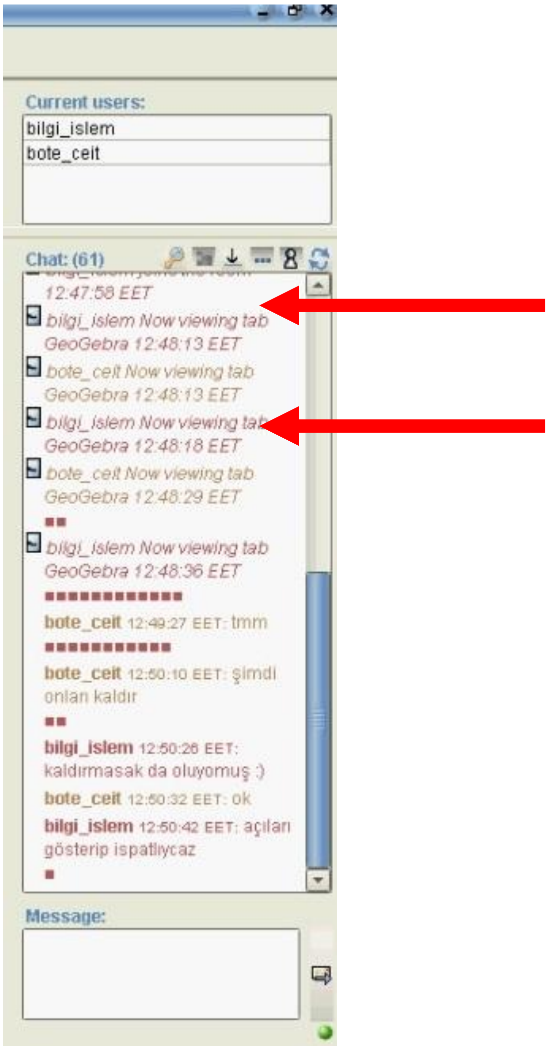

Figure 5.1 Appearance of Chat Tool

Another limitation participants mentioned is related to the construction area. If one of the partners move, or zoom in/out this area, these actions can not be seen from the other partner's screen. This is a violation of the “what you see is what I see” (WYSIWIS) principle in collaborative system design. Because of this problem, one partner sometimes could not see his partner's constructions well. In addition to this, just one person can construct at any given time on the whiteboard, and the other user just follows his/her actions. According to participants' comments and our observations, this property has both positive and negative effects. Positive effect is that there can be confusion if more than one person makes constructions at the same time. Taking turns on constructions facilitate the achievement of joint attention. Negative effect is that while one was constructing, the other one just looked at his/her actions passively. In most of our groups one of the participants tended to dominate the construction process, which is not ideal from an active/participatory learning perspective. However, the participant who is lurking on the construction process may still learn from his/her peers constructions, and provide feedback and make proposals for possible ways to approach the constructions by using the chat tool.

5.2 Collaboration Level

To investigate and assess the success of collaboration between partners, eye-tracking data are used in two ways. Data exported from Tobii Studio Software were processed, the percentages of gaze recurrence between partners for each session and team were calculated, and then the distributions of percentages of recurrence graphs over various time lag combinations were obtained. Considering these graphs, we can make general comments about the success of collaboration.

We examined that the degree of gaze overlap among partners will be high when they have high collaboration level. And the results of cross-recurrence analysis show that this assumption is true. This result is consistent with the literature since it has been reported by some studies that high-quality collaboration is positively correlated with high levels of visual recurrence (Jermann, Nüssli, Mullins & Dillenbourg, 2011; Richardson & Dale, 2005; Jermann & Nüssli, 2012). Specifically, considering the number of operations for each participant, partners having high quality collaboration show similar contribution on problems. On the contrary, there is a big difference between the number of operations partners did who have low quality collaboration, because they divided the work into solving problem and writing solution tasks. As mentioned in the literature part, they worked cooperatively, not collaboratively, because in collaborative learning team members do the whole work together (Dillenburg, 1999a), and they create shared understanding (Roschelle and Teasley, 1995).

Quantitative measures obtained from eye trackers such as gaze overlaps are still not enough to assess the quality of the knowledge co-construction process that takes place during collaborative learning. There is a need to understand the collaboration process in detail to better understand the organization of the meaning-making activities taking place in CSCL environments (Stahl, Koschmann & Suthers, 2006). In order to have a better understanding of the factors that contribute to the quality of collaboration processes, micro-level analysis of moment-to-moment details of interaction is a necessity (Barron, 2000; Sawyer, 2006; Stahl, Koschmann & Suthers, 2006). Interactions among participants are typically examined in CSCL research by analyzing the content of contributions and response patterns as captured in videos, chat logs, and computer logs of collaborative learning interactions (Roschelle, 1996; Roschelle & Teasley, 1995; Stahl, 2006; Koschmann, Stahl & Zemel, 2007; Koschmann & Zemel, 2006). By conducting interaction analysis of excerpts from our corpus, we found that as partners developed a shared understanding of what they are chatting about, as they exhibit anticipatory gaze patterns, and make complementary suggestions towards finding a solution to the problem at hand, the amount of gaze overlap increases. This result is consistent with the study of Jermann and Nüssli (2012), where they stated that actively engaged pairs who succeed in building shared understanding have high level of gaze overlaps.

However, CSCL researchers need more fine-grained distinctions among the patterns of activities observed via qualitative methods. The qualitative findings suggest that quality of collaboration is not just a matter of achieving gaze coordination, but establishing and maintaining a sense of mutual alignment and reciprocity. Anticipatory gaze patterns, suggesting the next relevant move, completing a move initiated by the partner can all be considered as strong indicators of collaboration quality, all of which contribute to high gaze cross recurrence values. Our current analysis of gaze recurrence cannot make such fine grained distinctions. Future work may aim towards finding interaction and gaze patterns that would allow the identification of such quality indicators from eye tracking data and interaction log files.

5.3 Implications for Research and Practice

Gaze recurrence analysis could be a viable method to evaluate different collaborative systems in terms of their success for facilitating joint attention. Facilitating effective communication and joint attention are important usability goals in collaborative systems development, and such aspects are not easy to evaluate empirically by using existing usability methods and user questionnaires. The gaze recurrence techniques can help towards devising usability evaluation methods for collaborative systems.

Considering the results of this study, awareness features are very important to provide users the means to increase their interaction quality during collaboration. But the design of these features can affect the interaction negatively, if they are not designed in a proper way. In order to design more usable environment, complex and overly crowded interface designs must be avoided, and color selection should be done in a more proper way to promote the legibility of the messages. In the case of VMT, even though a different color is assigned to each person, the poor contrast among the colors chosen led to reading difficulties. The awareness messages have a similar color-coding with poor contrast. In addition to adjusting the contrast of colors, peers could follow each other's actions more easily if awareness messages were marked with a different font type and size as compared to chat messages.

The other way of increasing the quality of collaboration is to promote reasoning together, and discussion among peers before the construction of problem, because we observed that the more peers discuss, and reason together before the construction process, the more they had shared understanding and shared attention. We suggest that when a collaboration process is designed, resoning together, discussion and suggesting solutions processes should be supported, and encouraged. CSCL scripts (Fischer, Kollar, Mandl & Haake, 2007) that promote such behavior could be tested further to see if such a pedagogical strategy would make a difference in improving the quality of collaboration in a future study.

5.4 Recommendations for Future Research

For the future research, an evaluation method for collaborative learning environment both from the process perspective and the usability perspective should be developed, because there is a big need to this kind of evaluation tool. The gaze recurrence analysis was based on a 4x4 matrix of static AOIs. The granularity level of the analysis could be expanded by considering overlaps between fixation locations. However, Tobii's default fixation filter needs to be fine tuned for the purpose of measuring joint attention at a more fine-grained level of analysis (Nüssli, 2011).

Methods that support dynamic AOIs could be developed by integrating the eye tracking system to the software environment, so that gaze recurrence over specific objects and text messages could be investigated. Such an approach may open up the possibility for employing data mining techniques to build better analytical tools. Such tools may be useful towards developing tools for automated assessment of collaborative learning. For instance, Meier, Spada and Rummel (2007) developed a rating scheme to assess the quality of computer supported collaboration processes which have nine dimensions, which are sustaining mutual understanding, dialogue management, information pooling, reaching consensus, task division, time management, technical coordination, reciprocal interaction, and individual task orientation. This rating scheme has been developed for collaboration environment based on a videoconferencing system, but it is questionable to what extent this scheme is applicable to all kinds of collaboration environments, such as the ones based on text-based communication. We recommend that a rating scheme assessing all kinds of collaboration environment should be developed. Furthermore, a rating scheme or method evaluating the usability of collaboration environment should be designed.

Because joint attention is at the heart of the collaboration process, there is a need to design more effective awareness mechanisms that would better support users for the achievement of joint attention. For example, Schneider and Pea (2013) developed an application where pairs can see the partners' gazes on the screen, and the results indicate that a higher quality of collaboration occurs in the shared gaze condition. In the future studies, different methods could be developed to promote and assess joint attention awareness features. In addition to this, study about evaluation of joint attention awareness features should be conducted to understand at what level these features support the collaboration processes.

In this study, when we formed the pairs, we selected people who knew each other, so we focused on the impact of the computer support on the collaboration process by controlling for the familiarization effect. However, familiriazition is an important process as well that is worth studying further. In order to understand the familiarization effect, the study should be conducted with people who have never met each other before. Furthermore, the effect of personality characteristics of people should be examined more carefully. As we have observed in our data some people may have a dominating personality and want to active the whole process on their own, which negatively impacts the collaboration process. These kinds of situations should be studied, and the effect of these situations should be revealed in terms of collaboration processess as a potential contribution to the CSCL literature.

Finally, we mainly used raw gaze location data of participants to study the gaze overlap during the collaboration process, but other features such as smooth pursuits, saccades and saccade durations could be examined in order to see whether they could serve as indicators of some situations or not. For instance, the eye transitions between construction area and chat area may differ among pairs having effective collaboration to pairs having ineffective collaboration. Considering these kinds of situations, different eye movements and patterns might be studied.

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APPENDICES

APPENDIX A: PARTICIPANTS' DEMOGRAPHICS

KATILIMCI BİLGİLERİ

İsim-Soyisim:______________________

Yaş: ______

Cinsiyet: □ Kadın □ Erkek

Eğitim Durumunuz: □ Lisans □1. sınıf □ 2. sınıf □ 3. sınıf □ 4. sınıf

□ Yüksek Lisans Kaçıncı döneminizdesiniz?: _____

□ Doktora Kaçıncı döneminizdesiniz?: _____

Öğrenim Görmekte Olduğunuz Bölüm: __________________________________

GeoGebra programını daha önce kullandınız mı? Evet □ Hayır □

Cevabınız Evet ise;

Ne kadar süredir kullanıyorsunuz? (ay veya yıl olarak):

Ne sıklıkla kullanıyorsunuz?:

□ Nadiren (2-3 ayda bir ya da daha az)

□ Bazen (ayda en az bir defa)

□ Sıklıkla (haftada en az bir defa)

□ Çok sık (hemen hemen hergün)

Ne kadar süredir bilgisayar kullanıyorsunuz?:

□ 1 yıldan az

□ 1-3 yıl

□ 4-6 yıl

☐ 7-9 yıl

☐ 10 yıl ve üzeri

Bilgisayar kullanabilme becerinizi nasıl tanımlarsınız?:

☐ Çok kötü

☐ Kötü

☐ Orta

☐ İyi

☐ Çok iyi

Ne kadar süredir İnternet kullanıyorsunuz?

☐ 1 yıldan az

☐ 1-3 yıl

☐ 4-6 yıl

☐ 7-9 yıl

☐ 10 yıl ve üzeri

Günlük ortalama kaç saat İnternet kullanıyorsunuz?:

☐ 2 saatten az

☐ 2-4 saat arası

☐ 4-6 saat arası

☐ 6-8 saat arası

☐ 8 saaten fazla

Autocad, Photoshop vb. çizim araçları kullandınız mı?: Evet ☐ Hayır ☐

Cevabınız Evet ise;

Hangi Program(lar)ı Kullanıyorsunuz?:

Ne sıklıkla Kullanıyorsunuz?:

□ Nadiren (2-3 ayda bir ya da daha az)

□ Bazen (ayda en az bir defa)

□ Sıklıkla (haftada en az bir defa)

□ Çok sık (hemen hemen hergün)

Chat programları kullandınız mı?: Evet □ Hayır □

Cevabınız Evet ise;

Hangi Program(lar)ı Kullanıyorsunuz?:

Ne sıklıkla Kullanıyorsunuz?:

□ Nadiren (2-3 ayda bir ya da daha az)

□ Bazen (ayda en az bir defa)

□ Sıklıkla (haftada en az bir defa)

□ Çok sık (hemen hemen hergün)

APPENDIX B: VMT EVALUATION FORM

VMT DEĞERLENDİRME FORMU

İsim-soyisim:_________

SİSTEM KULLANILABİLİRLİK ÖLÇEĞİ

Bu çalışma Orta Doğu Teknik Üniversitesi (ODTÜ), Enformatik Enstitüsü, Bilişim Sistemleri, yüksek lisans öğrencisi Selin Deniz UZUNOSMANOĞLU tarafından yürütülmektedir.

Bu anket genel olarak Virtual Math Teams ortamında verilen problemleri ekip arkadaşınızla beraber çözerken sistemden ne ölçüde memnun kaldığınızı öğrenmek amaçlı sorular içermektedir.

Aşağıda on maddeden oluşan anketi size göre en uygun olandan (Kesinlikle Katılıyorum), en az uygun olana doğru (Kesinlikle Katılmıyorum) işaretleme yapmanız beklenmektedir.

1- Kesinlikle katılmıyorum.

2- Katılmıyorum.

3- Kararsızım.

4- Katılıyorum.

5- Kesinlikle katılıyorum.

	1	**2**	**3**	**4**	**5**
1- Bu sistemi sıklıkla kullanacağımı düşünüyorum.					
2- Sistemi gereksiz bir şekilde karmaşık buldum.					
3- Sistemin kolay kullanıldığını düşündüm.					
4- Bu sistemi kullanabilmek için teknik bir kişinin desteğine ihtiyacım olabileceğini düşünüyorum.					
5- Sistemdeki çeşitli fonksiyonları iyi entegre olmuş biçimde buldum.					
6- Sistemde çok fazla tutarsızlık olduğunu düşünüyorum.					
7- Birçok insanın bu sistemi hızlı bir şekilde kullanabileceğini düşünüyorum.					

8- Sistemin kullanımını çok hantal buldum.					
9- Sistemi kullanırken kendimden emindim.					
10- Sisteme giriş yapmadan önce birçok şey öğrenmem gerekti.					

Sistemde hoşunuza giden ya da olumlu özellikler neydi? Neden hoşunuza gittiğini ya da olumlu bulduğunuzu lütfen açıklayınız.

Sistemde hoşunuza gitmeyen ya da olumsuz özellikler neydi? Neden hoşunuza gitmediğini ya da olumsuz bulduğunuzu lütfen açıklayınız.

Görevleri yaparken sistemde karşılaştığınız zorluklar nelerdir?

Sistem ile ilgili önerileriniz nelerdir?

Problem çözüm sürecinde ekip arkadaşınızla olan işbirliğiniz ne düzeyde gerçekleşti? İşbirliği sürecinizi açıklayınız. Soruları çözmede ne kadar katkınız oldu? Ekip arkadaşınızın katkısı nasıldı? Beraber soruları çözme sürecinizin olumlu ve olumsuz yönlerinden bahsediniz. Sistemin işbirliğinize katkısı nasıldı?

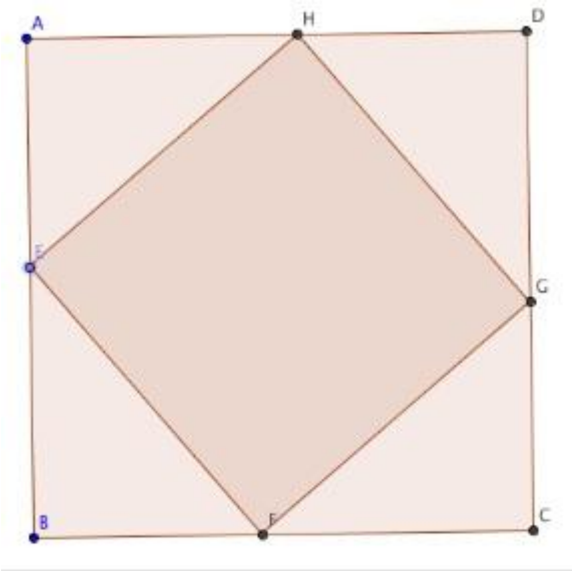
APPENDIX C: QUESTIONS

SORULAR

Bu sekmede 10 adet gorev bulunmaktadir. 45 dk sureniz bulunmakta ve yapabildiginiz kadar soruyu cozmeniz beklenmektedir. Her soru uzerinde tartisip cozum uzerinde anlastiktan sonra sonuclarinizi "Sonuc" sekmesindeki ilgili metin kutusuna yazmaniz beklenmektedir. Sorulari belli bir siraya gore cozmeniz beklenmemektedir.

1. Cokgen aracini kullanmadan bir kare olusturunuz. Olusturdugunuz seklin kare oldugunu ispatlamaya calisiniz.

2. Sekilde goruldugu gibi kare icinde kare olusturunuz. Ic kisimdaki karenin köselerinin distaki karenin kenarlarini ortalamasi gerekmektedir.



3. Sadece nokta, dogru parcasi ve cember araclarini kullanarak ikizkenar ucgen olusturunuz. Olusturduktan sonra bu ucgenin ikizkenar oldugunu ispatlamaya calisiniz.

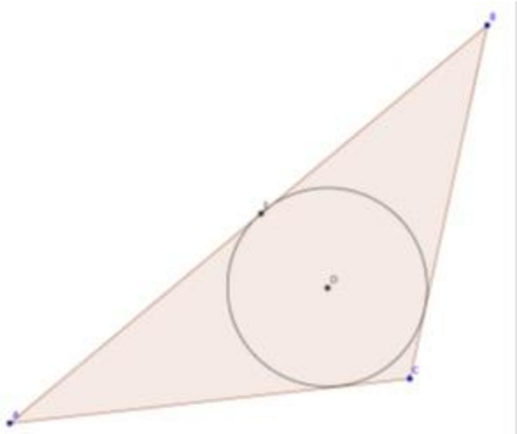
4. Bir eskenar ucgen olusturunuz ve bu ucgenin merkez noktasini bulunuz. Buldugunuz noktanin merkez nokta oldugunu ispatlayiniz.

5. Paralelkenar olusturunuz. Olusturdugunuz seklin paralelkenar oldugunu ispatlayiniz.

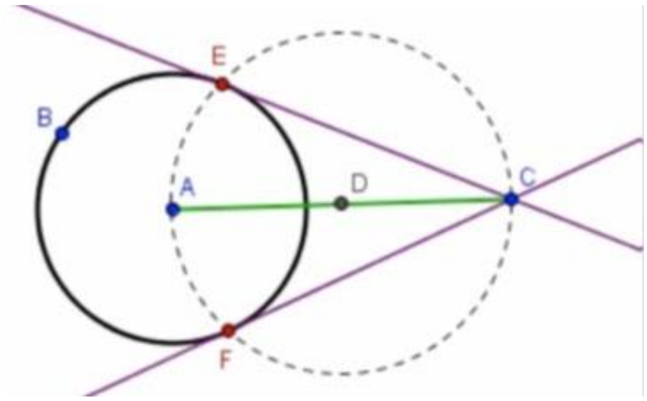
6. Sadece cember, dogru parcasi ve nokta araclarini kullanarak duzgun altigen (Esit uzunlukta kenarlar ve esit acilara sahip olmalidir.) olusturunuz. Olusturdugunuz seklin duzgun altigen oldugunu kanitlayiniz.

7. 3 adet paralel dogru ciziniz. Her bir kösesi bir dogruda olacak sekilde bir eskenar ucgen olusturunuz. Ucgenin eskenar oldugunu kanitlayiniz.

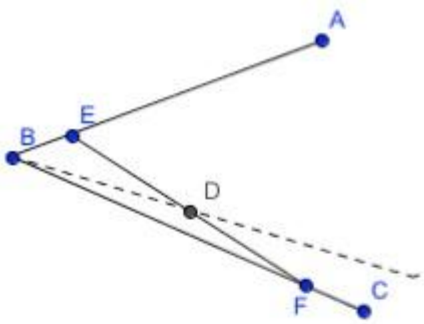
8. Sekilde goruldugu gibi bir ucgen icine 3 noktadan teget olacak sekilde bir cember ciziniz.



9. Bir cember ve cember disinda bir nokta belirleyiniz. Sekilde goruldugu gibi cember disinda belirlediginiz bu noktadan teget aracini kullanmadan cembere teget ciziniz.



10. Sekildeki gibi verilen bir ABC acisi ve bu acinin icindeki herhangi bir D noktasindan gecen EF dogru parcasinin orta noktasini D noktasi olarak olusturmaya calisiniz. D noktasinin orta nokta oldugunu ispatlayiniz.



APPENDIX D: CONSENT FORM

GÖNÜLLÜ KATILIM FORMU

Bu çalışma, ODTÜ Enformatik Enstitüsü Bilişsel Bilimler Anabilim Dalı'nda Öğretim Üyesi Yrd. Doç. Dr. Murat Perit ÇAKIR danışmanlığında, ODTÜ Enformatik Enstitüsü Bilişim Sistemleri Bölümü'nde yüksek lisans öğrencisi Selin Deniz UZUNOSMANOĞLU tarafından yüksek lisans tezi kapsamında yürütülmektedir.

Çalışmanın amacı, bilgisayar destekli ortamda işbirlikçi yöntemle problem çözme sürecini analiz etmektir. Bunun yanında, bu çalışmada kullanılan ortamın kullanılabilirliğinin ölçülmesi ve işbirlikçi problem çözme süreçlerine etkisinin gözlemlenmesi hedeflenmektedir.

Bu çalışma süresince katılımcıların göz hareketleri göz izleme cihazı ile kaydedilecektir. Uygulama öncesi katılımcıların bilgilerini edinmek için bir anket doldurulması istenecektir. Uygulama ODTÜ İnsan-Bilgisayar Etkileşimi Laboratuvarında ve eş zamanlı olarak ODTÜ Bilgisayar ve Öğretim Teknolojileri Eğitimi Bölümü Teknoloji ile Zengileştirilmiş Öğrenme Araştırma ve Uygulama Laboratuvarı'nda gerçekleştirilecektir. Uygulama sonunda sistemle ilgili bir anket doldurulması istenecektir. Uygulama yaklaşık 1 saat sürecek olup 30 üniversite öğrencisiyle çalışılması planlanmaktadır. Kayıtlar hiçbir şekilde ticari amaçlı kullanılmayacak, sadece bilimsel amaçlı kullanılacaktır. Bilgileriniz gizli tutulacak olup, kesinlikle üçüncü şahıslarla paylaşılmayacak ve sadece araştırmacılar tarafıından değerlendirilecektir. Uygulama sırasında herhangi bir nedenle çalışmayı yarıda bırakıp çıkma hakkınız vardır. Bu durumu araştırmacıya bildirmeniz yeterli olacaktır.

Bu çalışmaya katıldığınız için teşekkür ederiz. Çalışma ya da çalışmanın sonuçlarıyla ilgili daha detaylı bilgi almak için Selin Deniz UZUNOSMANOĞLU (Oda: BÖTE C-105, Tel: 0 312 210 41 83, E-posta: sdeniz@metu.edu.tr) ile iletişime geçebilirsiniz.

Bu çalışmaya tamamen gönüllü olarak katılıyorum ve istediğim zaman yarıda kesip çalışmadan ayrılabileceğimi biliyorum. Bilgisayar kaydımın alınmasını ve bilimsel araştırmalarda kullanılmasını kabul ediyorum.

İsim-Soyisim:

Tarih:

İmza:

APPENDIX E: TUTORIAL

VIRTUAL MATH TEAMS (VMT) ORTAMI

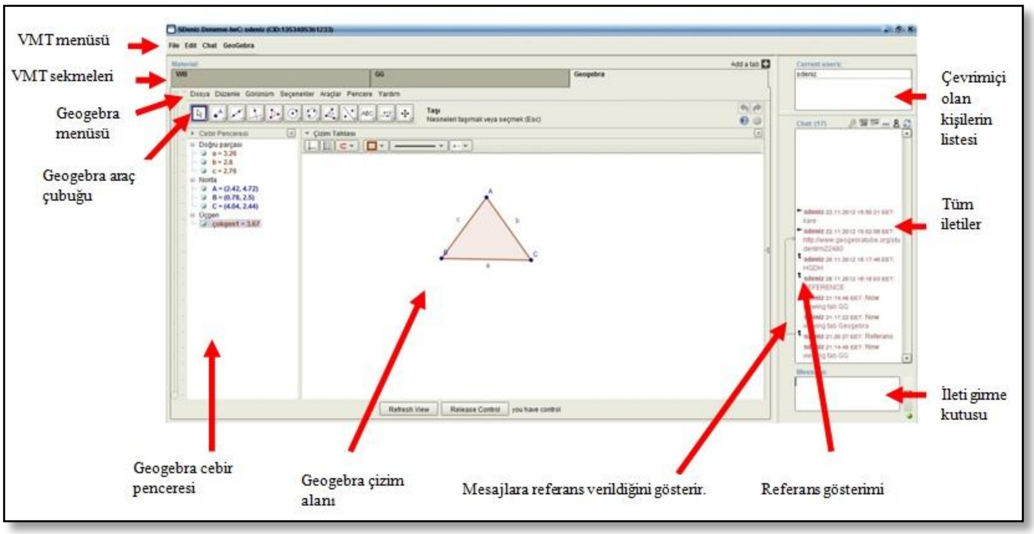
VMT ortamı, küçük grupların etkileşimli bir şekilde matematik problemleri üzerine tartışıp işbirlikçi bir şekilde yeni kavramlar öğrenip uygulayabilecekleri bir platform sunmaktadır. Dünyanın değişik ülkelerinden kişilerle çevrimiçi ortamlarda bir araya gelerek küçük gruplar halinde matematik problemlerini çözmek ya da matematik üzerine yeni fikirler paylaşmak amaçlı kullanılmaktadır. Böylece işbirlikçi bir şekilde bilgi paylaşımı, problem çözme, bilgi inşaası sağlanabilmektedir.

VMT ortamına http://vmt.mathforum.org adresinden giriş yaptıktan sonra kullanıcı adı ve şifrenizi görmenizle beraber aşağıdaki sayfa karşınıza çıkacaktır:

Burada ister kendiniz bir chat odası açabilir, isterseniz daha önceden açılmış olan bir chat odasına giriş yapabilirsiniz. Bu çalışmada "Geogebra" sekmesi kullanılacaktır.

VMT ORTAMINDA GEOGEBRA SEKMESİNİN KULLANIMI

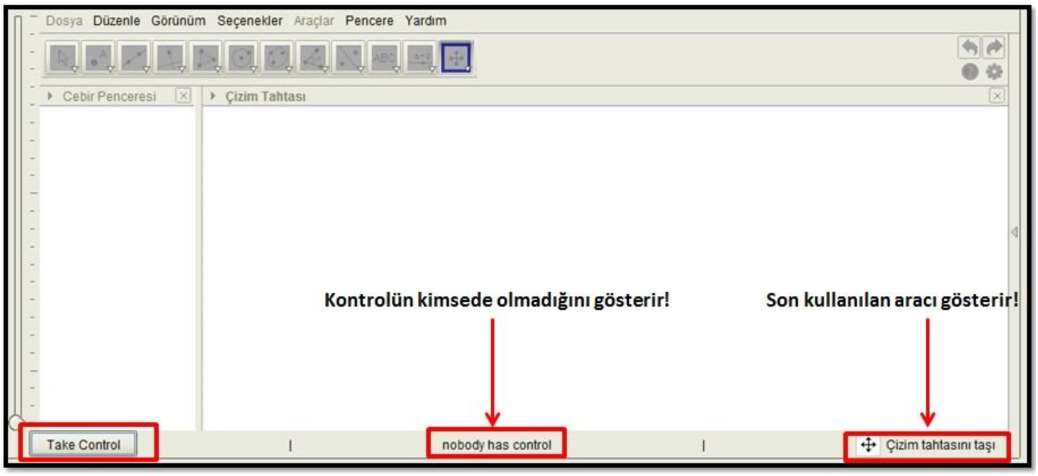
VMT ortamında Geogebra sekmesini tıkladığınızda aşağıdaki pencere görülmektedir:



Geogebra; geometri, cebir ve analiz için kullanılan dinamik bir matematiksel yazılımdır. Geogebra, etkileşim sağlayan bir sistemdir. Bu ortamın sunduğu çeşitli araçları (nokta, ışın, çember, vektör vb...) kullanarak çeşitli geometrik yapılar hazırlayabilirsiniz. Bunun yanında, oluşturduğunuz yapıların koordinatlarını **“Cebir”** penceresini kullanarak kendiniz değiştirebilirsiniz. Bunun için “Görünüm” sekmesinden “Cebir” seçeneğini tıklayınız.

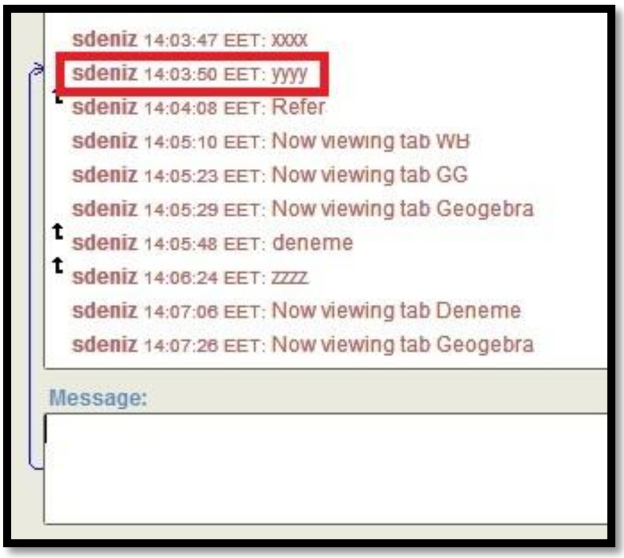
VMT ortamında Geogebra’yı ister tek başınıza ister arkadaşlarınızla etkileşimli bir şekilde kullanabilirsiniz. **“Chat”** kısmını kullanarak fikirlerinizi paylaşabilir ve kontrolü alarak düşündüğünüz düzenlemeleri Geogebra ortamına aktarabilirsiniz. Böylece işbirlikçi bir yöntemle istediğiniz yapıları oluşturabilirsiniz.

Ekip olarak çalışırken dikkat etmeniz gereken şey, herkesin aynı anda çizim alanında işlem yapamıyor olmasıdır. Kontrolü alıp çizim yapabilir, sonrasında ise kontrolü diğer arkadaşlarınıza bırakabilirsiniz. Bunun için şekilde görüldüğü gibi çizim alanının altındaki "**Take Control**" ve "**Release Control**" butonlarına tıklamanız gerekmektedir. Ayrıca butonların yanında "**nobody has control**" ve "**you have control**" mesajları görünecektir.

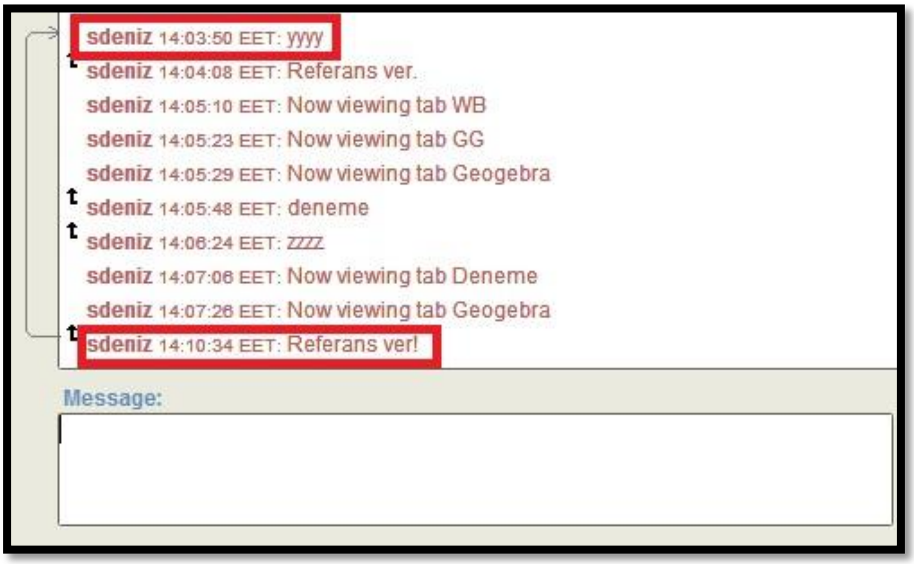


Chat ortamında daha önce girdiğiniz yazılara referans verebilirsiniz. Bunun için;

- Referans vermek istediğiniz daha önce yazdığınız mesajın üzerine çift tıklayın. Tıkladığınız mesaj ile mesaj giriş kutusu arasında şekildeki gibi bir ok oluşacaktır:

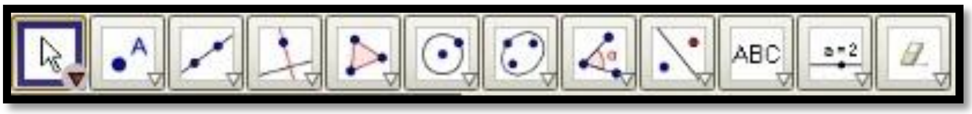


- Şimdi de mesajınızı yazın ve entera tıklayın.
- Aşağıdaki şekilde görüldüğü gibi yeni gönderilen mesaj ile referans verdiğimiz mesaj arasında bir ok oluşacaktır.



- Referans içeren mesajların yanında şekilde görüldüğü gibi küçük siyah oklar oluşmaktadır. Bu oklara tıklayarak referans verilen mesajı görüntüleyebilirsiniz.

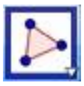
Aşağıdaki şekilde Geogebra'nın araç çubuğu görülmektedir. Sağ alt tarafındaki okları tıklayarak açılır menüde görülen diğer araçları seçip kullanabilirsiniz.



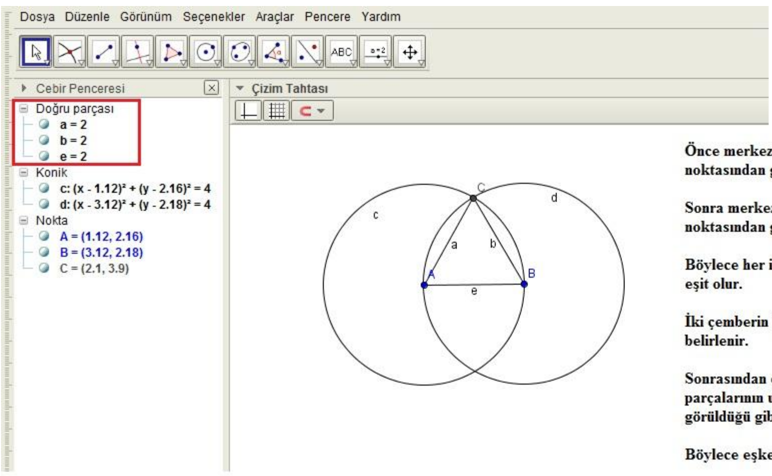
Bu dökümanda sık kullanılan bazı araçların kullanımı açıklanmaktadır:

- **Taşı**  **:** Nesneleri taşımak ya da seçmek için kullanılır.
- **Yeni Nokta**  **:** Yeni bir nokta oluşturmanızı sağlar. Çizim tahtasına ya da istediğiniz nesnenin üstüne tıklayarak konumlandırabilirsiniz.
- **İki Nesnenin Kesişimi**  **:** Nesnelerin kesiştiği yeri nokta ile belirtmek için kullanılır.
- **Orta Nokta veya Merkez**  **:** Seçtiğiniz iki noktanın ya da doğru parçasının orta noktasını belirler.
- **İki Noktadan Geçen Doğru**  **:** Belirlediğiniz iki noktadan geçen bir doğru oluşturmanızı sağlar.
- **İki Noktadan Geçen Doğru Parçası**  **:** Belirlediğiniz iki noktadan geçen bir doğru parçası oluşturmanızı sağlar.
- **Dik Doğru**  **:** Seçtiğiniz bir doğru ya da doğru parçasına dik bir doğru oluşturmanızı sağlar. Aracı seçtikten sonra doğruya yakın herhangi bir yere

tıkladıktan sonra doğruyu tıklayın. Böylece seçtiğiniz doğruya dik bir doğru oluşacaktır.

- **Paralel Doğru**  **:** Seçtiğiniz bir doğru ya da doğru parçasına paralel bir doğru oluşturmanızı sağlar. Aracı seçtikten sonra doğruya yakın herhangi bir yere tıkladıktan sonra doğruyu tıklayın. Böylece seçtiğiniz doğruya paralel bir doğru oluşacaktır.
- **Teğet**  **:** Seçtiğiniz bir çembere iki yönden teğet oluşturmanızı sağlar. Aracı seçtikten sonra çembere yakın herhangi bir yere tıkladıktan sonra çemberi tıklayın. Böylece seçtiğiniz çembere teğet oluşturmuş olacaksınız.
- **Çokgen**  **:** İstediğiniz şekilde bir çokgen oluşturmanızı sağlar. Çokgen aracını tıkladıktan sonra çizim tahtasında istediğiniz yerlere nokta koyduktan sonra, sonra ilk noktanın üzerine tıkladığınızda bir çokgen oluşacaktır.
- **Merkez ve Bir Noktadan Geçen Çember**  **:** Bu araç çember oluşturmanızı sağlar. Çizim tahtasında herhangi bir yere tıklayarak çemberin merkezini belirlemiş olursunuz. Ardından tıklayacağınız ikinci bir nokta ise çemberin çevresinde bir nokta olacaktır.
- **Açı**  **:** Bu araç açı ölçmeyi sağlamaktadır. Aracı seçtikten sonra istediğiniz üç yere saat yönünde tıklayarak açı oluşturmuş olursunuz. Eğer ssat yönünün tersi bir şekilde üç noktaya işaretlerseniz dış açıyı görmüş olursunuz. Ayrıca bu aracı kullanarak, kesişim halindeki iki doğru ya da doğru parçasının arasındaki açıyı da ölçebilirsiniz.
- **Nesneyi Sil**  **:** Bu araç, seçtiğiniz nesnenin silinmesi sağlar.

ÖRNEK



Önce merkezi A noktası olan ve B noktasından geçen bir çember çizilir.

Sonra merkezi B noktası olan ve A noktasından geçen bir çember daha çizilir.

Böylece her iki çemberin yarıçapları birbirine eşit olur.

İki çemberin kesişim noktası C noktası olarak belirlenir.

Sonrasından çizilen a, b ve c dokru parçalarının uzunlukları cebir penceresinde görüldüğü gibi birbirine eşittir.

Böylece eşkenar üçgen çizilmiş olur.

APPENDIX F: CURRICULUM VITAE

CURRICULUM VITAE

PERSONAL INFORMATION

Surname, Name: Uzunosmanoğlu, Selin Deniz

Nationality: Turkish (TC)

email: sdeniz@metu.edu.tr

selindenizu@gmail.com

EDUCATION

Degree	**Institution**	**Year of Graduation**
B.S.	METU Computer Education and Instructional Technology	2010
M.Sc.	Information Systems	2013

PROFESSIONAL EXPERIENCE

Year	**Place**	**Enrollment**
2010 - Present	METU Computer Education and Instructional Technology	Research Assistant

PUBLICATIONS

1. Uzunosmanoglu, S. D., Cicek, F., Duman, M. (2012). *Trends in M-Learning*. Paper presented at the annual meeting of the 6th International Computer & Instructional Technologies Symposium: Gaziantep, Turkey.
2. Cakir, M. P., Uzunosmanoglu, S. D. (2013). Position paper presented at the workshop of the 10th International Confererence on Computer Supported Collaborative Learning; Madison, USA.

TEZ FOTOKOPİSİ İZİN FORMU

ENSTİTÜ

Fen Bilimleri Enstitüsü ☐

Sosyal Bilimler Enstitüsü ☐

Uygulamalı Matematik Enstitüsü ☐

Enformatik Enstitüsü ☐

Deniz Bilimleri Enstitüsü ☐

YAZARIN

Soyadı : UZUNOSMANOĞLU
Adı : Selin Deniz
Bölümü : Bilişim Sistemleri

TEZİN ADI (İngilizce) : EXAMINING COMPUTER SUPPORTED COLLABORATIVE PROBLEM SOLVING PROCESSES USING THE DUAL EYE-TRACKING PARADIGM

TEZİN TÜRÜ : Yüksek Lisans ☐ Doktora ☐

1. Tezimin tamamından kaynak gösterilmek şartıyla fotokopi alınabilir. ☐
2. Tezimin içindekiler sayfası, özet, indeks sayfalarından ve/veya bir bölümünden kaynak gösterilmek şartıyla fotokopi alınabilir. ☐
3. Tezimden bir (1) yıl süreyle fotokopi alınamaz. ☐

TEZİN KÜTÜPHANEYE TESLİM TARİHİ : …………………….