USABILITY EVALUATION OF DYNAMIC GEOMETRY SOFTWARE THROUGH EYE TRACKING AND COMMUNICATION BREAKDOWN ANALYSIS

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USABILITY EVALUATION OF DYNAMIC GEOMETRY SOFTWARE THROUGH EYE TRACKING AND COMMUNICATION BREAKDOWN ANALYSIS

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ABSTRACT

USABILITY EVALUATION OF DYNAMIC GEOMETRY SOFTWARE THROUGH EYE TRACKING AND COMMUNICATION BREAKDOWN ANALYSIS

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The use of information technology in mathematics education has become popular due to the increasing availability of software applications designed for constructing mathematical representations. In this study, we conducted a usability evaluation of GeoGebra, which is a commonly used math education tool that provides dynamic geometry, spreadsheet and algebra features. The study consists of three usability experiments. In the first experiment, an eye tracking study was conducted where individual participants performed basic geometric constructions by using the basic features of GeoGebra and a similar, well-known math education software called Geometer's Sketchpad. Constructions completed in each interface were compared in terms of task completion times, accuracy and fixation durations in an effort to identify usability issues. According to results, there are no significant differences between GeoGebra and Geometer's Sketchpad in terms of usability measures. In the second study, pairs of students collaboratively attempted more complex geometric constructions in the GeoGebra environment by using a mouse and a touch screen interface. The aim of the second experiment was to observe how different interfaces would influence the use of the GeoGebra tool in an ecologically more realistic setting. We hypothesized that the touch screen interface would help students with the geometry tasks as it resembles the familiar pen&paper based interaction with mathematical representations. Episodes where participants experienced breakdowns during their collaboration due to system usability issues were identified and analyzed with qualitative methods. Contrary to our expectation, the results indicated that participants experienced more breakdowns while using the touchscreen interface, due to the inadequate support GeoGebra provides for touch-based gestures. Finally, an eye tracking study was conducted on the mobile version of GeoGebra. Our findings suggest that the mobile version primarily replaced the function of the mouse in the desktop version with the finger, and did not take advantage of the gestures supported by the multi-touch screens of new generation tablet computers. Based on the empirical findings of the study, design ideas for improving the usability of the existing GeoGebra desktop and touch-based mobile interfaces are proposed.

Keywords: usability, Geogebra, breakdown analysis, eye tracking

ÖZET

DİNAMİK GEOMETRİ YAZILIMLARININ GÖZ İZLEME VE İLETİŞİM KIRILMA DURUMU ANALİZİYLE KULLANILABİLİRLİK DEĞERLENDİRİLMESİ

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Bilgi Teknolojilerinin Matematik eğitiminde kullanılması matematiksel gösterimlerin oluşturulması için tasarlanmış yazılım uygulamalarının ulaşılabilirliğinin artması sonucunda yaygınlaşmaktadır. Bu çalışmada, dinamik geometri, hesap çizelgesi ve cebir özellikleri sunan ve yaygın olarak kullanılan bir matematik eğitimi programı olan GeoGebra yazılımı kullanılabilirlik açısından değerlendirilmiştir. Çalışma üç adet kullanılabilirlik deneyinden oluşmaktadır. İlk deneyde bireysel katılımcıların, GeoGebra'nın ve benzer, tanınmış bir matematik eğitimi yazılımı olan Geometers Sketchpad'in temel özelliklerini kullanarak basit geometri yapılarını oluşturdukları bir göz izleme çalışması yapılmıştır. Her bir arayüzde tamamlanan yapılar, kullanılabilirlik sorunlarını ortaya çıkarmak amacıyla görev tamamlanma süresi, doğruluk ve göz sabitlenmesi süresi açısından karşılaştırılmıştır. Sonuçlara göre, GeoGebra ve Geometers Sketchpad yazılımı arasında kullanılabilirlik yönünden büyük bir fark bulunmamıştır. İkinci çalışmada, iki kişilik öğrenci grupları işbirlikçi bir şekilde GeoGebra ortamında fare ve dokunmatik ekran arayüzü kullanarak daha karmaşık geometrik yapılar oluşturmaya çalışmışlardır. İkinci deneyin amacı ekolojik olarak daha gerçekçi olan bir ortamda farklı arayüzlerin GeoGebra aracının kullanımını nasıl etkilediğini gözlemektir. Matematiksel gösterimler için tanıdık olan kağıt-kalem etkileşimine benzer olduğundan dokunmatik ekran arayüzünün öğrencilere geometri görevlerinde yardımcı olacağı varsayılmıştır. İşbirliği sırasında sistemin kullanılabilirlik sorunları sebebiyle katılımcıların kırılma durumları yaşadığı aralar tespit edilerek nitel yöntemlerle analiz edilmiştir. Beklentilerin aksine sonuçlar, GeoGebranın dokunmatik hareketler için yetersiz destek sağlaması sebebiyle katılımcıların dokunmatik ekran arayüzünü kullanırken daha çok kırılma durumu yaşadıklarını göstermiştir. Son olarak, GeoGebra'nın mobil vesiyonu üzerine bir göz izleme çalışması yapılmıştır. Bulgular, masaüstü versiyonundaki farenin yerini mobil versiyonda parmağın aldığını ve yeni jenerasyon tablet bilgisayarların multi-touch ekranlarca desteklenen jest ifadelerinden yeterince faydalanılmadığını göstermektedir. Çalışmanın empirik bulgularına dayanarak GeoGebra'nın varolan arayüzlerinin kullanılabilirliğini geliştirecek tasarım fikirleri sunulmuştur.

Anahtar Kelimeler: kullanılabilirlik, Geogebra, kırılma durumları analizi, göz izleme

This thesis is dedicated to My family

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LIST OF ABBREVIATIONS

AOI: Areas of Interests

CAS: Computer Algebra System

DGS: Dynamic Geometry Software

Exp.: Experiment

HCI: Human Computer Interaction

ICT: Information and Communication Technologies

ISO: International Standards Organization

IS: Information Systems

METU: Middle East Technical University

M.Sc.: Master of Science

Ph.D.: Doctor of Philosophy

GM: Geogebra Mobile

SUS: System Usability Scale

Q: Question

RQ: Research Question

CA: Conversation Analysis

CHAPTER 1

INTRODUCTION

Over the last few decades, Information and Communication Technologies (ICT) have assumed an increasingly important role in the teaching of mathematics and science in the education system. Computers in the classroom have become an indispensable tool for supporting teaching and learning (Wenglinsky, 1998). Innovations in ICT have made computing a ubiquitous phenomenon where devices such computers, tablets, and smart phones are widely adopted in our daily lives as well as in educational activities (Inspectorate, 2000). Most governments in the world recognize the impact of ICT on education, and develop policies to provide students and teacher access to the Internet, software and hardware in order to promote effective use of ICT at schools (Chrysanthou, 2008).

In the history of instructional technology, researchers have explored several approaches to enrich and support learning activities in math and science classrooms. The history of applying computers to mathematics learning began with the drill-and-practice programs implemented in the computer-assisted instruction (CAI) paradigm (Kaput and Thompson, 1994). IBM's Course writer and PLATO were among the first operational systems used at campuses in the US in 1960s that aimed to provide increasing access to instructional materials to students so that they can master the materials at their own pace (Koschmann, 1996).

At the beginning, drill and practice based computer-aided instruction programs were used most commonly to mimic typical learning exercises within schools, without necessarily taking advantage of the new opportunities these tools offer for interacting with teaching materials (Finlayson, 1998). Constructivist learning platforms that provided opportunities for knowledge construction, especially those that incorporated Logo, were innovative in the sense that they transformed technology into a cognitive tool to stimulate Mathematical thinking (Papert, 1980; De Corte, 1996). In Logo students are transformed from tutors to tutees, where they teach the computer how to carry out math operations by using a programmable gaming environment. Teachers were turned into facilitators in a classroom rather than an instructor; and students were expected to gain knowledge from their experiences by actively constructing executable Logo program in this approach (Agalianos, 2001).

Early CAI and Logo environments provided limited representational resources. Advances in computing and multimedia have enabled students to visualize mathematical concepts that are not possible with earlier systems or with the traditional resources such as textbooks. There are many kinds of software, which can be used for math education (Bakara, Ayuba, & Luanb, 2010). Main types of mathematics education software that are currently being used are Dynamic Geometry software, spreadsheets and Computer Algebra Systems (CAS) (Drijvers & Trouche, 2007).

Many pedagogical environments for math education have been developed, such as Cinderella (www.cinderella.de), Geometer's Sketchpad (www.keypress.com/sketchpad), and Cabri geometre II+ (www.cabri.com), and Geogebra (www.geogebra.org), among others. This thesis study focus on Geogebra, because it is a free Dynamic Geometry Software (henceforth DGS) that also provides basic features of a Computer Algebra System to bridge the gaps between math domains such as geometry, algebra and calculus (Domènech & Aymemí, 2009) and is freely available at www.geoegebra.org. The software links synthetic geometric constructions (geometric window) to analytic equations, and coordinates representations and graphs (algebraic window). As open source dynamic mathematics software with an increasingly international user group, GeoGebra tries to combine the ease-to-use of dynamic geometry software with the versatile possibilities of CAS (Hohenwarter & Preiner, 2007). This software combines geometry, algebra and calculus into a single and easy package for teaching and learning mathematics from elementary to university level (Hohenwarter, J., & Lavicza, 2008). Moreover, according to Hohenwarter and Preiner (2007), GeoGebra appears to be user-friendly software that can be operated intuitively and does not require advanced skills to get started.

Domènech & Aymemí (2009) stated that students encounter many types of difficulties when learning mathematical concepts and solving such problems often require coordinated reasoning over symbolic expressions and visualizations. Although students can face structural and visualization problems when learning geometry, developing deductive reasoning skills can be considered as the biggest challenge for the students. In particular, students may have difficulty moving from geometry based on shallow visual properties to a geometry based on a deeper understanding of the structural patterns that bring together, primitive objects such as points and lines for constructing more complex geometric representations (Domènech & Aymemí, 2009).

From a pedagogical perspective, it has been argued that dynamic geometry environments tend to favor certain types of empirical justifications and inhibit formal justifications in math education. However, such software tools provide an environment in which students can experiment freely with math objects to explore relationships among mathematical concepts and methods (Domènech & Aymemí, 2009). This is especially helpful for students who have difficulty relating symbolic/algebraic representations with their graphical realizations. For example, students can observe how changing the radius of a cylinder changes the side area both graphically and symbolically in an environment like Geogebra. In other words, students can observe the implications of a visual action on the quantities and vice versa, which will help them understand the relationships among different ways to represent the same mathematical concept. Realization of such connections among different representations is considered as an indication of deep learning of mathematical concepts (Sfard, 2008), and dynamic geometry software has the potential to stimulate and facilitate the development of such deep level of understanding.

The realization of such benefits depend on to what extent the interface effectively supports students to construct and manipulate dynamic representations. Systems such as Geogebra and Geometer's Sketchpad require users to add and manipulate basic primitive constructs such as points, angles, lines, and circles. These primitives need to be combined in specific ways to construct even more complex objects that are typically used in the math classroom, and combining objects often involve specific interface actions such as selecting two points to combine with a line, or dragging a point to change its coordinates. Although these interface actions are based on traditional mouse-based gestures used for desktop applications, learning appropriate use of the features for building math representations may not necessarily be a trivial matter for the students. Consequently, usability issues involved with the design of the interface elements and gestures acting on them have important educational consequences. However, systematic usability studies of primitive interface elements provided by dynamic geometry tools are not widely covered in the literature. Existing evaluations tend to focus more on pedagogical aspects.

1.1 Purpose of the Study

The purpose of this thesis study is;

- To compare and evaluate the effectiveness and efficiency of Geogebra and Geometers' Sketchpad interfaces for constructing basic geometric shapes,
- To explore the effectiveness of mouse and touch-pad based interfaces for using Geogebra in a collaborative problem solving context,
- To explore the effectiveness of the iPad version of Geogebra that supports multi-touch interaction,
- To suggest interaction design ideas to improve upon the detected usability issues.

1.2 Significance of the Study

This thesis involves a usability evaluation of dynamic geometry environments to evaluate their existing interfaces and to explore some possibilities for making the interaction more natural and effective. For that reason, third usability experiments were conducted, where the first one involves an eye tracking study focusing on evaluating the ease of use of interface primitives for two popular dynamic geometry applications. The second experiment involves the use of the Geogebra environment in a collaborative problem-solving context to arrive at more ecologically valid scenario. The second study also explores to what extent a tablet interface that allows users to draw on the screen would contribute to the usability of this environment in contrast to the mouse-based interface. The third study employs the mobile eye-tracking stand to evaluate the mobile implementation of Geogebra on iPad. Overall, these three studies altogether aim towards exploring the usability issues involved with desktop and mobile versions of dynamic geometry environments. The findings of this thesis may inform the developers about existing usability issues and point out ways to address some of these issues through better utilization of the affordances of multi-touch interfaces. Ultimately, such improvements may help students engage with geometric objects in a more effective and naturalistic way. Such improvements may make abstract geometric concepts more tangible and accessible for the students, and thus help them develop a deeper understanding of geometric principles.

1.3 Background of the Study

The International Organization for Standardization (ISO) defines usability as "the extent to which the product can be used by specified users to achieve specified goals with effectiveness, efficiency and satisfaction in a specified context of use" in the standard of ISO 9241-11. Satisfaction, effectiveness and efficiency are important concepts for usability context as well as predictability and ease of use.

During the usability tests, the above concepts are taken into account. The testers are observed while carrying out the given tasks when a formal usability test is applied (Battleson, Booth, & Weintrop, 2001).

Usability of a system together with the aesthetics issues affects users' preferences. While considering the system design process, usability should be assessed (Kay, 2009). The users play an important role for the system as the effectiveness and usefulness of these technologies depend on the people who would use the system (Karagöz, 2013). One of the important issues is to provide feedback to the users (Dutta, 2003). For example, one way of giving feedback would be the error messages, as long as they are appropriate and correct for the related situation. These messages should help the user to resolve the issues. If this were not the case, the users would be confused and not feel comfortable using the system.

Computer technology for teaching mathematics has gone through a dramatic growth over the last couple of decades in terms of availability and development (Light, 1989). Governments spend substantial amount of money to equip schools with the necessary software, Internet access as well as hardware. Students develop a positive attitude towards mathematics as ICT usage enables them to see it as simple number activities. Interactive learning using computers is different and more interesting than the teacher-centered math instruction with white/black boards (Hoyles, 1989 ; Fox, 2000).

GeoGebra, which combines geometry and algebra, has much to offer to education (Hohenwarter & Preiner, 2007). It is designed for education and encourages students to learn mathematics (Hohenwarter & Preiner, 2007). It is interactive and promotes mathematical explorations as well as providing a wide range of dynamic mathematical concepts. It also provides visual and conceptual feedback to the user and as it is free, it is easily accessible from home as well as from school. They can practice, do homework, prepare for their lessons and revise from home. It also supports multiple languages and is a great asset for classrooms that have multilingual learners.

As it is an open source, its users can communicate worldwide with other users. They can create and share their contributions or use templates provided with the ability to customize to their needs using GeoGebraWiki tool. There is a user forum where they can share ideas and discuss questions (Hohenwarter & Preiner, 2007).

Computers can be used at three different levels in teaching of the daily mathematics lessons; these would be at a class level, the group level and the individual level. Used effectively, computers in classrooms can create a teaching environment that is favorable to teachers (Fey, 1989). Computer use can also free teachers from the demands and difficulties of whole class teaching by creating an environment of collaborative work and peer support (McDonald, 1997).

1.4 Statement of the Problem

It is not easy for students to learn and grasp the drawing of geometric shapes (Noraini, 2009). Inadequate learning of geometry leads to restrictions in constructing structures. It is for the purpose of making up for this deficiency that dynamic geometry software has been developed. Unlike the traditional methods, such software emerges and is used to enhance the students' creativity. There are even studies on how much they are adopted by students and teachers. Considering the literature, there appears a lack of studies on the examination of the usability of these environments. Therefore, we decided to analyze the GeoGebra program, very much mentioned in literature and frequently used at schools, in terms of usability. Geogebra is a DGS free and open to everybody, trying to help students and teachers at different platforms. We tried to understand the situation of this program used both as multiple and as single. Also, it has been thought that it is necessary to analyse the existing versions of the software on touchpad pen and touchpad screen environments, which are among the innovations brought by the developing technology.

In particular this thesis will seek to answer the following questions:

1. How do Geogebra and Geometer's Sketchpad systems compare with each other in terms of their effectiveness and efficiency for building basic geometric constructions?

2. What are the usability issues involved with Geogebra in a collaborative problem-solving context that requires more complex geometric constructions?

3. Does the touchpad interface provide better support for building more complex geometric objects as compared to the mouse-based standard interface of Geogebra?

4. What are the usability issues involved with the tablet version of Geogebra? To what extent these issues parallel the ones identified for the desktop/touch pad version of Geogebra?

CHAPTER 2

LITERATURE REVIEW

2.1 Instruction Technology

The recent two decades have witnessed fast and extensive alterations in our societies in field of technology. Information and communication technology (ICT) undergoes big and fast advancements and these influences affect our whole life (Chrysanthou, 2008). In a study by Allen (2007), for example, he seems to have foreseen that digital literacy is sure to play a significant role in our future lives. Not surprisingly, today students spend most of their times in a world dominated by ICT.

The existing situation with the emerging ICT facilities has pressurized the professionals who are engaged in teaching, and so they have started to change their opinion of how to teach and learn effectively (Chrysanthou, 2008). In this context, computers in particular have come to be considered as indispensable devices in the classrooms. Similarly, Davis (2001) argues that ICT can play many roles in education that will continue to develop: ICT aspects of core skills, ICT as a theme of knowledge and ICT as a means of enriching learning.

With so much significance attached to it, ICT should be explained in detail: It means 'Information and Communication Technology' and in the education context it refers to (a) the technological equipment available for educational use, (b) associated skills that students and teachers have to acquire, and (c) a separate subject in many national curricula (Chrysanthou, 2008). By using ICT, students are encouraged to learn independently and to make choices based on their critiques and judgments (DfEE., 1999).

As in other fields of education, ICT's introduction to mathematics education had an important impact on educational practice (Lu, 2008). For this purpose, Hershkovitz and Schwartz (1999) enquired into the differences between ICT-integrated and paper-and-pencil learning environments, and arrived at the conclusion that the process of learning is supported by paper-and-pencil environment in a relatively passive manner. In addition, some studies have come up with the finding that ICT, when applied in the mathematics education, creates changes in the classrooms through active engagement and higher efficiency in mathematics (Hershkovitz et al., 2002). Moreover, ICT also facilitates the communication between teachers and students about mathematics (Hershkovitz, et al., 2002).

In the face of such contentions to the favor of ICT in education, paper and pencil should always take place in the classrooms due to their simplicity and convenience. It can even be argued that ICT, if used inappropriately, may have the capacity for hindering the activities of problem-solving and justification in the processes of learning and teaching of mathematics

(Yerushalmy, 2005). With consideration paid to the advantages and disadvantages of both ICT and paper-and-pencil environments, what seems fit to do is not to separate but to combine them. It is today hardly possible to oust either of them from the classroom environment, and thus current research in field of mathematics has been chiefly focusing on finding more effective ways to implement ICT in mathematics education.

2.2 Constructivist Learning Environments

Instructional designers aim to produce an instructional episode for the students with measurable outcomes. In it learners are supposed to interact with knowledge that is prescribed and transmitted to them either via a teacher or some other mechanism. Instructional sequences or a prescriptive set of activities or thoughts can be observed as they appear not to be a new theory under the history of constructivism in education and philosophy (Duffy & Cunningham, 1996). Constructivism lays the emphasis on learning rather than instruction and challenges the instructional designer to look for new models; however, it defies the concept of a model. With this idea in mind, Wilson defines a constructivist-learning environment as "a place where learners may work together and support each other as they use a variety of tools and information resources in their guided pursuit of learning goals and problem-solving activities" (Wilson, 1996, p.5).

Constructivist learning environments (CLEs) are often defined as technology-based spaces where students explore, experiment, construct, converse and reflect on what they are doing to learn from their experiences (Jonassen, Peck, & Wilson, 1999, p. 194). As can be understood from this definition, CLEs are largely advantageous to traditional instructional settings with the teacher in the centre in that they are more student-centered and focus on collaborative learning (Jonassen, Peck, & Wilson, 1999; Sherman & Kurshan, 2005). For the realization of these advantages, however, there is a need for the thoughtful organization and design of learning environments.

2.3 Computer Supported Collaborative Learning

Computer supported collaborative learning (CSCL) is a relatively new discipline within the domain of learning sciences. CSCL considers learning as a fundamentally social phenomenon, and primarily focuses on supporting collaborative learning activities through multi-user systems over networked computers (Stahl, Koschmann & Suthers, 2006). Concerned with education, it refers both to formal educations at all levels and to informal education (Uzunosmanoğlu, 2013).

As a result of the increased popularity of the computer and internet, governments have made it their essential aim to extend the availability of internet to as many students as possible. Besides, group-learning and co-working on the developing of shared ideas are among the purposes of education literature (Stahl, Koschmann, & Suthers, 2006).

CSCL is also effective in overcoming the argument that computers and computer systems isolate the individuals as they require them to sit before the screens in a passive manner on their own and thus promote anti-social learning (Stahl, Koschmann & Suthers, 2006). In doing so, CSCL implies that it is of necessity to develop new computer systems, software and applications. The purpose of doing so is to encourage users towards intellectual exploration and social interaction by offering them creative and joint activities.

How CSCL manages this is through collaborative learning with e-learning, and the fusing of them into a single entity. They are seen as the "organization of instruction across computer networks" (Stahl, Koschmann, & Suthers, 2006, s. 409-426). Conventional e-learning places the primary emphasis on the digital presentation of the educational content and its spread to as many learners as possible. Because it is commonly assumed that learners would regulate their own pace in getting through the educational materials in this system, it will most probably do away with the condition of traditional classroom education that teachers and learners should share the same time and space. To Stahl, Koschmann and Suthers (2006), however, some problems may arise from the application of this content production and dissemination approach to e-learning. The first problem has to do with the process of generating the learning content. The second problem is the product of the fact that online courses require the teachers to make more effort than classroom lessons.

Naturally, the need to offer students such collaborative activities requires curriculum, pedagogy and technology to be carefully combined, planned, and implemented. It would, otherwise, be difficult to ensure interaction and collaboration in that environment. Besides its attention to collaborative learning through networked computers, CSCL also includes face-to-face (F2F) collaboration mediated by computers. For this reason, collaborative learning with ICT technology is studied by CSCL with its various forms. These forms may range from distant communication and e-learning to F2F interaction, either synchronously or asynchronously.

2.4 Dynamic Geometry Software

Dynamic geometry software is the one that allows geometric shapes and structures to be formed on the computer screen of the user through various concrete tools (Olkun, Gülbağcı, Öztürk, Açıkgöz, Kandemir, & M., 2008). Under this title, first a brief mention will be made of Van Hiele Geometric Thinking Levels lying on the basis of dynamic geometry, and then the subject will be elaborated under the title of DGS.

2.4.1 Van Hiele Geometric Thinking Levels

It is assumed in school geometry that students should think in a formal deductive level about geometry. This is why geometry is presented as a formal axiomatic system of reasoning in geometry classrooms. According to Van Hiele (1986) there is a sequential level of progress of geometric reasoning, and teachers should adjust their teaching strategies to provide instruction appropriate to each thinking level. To him, the first level is visual and begins with nonverbal thinking. At this stage, students first see geometric shapes to identify them, but they fail to know what properties or attributes they have. For example, they can see and identify a square but cannot recognize that there are four equal sides of a square. This visual stage at which students can classify the shapes according to their geometric appearance is followed by the analytic stage at which they learn the properties of specific objects. They, for example, recognize that a triangle has three sides and three angles which amount to 180 degree when added. At the third stage, which is informal deduction level, children arrive at logical reasoning or conclusions about the attributes of shapes or relations among these attributes. Thus, they would reason that "a square is a rectangle since it has the opposite sides equal, and has four right angles." In van Hiele's theory, the fourth and fifth stages are formal deduction and rigor. Elementary-school students are unlikely to achieve these stages, though van Hiele levels are not age-dependent (Olkun, Sinoplu, & Deryakulu, 2005).

2.4.2 Dynamic Geometry Software

The teaching of mathematics utilizes a variety of software types in general: Computer Algebra System (CAS), Dynamic Geometry Software (DGS) such as GSP, Cabri-géomètre, and open source software- Java Applets, GeoGebra, etc. (Laborde, 2001; 2003; 2007; Strässer, 2001; Kokol-Voljc, 2003). Each of these forms often deals with specific aspects of mathematical teaching and learning. For example, algebraic topics are frequently taught with CAS, while geometrical topics are taught with DGS programs. The main reason is the concentration of CAS on the manipulation of expressions while in DGS the emphasis is on the correlations between points, lines, circles and so on (Schneider, 2007). Recent years have witnessed an increased awareness of integrating graphical, numerical and algebraic representations. In this context, Pederson (1983) maintains that geometry is a skill of the eyes and hands as well as minds. In other words, it is a visual, manual and intellectual skill. One can obtain great visualization capability and dynamic changeability for teaching through mathematical software, which is therefore well-placed to support the common visual and dynamic areas in geometry.

DGS, for example, affords dynamic geometrical constructions and visualization for motions of objectives by dragging and investigation from various angles in supporting the learning process (Laborde, 1998; Healy and Hoyles, 2001). Laborde (1998) draws attention to the characteristics of DGS by using a "real" model on Euclidean geometry. It puts a physical touch on theories. On the other hand, one of the vital components of DGS is the feedback of diagrams resulting from the use of geometrical primitives. However, it also offers a number of opportunities. One of them is the direct interaction with the tools provided by the system that enables construction, manipulation and exploration of figures on one hand and discovery of the relationships between multiple representations on the other. DGS also has some other fundamental features such as efficiency in mathematics manipulation and communication for learning. The reason is that teachers have the chance to demonstrate and post the content with it, but students join the interactive learning, as well. The effective coupling of visual representation with other forms of representation and interactivity between students as learners and mathematics as target would contribute to the process of learning (Healy and Hoyles, 2001).

Currently, technology is used in teaching practices through computer algebra and dynamic geometry and the research over them divides each sphere into different areas for study. Nevertheless, Dubinsky objects to this division and argues that such areas as functions and graphs overlap with algebra (Dubinsky & Harel, 1992). If they are both examined together, this may bring about enormous implications on education and connections between them and it cannot be ignored (Edwards & Jones, 2006).

Despite such striking observations, literature on the relationship between both fields and the use of technology lacks research and material. Therefore, there is certainly a need for a combination of DGS and CAS, which is known to those interested in the issue (Hohenwarter & Fuchs, 2004). But even so, the reason why software designers attempt to combine them is that there are completely different constructs in software design. In this context, GeoGebra could be seen as the leading software, but there is still a need for research over whether DGS and CAS can be successfully linked by it in the scarcity of supporting evidence.

2.5 Geogebra

Geogebra is a term derived from the terms Geometry and Algebra. It was Hohenwarter (2004) who developed GeoGebra in order to support the secondary mathematics teaching by connecting students' understanding of the connection between geometry and algebra. GeoGebra is a multiplatform dynamic mathematical software as it has a window that is divided into two parts, Algebra window (left side) and Geometry and Graphics window (right side) (see in Figure 1).

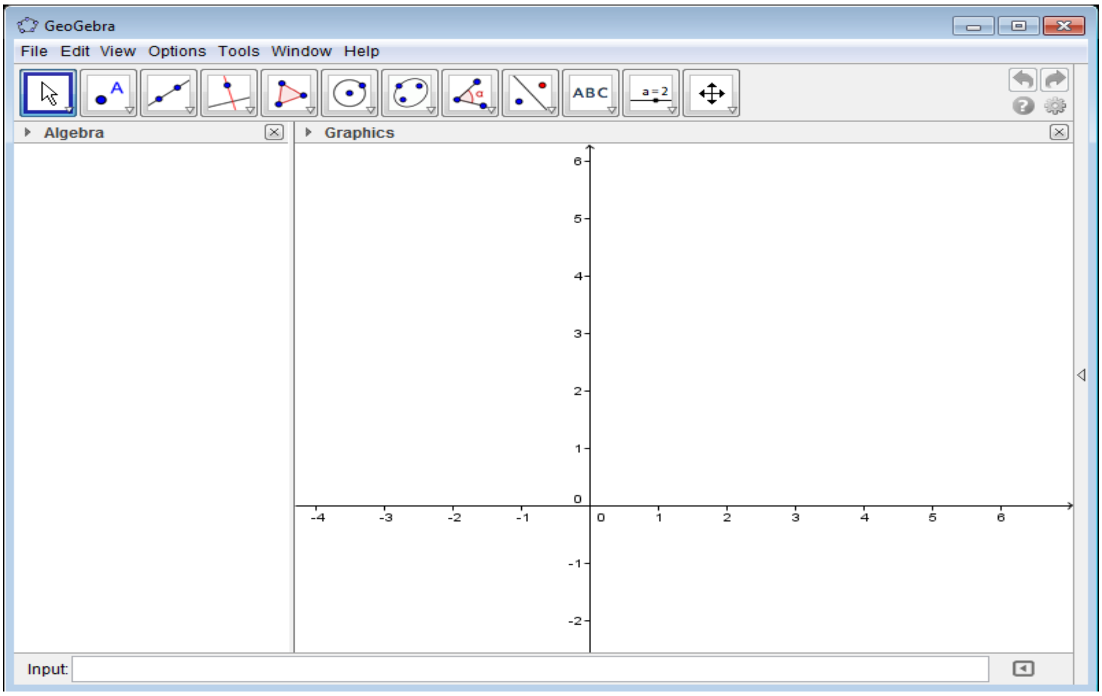


Figure 1: Geogebra Screenshot

Like other dynamic geometry systems, GeoGebra also functions with points, vectors, segments, lines, and conic sections. On the other hand, one can directly enter the equations and coordinates into the grid at the bottom of the window. Thus, a bidirectional combination and a closer connection can be ensured between visualization capabilities of CAS and dynamic changeability of DGS. While most of those who are interested in GeoGebra focus on the teaching of geometry, GeoGebra is also quite feasible in the teaching of algebra mainly lying in functions and graphs. The fact that functions which are first defined algebraically undergo then a dynamic change (Sangwin, 2007) bears a lot of significance in that it is capable of connecting the crucial parts of multiple representations of mathematics, which are numerical, algebraic, geometrical and graphical and which are far beyond the reach of other DGS and CAS.

It is a generally-held belief that anything lacks quality control if it is free. This principle is often thought of as applicable to GeoGebra, which is open-source software, not commercial. It should be added at this point that this is a misunderstanding or misgeneralization because if free software of GeoGebra makes almost no sense without proper training and collegial support. And it is for this very reason that the International GeoGebra Institute (IGI) is organized, as it is intended to give support to the collaboration between teachers and researchers and to provide professional development for teachers (Hohenwarter & Lavizca, 2007). Being an organization not aiming at profit, the Institute receives the funding chiefly from Europe and the U.S (Hohenwarter et al., 2008). Teachers interested in teaching mathematics by using GeoGebra demand a support system and professional development so that they can improve their skills in it (Hohenwarter and Preiner, 2007). Guided and supported by IGI, Geogebra thus increases the extent to which teachers keep eager to incorporate this new technology into their teaching practices.

2.6 Human Computer Interaction

It is possible to define human-computer interaction (HCI) as a discipline intended to design, implement and evaluate interfaces and interactive systems. It is designed to be used by humans. HCI is also concerned with the aftermath of the moment when these systems are released for human use; in other words, their effectiveness, efficiency and pleasure for the users are among the concerns of HCI (Öz, 2012).

Baker, Greenberg, and Gutwin (2002) define Human–Computer Interaction (HCI) as the study, planning and design of the interaction between individuals and computers. On the other hand, in a number of cases it is considered as the association of behavioural science, computer science, design and other study fields (Diaper & Sanger, 2006). In another definition, Dix, Finlay, Abowd and Beale (1993) refer to human computer interaction as a discipline that deals with designing, assessing and implementing interactive computer systems in such a way that they can be used by humans (Dix, Abowd, & Beale, 1993). With such definitions above, HCI emerged in the early 1980s as an area of research and practice in field of computer science (Carroll, Human–Computer Interaction, 2009). However, HCI has since grown to be an integral part of almost all stages of software development, starting with the gathering of requirements, prototype design, implementation and evaluation.

As can be seen in its title, the notion of interaction is the key concept in Human Computer Interaction. Men today need to interact with technology almost everywhere. This technology especially includes the one with software, which is capable of facilitating their work by serving their field. The concept of interaction is essential here, but one cannot help asking how people interact with software. When this question is answered in a disciplined way, the answer serves to define the field of HCI. From this perspective, Carrol (1997, p. 62) defines HCI "as the visible part of the computer science".

Human-computer interaction is still in the process of developing and it is particularly applied to social and behavioural sciences (Carrol, 1997). Consequently, HCI specialists have become well integrated in system or software development phase in the industry. They have also explicitly engaged themselves in project management.

Karam and Schraefel (2005) stated that HCI has a multidisciplinary nature (Karagöz, 2013). Moreover, HCI has had a rapid and steady spread for 30 years to a large extent. It even attracts professionals from several disciplines and incorporating diverse concepts and approaches today (Carrol, 2009).

2.6.1 User Interface

Schneiderman (1998) defines user interface as the point at which there occurs an interaction between the computer and the human. Strijbos, Martens, Prins and Jochems (2006), on the other hand, define the user interface as the system through which individuals (users) interact with computers. The user interface requires software, and hardware elements. In addition, the user interfaces are used by a variety of systems. With them, the means of inputting enables the user to affect the system and that of outputting makes the system capable of illustrating the effects of the user's manipulations. HCI engineering aims to create a user interface making it efficient, enjoyable and easy to interact with the computer. This interaction is also expected to contribute to the achieving of the results desired. In other words, the user is required to offer minimal input so that he/she can obtain the desired output. Through the machine, the probable outputs that are undesired should be minimized (Wald, 2005).

By means of an interface, the users interact with the product to achieve their goals. There are the system lets the users discover and learn its content and then respond to their commands or actions. As stated by Hackos and Redish (1998), there can be various forms of interfaces, including the screens for software applications on mainframe terminals and the pages of a website.

2.6.2 Usability

As a term that has grown important in software and product design over the past 30 years, usability can be defined (Nielsen & Loranger, 2006) as "a quality attribute relating to how easy something is to use. Also, the International Standard of Organizations (ISO) defines the usability in the standard of ISO 9421-11 as follows: "Usability is the effectiveness, efficiency, and satisfaction with which specified users achieve specified goals in particular environments". More specifically, it refers to how quickly people can learn to use something, how efficient they are while using it, how memorable it is, how error-prone it is, and how much users like using it. If people can't or won't use a feature, it might as well not exist." The need to design more usable systems has come to be the inevitable outcome of the industry because of the important benefits brought by it, such as increased productivity, reduced errors, reduced need of user training and user support and improved acceptance by the users (Jaspers, 2009).

As can be seen in the definition of ISO, the concept of usability has got three attributes; efficiency, effectiveness and satisfaction. These attributes are defined by Liljegren (2006) as follows: "Effectiveness is the accuracy and completeness with which specified users can achieve specified goals in particular environments. Efficiency is the resources expended in relation to the accuracy and completeness of goals achieved. Satisfaction is the comfort and acceptability of the work system to its users and other people affected by its use." (Liljegren, 2006, p. 346).

To Nielsen (1993), there are five attributes of usability, which should all be supported by the systems. These are as follows (as cited in Liljegren, 2006, p. 346):

* Learnability: The system or an interface should be easy-to-learn so that end-users can rapidly overcome some work by using the system.

* Efficiency: The system should be efficient-to-use so that when the system is learned by the users, it can also be used with a high proportion of productivity.

* Memorability: The system should be easy-to-remember, so that the users should be able to remember everything with the system even they did not used the system for some period and they should not have to learn everything all over again.

* Errors: The system should have a low error rate, so that users encounter with few errors during the use of the system and they should get rid of errors easily.

* Satisfaction: The system should be pleasant to use, so users are subjectively satisfied when using it.

In Diaper and Colston's words (2006), usability includes techniques with which to measure usability. It also requires that the principles behind the elegance or efficiency of HCI should be studied. The clarity and elegance in the designing of a computer program are the fields of study of usability both in computer science and HCI (Dix et al., 1993). Usability differs from the satisfaction and experience enjoyed by the user in that one of its targets is also usefulness.

2.6.3 Usability Evaluation Methods (UEMs)

In the literature, there are various proposals for the classification or grouping of the usability evaluation methods. One of those who grouped usability evaluation methods is Liljegren (2006), who grouped them into two categories, one analytical and the other empirical. Analytical UEMs are based on the reasoning capacity of one or more evaluators. Despite the fact that empirical UEMs depend on data collected from actual users, it is unnecessary to involve them. Liljegren (2006) categorizes four UEMs as common and current either in analytical or empirical UEMs. He lists these common methods as hierarchical task analysis (HTA), cognitive walkthroughs (CWT or CW), heuristic evaluation (HE) and usability tests.

2.6.3.1 Interviews

Interviewers aim to get to know the experiences and expectations of the users through their interviews. With the questions formulated in this method, the desired information can be obtained by directing them to the users and asking them to answer these questions verbally (Karagöz, 2013). The recorded responses of the users are later listened for the information desired. There are, however, two types of interviews that can be used; one is structured interviewing and the other is unstructured interviewing (Card, Newell, & Moran, 1983).

While making an unstructured interview, the methods are applied during the initial phases of usability evaluation. At this stage, investigators hope to learn about the user's experience as much as possible. However, they do not have fixed agendas. Rather than looking at any specific element of the system, they are chiefly intent on having information about which procedures the users adopt as an indication of their experience as well as about what they expect from the system as suggestive of their expectations (Gould & Lewis, 1985). On the other hand, structured interviews have got a predetermined and specific agenda. Additionally, they release a set of questions intended to guide and direct the interview.

For a comparison, it could be said that while structured interviews are more like an interrogation, unstructured interviews are closer to a conversation (Hoyoung, et. al., 2002). It is also possible to make a mention of the advantages and disadvantages of using interviews. For instance, they are capable of developing the relations with customers. Besides, they are very applicable for the exploration of comprehensive information. On the same note, they entail very few participants. However, interviews cannot be carried out remotely, a point that makes it disadvantageous to some extent. In addition, the usability issue of efficiency is not addressed (Tognazzini, 1992).

2.6.3.2 Task Analysis

What is meant by task analysis is the learning of the users' goals and the way they work. If individuals have their own goals, they refer to the task analysis in order to carry out the tasks. The term 'task analysis' also points to the steps to be taken by the users for the purpose of achieving these tasks (Karagöz, 2013). It also assesses the cognitive processes or actions of users. A thorough task analysis is also conducted to understand the present system and the flow of information within it, which is of significance in maintaining the present system and has to be integrated or substituted with new systems. Proper allocation and design of the tasks within the new system is also possible with task analysis. It is possible to specify the function not only in the system but also in the user interface. What makes it beneficial is also the chance to offer knowledge of various tasks intended to be performed by the user. It, therefore, serves to establish the functions and features of the systems.

2.6.3.3 Think Aloud Method

Those who participate in this method express their opinions on a given application as they perform the tasks. Capable of providing insight into the user's attitude, the technique is advantageous in several ways. Not only is it vital in indicating problems, but it is relatively simple to establish, as well (Medlock et al., 2002). That it is cheaper and the results with it are closer to the real experiences is another advantage of it (Lund, 1997).

2.6.3.4 Eye Tracking Methodology

In eye tracking methodology, a researcher can observe and measure the eye movements of individuals so as to find out where an individual is looking at a given time. The researcher can also know the way the individual's eyes change from one location to another. Upon tracking the individuals' eyes, HCI researchers will get the chance to learn about the visual and information processing mediated based on the display. Thanks to this method, HCI researchers are also capable of getting acquainted with the factors affecting the usability of the system interfaces (Kuniavsky, 2003). The eye movements, when recorded, may also offer an idea source of data used in the interface evaluation and capable of informing the design of enhanced interfaces. Additionally, this method may prove advantageous for disabled individuals as eye movements may be used as control signals that enable individuals to interact directly with interfaces through these movements, or without using keyboard or mouse.

For the realization of this technique, an infrared camera should be placed beneath or near display monitor on the uniform desktop computer, and thus it can identify and record the slightest eye movements for their characteristics. This is possible largely with the infrared light from the LED within the camera, producing strong reflections in the features of the target eye in order to make them very easy to track.

In eye tracking research there are two basic types of eye movements; fixations and saccades. The former movement, *fixation* can be defined as “the moment the eyes are relatively stationary, taking in or encoding information” (Poole & Ball, 2005). In other words, the user fixes his or her eyes on something on the screen (Nielsen & Pernice, 2010). It is during these fixations that visual information can be extracted, because eyes are relatively motionless then and focus on something. On the other hand, *saccade* is an eye movement taking place between fixations and typically lasting 20 to 35 milliseconds” (Poole & Ball, 2005). It is also possible to define saccade as quick movement of the eyes from one fixation to the next (Nielsen & Pernice, 2010). The main aim of this movement is to carry or move the eyes to the next viewing position (Poole & Ball, 2005). It may take an eye just one second or shorter to jump from one object to another.

In the context of usability, several eye tracking measures are used due to their relationship to key usability constructs such as effectiveness and efficiency. In particular, measures such as first time to fixate on a target interface item, the distribution of fixations on the interface as the user is searching for a specific feature/function are often used as indicators effectiveness. Moreover, measures such as average fixation duration, fixation count and the distribution of saccade lengths are often considered to relate to efficiency since they relate to measures of effort the user experiences while performing a specific task.

2.7 Breakdown Analysis

Systems are generally used in a social context where the system may function as a resource for mediating the interaction of multiple parties. In the context of working on a collaborative task by using an interface, partners establish the relevance of specific system features to their ongoing task in their talk as they refer to different features and verbalize the issues they may be experiencing with those features. Such settings of social interaction offer an opportunity for usability researchers to evaluate system features as they are put into use in an actual work setting. The breakdowns in conversation that occur due to system related issues are especially informative for investigating usability issues. This section describes the key concepts related to this naturalistic usability evaluation method.

2.7.1 Breakdowns

Wright and Monk (1989) proposed a design evaluation method established on two concepts:

Critical incident: It can be defined as user behaviour that is suboptimal as regards the functionality provided by the system and the intention of the users. Critical incidents can be observed in video records, system logs or even contemporaneous observation.

Breakdown: It can be defined as the moment when the user notices the properties of the system and mentally break downs or decomposes his or her understanding of the system in order to rationalise the problem experienced. Winograd and Flores (1987) described how breakdown would occur as follows: "A computer is usable to the extent that it serves to fulfil a task in a transparent fashion. Ideally, the user works without being aware of the system as a separate entity. Only in the case of breakdown and the subsequent need for analytical interpretation of the artifact as possessing properties in its own right does the system become part of the subjective experience of the interaction".

Wright and Monk (1989) assessed a user studying on a bibliographic data base for ten hours in sum. They evaluated four kinds of data: system logs from free use; system logs from the user performing set tasks; retrospective verbal protocol obtained during re-enactment of system logs, and concurrent verbal protocol (or co-operative evaluation – i.e. the evaluator co-operates by verbalising during interaction) .Critical incidents were available on the first three kinds of data while breakdowns were obtained from the last one, namely the concurrent verbal protocol (Urquijo, Scrivener, & Palmén, 1993).

If a task is conducted collaboratively, there is not a compulsory case for verbal discourse. It is not obligatory for the participants to think aloud and when they do so, this is for the purpose of cooperating with their partner, not the experimenter. In fact, it could be said that a verbal protocol is established during the collaboration between the participants whatever their number may be. In general, it is expected to offer more reliable breakdowns, which are to be reported for the sake of the partners of the cooperation. The purpose of doing so is to make the usability problems experienced by the breakdown reporter known and clear to the public. (Urquijo, Scrivener, & Palmén, 1993). For this very reason, we got the opinion that that Breakdown Analysis could be a useful tool for evaluating the performance of Geogebra system.

2.7.2 The role of the Model of Interaction in Breakdown Analysis

In the Breakdown Analysis method, breakdowns are classified on the basis of the interaction model. Classification is not intended to put a breakdown event into a neat slot, but to increase the quality of the information concerning the breakdown such that it may more readily assist the evaluator in identifying the underlying cause (Booth, August, 1990).

In this method, the user is directly involved in four primary interactions which are in between and each of which may undergo breakdown.

User and task: If the user is not knowledgeable enough to achieve the purposes within the task or if he or she has difficulties understanding it, a breakdown may occur.

User and tool: Breakdowns here are related to the two elements composing a tool. These are hardware and software interfaces. There may occur two kinds of problems involving either or both of these elements. One of these problems is the tool failure, where a technical problem occurs, and the other is the user-tool mismatch, where the user fails to understand the tool.

User and Environment: If the user feels aware of some intrusive property of the environment, a breakdown is likely to occur.

User and user: Such breakdowns come up during or in communication not related to tasks just about communications.

Different Types of communication breakdowns may occur (Urquijo, Scrivener, & Palmén, 1993, p.287):

Sufficiency: If a partner is provided with inadequate information in such a way that he or she will not understand the sender's intention, sufficiency breakdown occurs.

Clarity: Clarity refers to the quality of hearing or reading, so a breakdown in clarity results from an inaudible or illegible message.

Comprehension: If one partner is unfamiliar with the cultural, religious or traditional practices of the other, this may hinder or reduce comprehensibility, and thus a comprehension breakdown occurs.

Attention: Breakdown of attention is usually the result of the receiver's absorption in the task or of some attention loss caused by some external distraction.

Coordination: The inability of the users to coordinate their utterances causes them to interrupt each other, thus leading to coordination breakdown.

Feedback: If the source cannot receive any acknowledgement from the receiver, feedback breakdown occurs.

2.7.3 Breakdown Analysis

In medical circles, a breakdown is defined as the pathology of a system ailment, and in this case the first step is to identify the symptoms, the second is to diagnose the illness and the third is to prescribe a method of treatment. Similarly, in the case of breakdowns in educational technology context, an evaluation method based on BA consists of three stages (Urquijo, Scrivener, & Palmén, 1993).

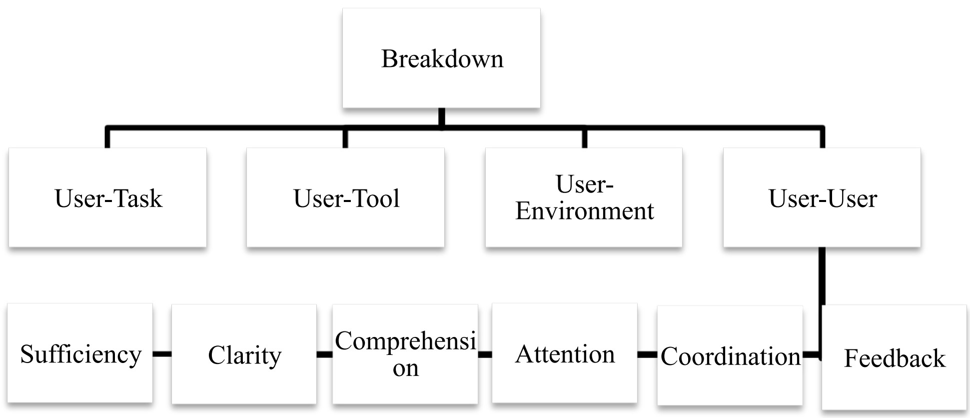


Figure 2: Classification of Breakdowns (reproduced from Urquijo, Scrivener & Palmen, 1993, p. 288)

At Stage 1, breakdowns are identified, transcribed and categorized without enquiring into what causes them. Therefore, this stage consists of three steps: detection, transcription, and category assignment. For detection of any breakdown, which is the first step, either system use is directly observed, or video-recordings of the user-system interaction are observed. In the second step here, breakdown, which has already been detected in Step 1, is transcribed. In the third step, the transcribed breakdowns are categorized according to the breakdown definitions associated with the Model of Interaction (Urquijo, Scrivener, & Palmén, 1993).

At Stage 2, causal diagnosis is made. In other words, the underlying causes of the breakdowns documented at Stage 1 are discovered. This stage follows the completion of the process of identifying and classifying the breakdowns at stage 1. The common question at this stage is "What causes the breakdown?" or "What is causing the breakdown?" (Urquijo, Scrivener, & Palmén, 1993)

At Stage 3, remedy is prescribed. To do so, the information from the previous stages is employed as a basis for remedies towards the problems causing the breakdown. Especially what is discovered to be the cause of a breakdown becomes the strongest means of remedy for the breakdown.

There are two basic steps in breakdown analysis. The first step consists of identifying and collecting the breakdown episodes and the second step involves analysing their structure and development.

A dialogue takes place among users as they are involved in an activity with a piece of software. It is important to focus on the moments of the change in a conversational topic regarding users' actions and software's successive states, for it provides an important source of information about the way the features of the software help maintain the users on the topic. Therefore with a detailed analysis of the quality of the changes in topic due to breakdowns, the relative contribution of users' processes and software behaviours to the flow of action can be determined.

2.7.4 Conversation Analysis

CA is a methodological perspective in the sense of methodology proposed by Valsiner, (2000), who came up with methods well suited to the investigation of socio-interactional processes and the organization of human action, especially in the realm of communicative practices. Not only do CA applications to HCI offer us already-used rules and patterns *(see, for instance, Norman and Thomas*, *1991)*, but they also contribute to the implementation of interactive systems (Woodland & Povey, 2002). CA can also be applied to software evaluation. It can be used to discover the support of any software in users' learning and activity.

CA places the emphasis on dialogues, tracing them in relation to the software features that support or disrupt joint attention and cooperation. For this purpose, CA just has the analytical tools to investigate the sequencing of utterances in dialogue, its emergent topical structure, the mechanisms for maintaining mutual intelligibility, and the alike. Now that users have focused on the interface, it can be examined through their talk. In sum, CA makes it possible for us to make a detailed examination of users' dialogue and to view the software itself as a semiotic medium for interactions among users and the author/designer (Meira & Peres, 2004).

2.8 Cognitive Load Theory

The main concern of cognitive load theory (CLT; Paas, Renkl and Sweller 2004; Sweller 1988, 1999) is the learning of complex cognitive tasks under the general assumption that the working memory is very limited in the human cognitive architecture (Miller 1956; Baddeley 1992; Sweller et al.1998; Cowan 2001; Schimpf & Spannagel, 2004). What is meant by the term 'complex' results from the fact that the number of information elements and their interactions that need a simultaneous processing for the starting of meaningful learning impose a great burden on learners. (Paas, Renkl, & Sweller, 2004)

There are three types of cognitive load in CLT. The term 'intrinsic' is applied to the load when it is imposed by the number of information elements and their interactivity. If imposed by the way the information is introduced to learners and by the activities learners are required to learn, it is called 'extraneous' or 'germane'. Intrinsic, extraneous, and germane load are regarded as additive because, when taken together, the total load cannot exceed the memory resources available if learning occurs (Paas, Renkl, & Sweller, 2004).

There is a need for learning materials to keep extraneous cognitive load as low as possible in the process of learning in order that they can be effective. For instructional conditions to be effective, however, not only is it necessary to free cognitive capacity by reducing extraneous load, but it is also of importance to present the learning materials in such a way as to make germane load as high as possible (Paas, Renkl, & Sweller, 2004).

Sometimes the interface may offer irrelevant elements, and in this case it is incumbent on students to distinguish between the important and unimportant, or relevant and irrelevant information for their learning (Reis, et al., 2012). The removal of irrelevant information in this way could decrease extraneous cognitive load and free the cognitive capacity for essential learning processes (Mayer, 2001).

The instructor is expected to provide learning environments and instructional materials to learners so that extraneous cognitive load can be reduced and cognitive capacity can be freed for learning processes through their proper design. The complex task of using a DGS to solve a mathematical problem requires the novices first to learn how to use the software for their goals. Second, they have to acquire mathematical concepts and processes underlying the task. If you design the user interfaces in a proper way, extraneous load can be reduced and this, in turn, can free cognitive capacity, which is then available for germane cognitive load needed for learning mathematics (Schimpf & Spannagel, 2004).

Whether usability can be improved depends on; a) whether learning can be made easier, b) whether the time spent on memorizing operations can be reduced, and c) whether interaction errors can be pruned away. The more features interfaces have, the more problematic and complex they will be for novice users but the more useful for experienced ones (Reis, et al., 2012).

2.9 Existing Usability Studies on DGS

In terms of their usability, studies about the dynamic geometry platforms emphasize the educational outputs. There are even studies on how much DGS are adopted by students and teachers in classrooms. Considering the literature, there appears a lack of studies on the examination of the usability of these environments. There are two main studies focusing on the usability of DGS environments. First of them was conducted by Hohenwanter and Lavizca in 2010. They evaluated difficulties of Geogebra tools. This study was carried out with the participation of 44 mathematics teachers. The teachers were asked to range the Geogebra tools from 0= very easy to 5=very difficult. According to the results, Hohenwanter and Lavizca classified the tools. They mentioned that "Easy-to-use" tools can be used individually at home or school without specific instruction, "middle" group tools should be demonstrated by presenters and before using "difficult-to-use" group tools, participants should be prepared using different actions (Hohenwarter, Hohenwarter, & Lavicza, 2010). Another study was conducted by Konterkamp and Dorhman in 2010. They mentioned DGS interfaces and supported approaches to these interfaces. They used a prototype of Cinderella to investigate the possible uses of multi-touch screens for constructing dynamic drawings. They evaluated how Cinderella supports multi-touch features. According to their study, there are some issues are not solved in user interface design for DGS and the existed strategies should need usability testing (Kortenkamp & Dohrmann, 2010).

Among these two studies that we deal with, as the first one is about evaluating the tools in terms of their easiness and difficulty, the second study was mentioning the applicability of the multi-touch specialties on DGS; however, there is a huge gap on this subject in the literature. It seems that there is not enough studies about how DGSs make use of the multi-touch secialitites better. We tried to detect the problems at the available implementations addressing this gap by providing solutions.

CHAPTER 3

METHODOLOGY

In this study, we conducted a usability evaluation of dynamic geometry software in three different scenarios of use. The first usability experiment comprises an eye tracking study that compares two dynamic geometry systems in terms of how individual users engage with basic drawing functions provided by each interface. The second usability experiment evaluates Geogebra in a collaborative problem-solving scenario where a pair of participants interacts with the environment with two different input devices, namely a mouse and a touchpad pen. In the third study, the recently released iPad version of Geogebra is evaluated by using a mobile eye-tracker stand. In this chapter, we present our research questions, and then mention about design of the study. The participants of this study, environment, software, instruments and data analysis methods are presented.

3.1 Research Questions

This work seeks to conduct a usability evaluation of dynamic geometry environments for facilitating students' effective engagement with abstract geometric concepts. Through a series of three usability experiments the study aims to identify usability issues in the present desktop and mobile interfaces in an effort to explore ways to improve students' engagement with geometric reasoning by constructing, manipulating and reflecting upon geometric objects.

In this study; we will try to find answers to the questions listed below:

1. How do Geogebra and Geometer's Sketchpad systems compare with each other in terms of their effectiveness and efficiency for building basic geometric constructions?

2. What are the usability issues involved with Geogebra in a collaborative problem-solving context that requires more complex geometric constructions?

3. Does the touchpad interface provide better support for building more complex geometric objects as compared to the mouse-based standard interface of Geogebra?

4. What are the usability issues involved with the tablet version of Geogebra? To what extent these issues parallel the ones identified for the desktop/touch pad version of Geogebra?

3.2 Design of Study

Demographic information about participants was collected in all studies with a questionnaire containing questions about gender, age, educational background, computer usage skills and past experience with GeoGebra and Geometer's Sketchpad. In the first study, a single user carried out given tasks by using both Geogebra and Geometer's Sketchpad. The Tobii T120 Eye Tracker was used to collect video screen recordings and measures such as number of fixations, fixation counts, total visit durations, and number of mouse click counts over specific areas of interests (AOI).

In the first study, the videos of screen recordings provided by the eye tracker were watched and the extracted gaze features were statistically analyzed. In the second study we used different methodology where two participants collaboratively used Geogebra at the same time. They tried to answer the given math questions by discussing with each other and taking coordinated turns on the interface. A dialogue based approach called breakdown analysis was used to analyze the transcripts of this collaborative problem solving sessions. Using Camtasia Studio, Transana software and a Video Camera, the participants' gesture communications and utterances were analyzed in detail. In the third study, the Tobii mobile eye tracking system with the X2-60 stick eye tracker and the mobile stand were used to collect gaze information and video recording of users' interaction with the tablet version of Geogebra. Since the mobile eye tracker can only track an individual, users attempted the given problems individually in this study. Finally, after the experiment, participants filled a questionnaire containing open-ended questions related to their experience.

To sum up, we used a mixed method approach, where the data collected via questionnaires, eye-trackers, screen recordings, video cameras and open-ended questions were subjected to quantitative and qualitative analysis. This data is used to evaluate dynamic geometry environments in terms of their effectiveness, efficiency and satisfaction, which altogether account for the usability of such environments. In particular, effectiveness is assessed through the number of tasks that could be accomplished by the participants and the specific comments that they made when they experienced difficulty for achieving their goals. Efficiency is evaluated in terms of fixation measures and task completion times as indicators of the mental and physical effort required by the basic geometry construction tasks. Finally, satisfaction is investigated through user comments and relevant questionnaire items.

3.3 Participants

Dynamic geometry environments such as Geogebra and Geometers' Sketchpad are designed to support a wide range of curricular activities suitable for middle school to university level. In this study, we mainly focus on identifying usability issues when these interfaces are used by university students. We recruited a total number of 28 students from METU for the three case studies conducted as part of this study. Therefore, the findings of this study are generalizable to the population of university students only, which presents a targeted user population for the developers of dynamic geometry software.

In the first study, six end-users were recruited who were research assistants at Middle East Technical University. All of them were female graduate students. They were 23, 23, 27, 28, 29, 32 years old respectively ($M=27$). Two of them were in the PhD program and four of them were master's students. They rated themselves as advanced computer users. Half of the participations had experience in using Geogebra. The rest did not have any experience with the systems. On the other hand, except two participants, all of subjects had prior experience using Geometer's Sketchpad.

Table 1: Statistics about First Study

	Age	Educational Level	The degree of computer usage	Experience of using Geogebra	Experience of using G.Sketchpad
N	6	6	6	6	6
Mean	27,00	1,33	6,83	2,00	1,83
Median	27,50	1,00	7,00	1,50	2,00
Minimum	23	1	5	1	1
Maximum	32	2	8	4	3

All subjects volunteered to participate in the experiment and signed an informed consent form approved by the METU Human Subjects Ethics Committee.

In the second study, our sample included 12 end-users who are students in Middle East Technical University. 3 of them were female the others were men. 8 of them were undergraduate students, 3 of them were master's students and one of them was a PhD student. All participants highly rated their computer and basic math skills. None of them had prior experience with Geogebra.

Table 2: Statistics about Second Study

	Age	Computer Skills	Math Skills	GeoGebra Experience	Geogebra Usage
N	12	12	12	12	12
Mean	24,92	7,33	8,17	,00	,00
Median	23,00	7,00	8,00	,00	,00
Minimum	22	5	6	0	0
Maximum	37	9	9	0	0

In the third study, our population in this study was 10 end-users who are students in Middle East Technical University. 7 of them were female the others were men. 6 of them were master student and four of them were PhD student. All of them have computer and basic math skills. None of them has Geogebra experience.

Table 3: Statistics about Third Study

	Age	Educational Level	Computer Skills	Math Skills	GeoGebra Experience	Geogebra Usage
N	10	10	10	10	10	10
Mean	26,50	2,40	7,80	6,20	,00	,00
Median	26,00	2,00	8,00	7,00	,00	,00
Minimum	24	2	6	2	0	0
Maximum	31	3	9	9	0	0

3.4 Ethics

Due to ethical concerns over the volunteers of our experiments, we could not store any of their private data. The participants of our experiments were formed by volunteers who were provided with a form informing them of the following: purpose of the study/experiment, confidentiality of the data gathered from the experiments involving them and how long and where the experiment would be. We also wrote in this form that they could leave the experiment at any time they liked to (See appendix C).

3.5 Materials, Apparatus and Software

In this thesis study, three surveys and the Tobii Studio software, and Camtasia 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. In the second study, a modified version of this survey was used to gather demographics information. This survey consists of 6 questions about gender, age, educational background, computer usage skills and time period, mathematical skills and experience about GeoGebra (Appendix B).

The second data collection instrument is a questionnaire containing the System Usability Scale. We used a scale known SUS (System Usability Scale) developed by John Brooke from Digital Equipment Corporation in 1986 (Brooke, 1986) (Appendix D). This scale is used to evaluate the usability of systems or products effectively through a quick and practical way as Sauro puts it “SUS can be used on very small sample sizes (as few as two users) and still generate reliable results” (Sauro, 2011).

This questionnaire was composed of 10 questions with 5 options of answer for the participants to select from 0 being the least positive and 5 being the most positive; they were restricted to one option per question .The score range of this program ranged in between 0 and 100. 0 being the least effective and 100 being the most productive.

The conversion of the 10 question questionnaire to the 100 scale is calculated as follows: For odd items selected: subtract one from the user responses. For every even-numbered item: subtract the user responses from add up the converted responses for each user and multiply that total by 2.5. This converts the range of possible values from 0 to 100 instead of from 0 to 40. These two questionnaires were translated from English to Turkish by Kürşat Çağıltay (Çağıltay, 2011).

Tobii T 120 eye tracking devices were used. The devices tracked both eyes of the participants, and gathered information of the participants where they looked on the screen, how long and how many times they looked and at which locations on the screen using the reflectors and the infrared detector cameras (Uzunosmanoğlu, 2013). The technical specifications of Tobii T 120 are as follows. It is composed of 17 inch flat LCD screen, can capture the participants glance with a 0.5 degree of accuracy at 60-120 frames per second. The T 120 can very accurately observe the eyes provided users move their heads within a certain limit, i.e. 30 cm on a horizontal axis, 22 cm on a vertical axis, and 70 cm backward or forward to the screen. Otherwise the T 120 loses the subject’s eye-movements and its accuracy (Tobii T60 & T120 Eye Tracker User Manual, 2011).

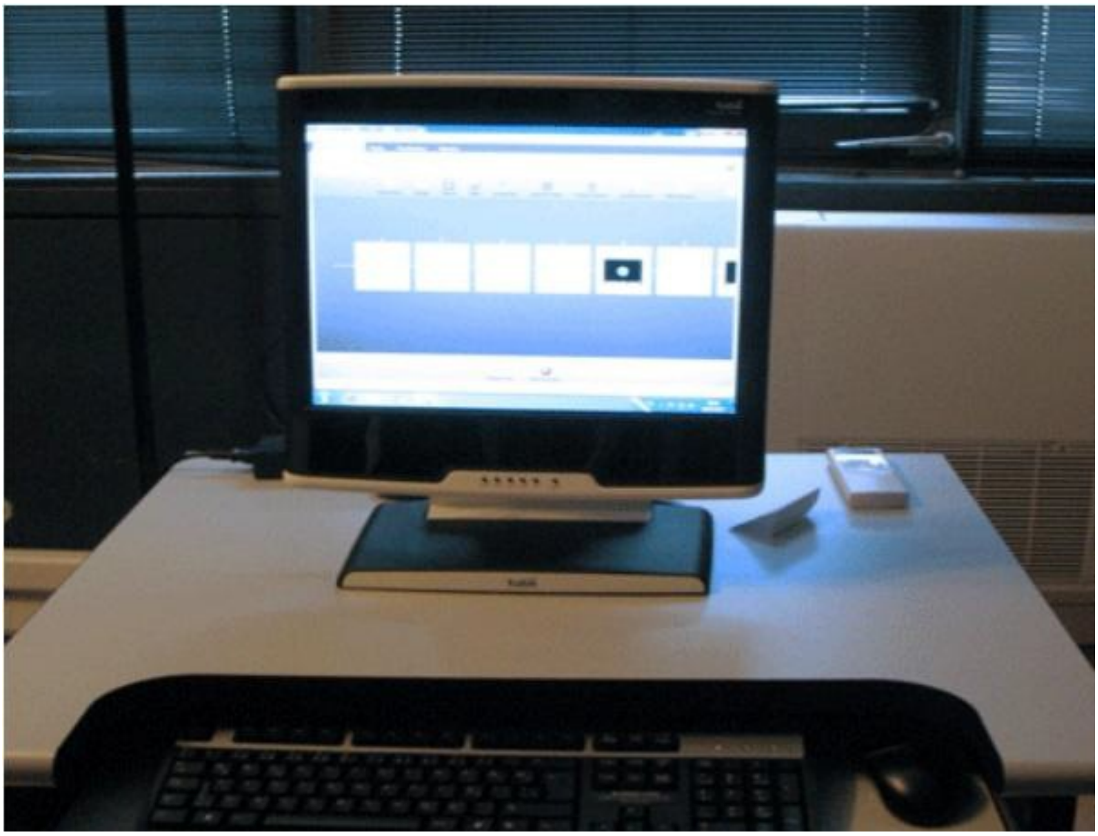


Figure 3: HCI Laboratory in METU

In the second study, Camtasia Studio 8 software was used. This software has advanced editing and Publishing Techniques and video of Screen Record. In this study, we used Camtasia Recorder; you record exactly what you want: the entire screen, specific dimensions, a region, a window, or an application. Recorder is designed to be simple and easy-to-use starting with your first recording—just click the Record button and begin your onscreen activity.

Recorder automatically records:

Microphone audio recording, System audio recording (not supported on the Microsoft Windows XP operating system), Smart Focus zoom and pan key frames to automatically optimize the viewing experience, Keyboard shortcut data that generates automatic callouts in Editor. Cursor data that allows you to customize the cursor in Editor.

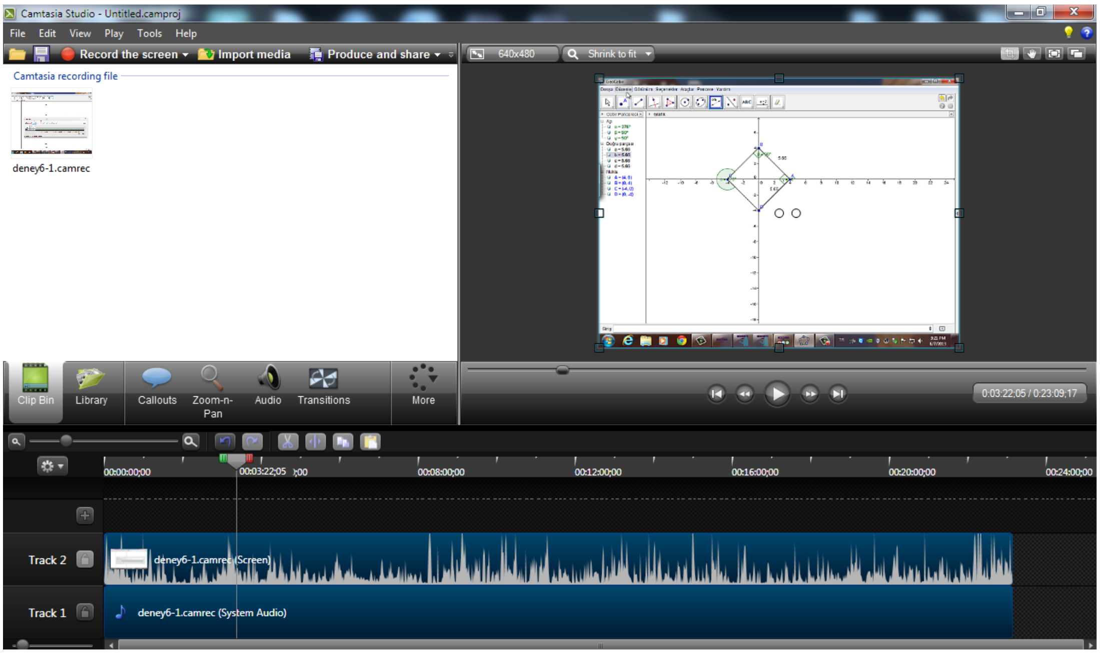


Figure 4: Camtasia Studio 8 Window

Moreover, in this study we used a video camera.

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 observed qualitatively.

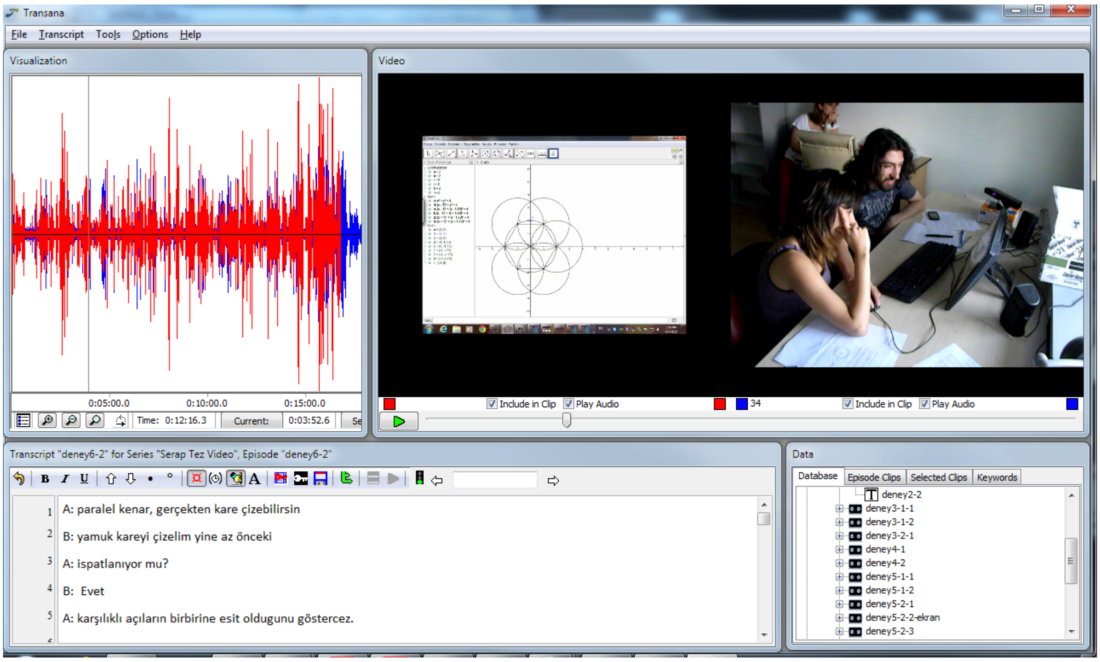


Figure 5: Transana 2.51 Window

Furthermore, in this study, we used Wacom DTU-1631 widescreen LCD display was used. This display supports interactive pen and mouse. It can be used Microsoft Windows 7, Vista or XP or Mac OS X 10.4 or greater operation systems. It's screen size is 15.6 inch, 346.23 x 195.54 mm (13.64 x 7.70 in). It has 1366 x 768 number of pixels (Interactive Pen Display USER'S MANUAL, 2010)

Figure 6: Wacom DTU_1631

In the third study, stand-alone eye tracker Tobii X2-60 was used. This eye tracker device tracked both eyes of the participants, and gathered information of the participants where they looked on the screen, how long and how many times they looked and at which locations on the screen using the reflectors and the infrared detector cameras (Uzunosmanoğlu, 2013). The technical specifications of Tobii X2-60 are as follows. It a small and portable eye tracker, so it can be used for different studies such as on labtops, mobile devices, and real word interfaces and TV screens (Tobii X2-60 Eye Tracker User Manual).

Figure 7: Tobii T X2-60 Eye Tracker

3.5.1 Geogebra

GeoGebra is dynamic mathematics software for schools that join geometry, algebra and calculus.

On one hand, GeoGebra is an interactive geometry system. You can do constructions with points, vectors, segments, lines, polygons and conic sections as well as functions while changing them dynamically afterwards.

On the other hand, equations and coordinates can be entered directly. Thus, GeoGebra has the ability to deal with variables for numbers, vectors and points (Hohenwarter, J., & Lavicza, 2008).

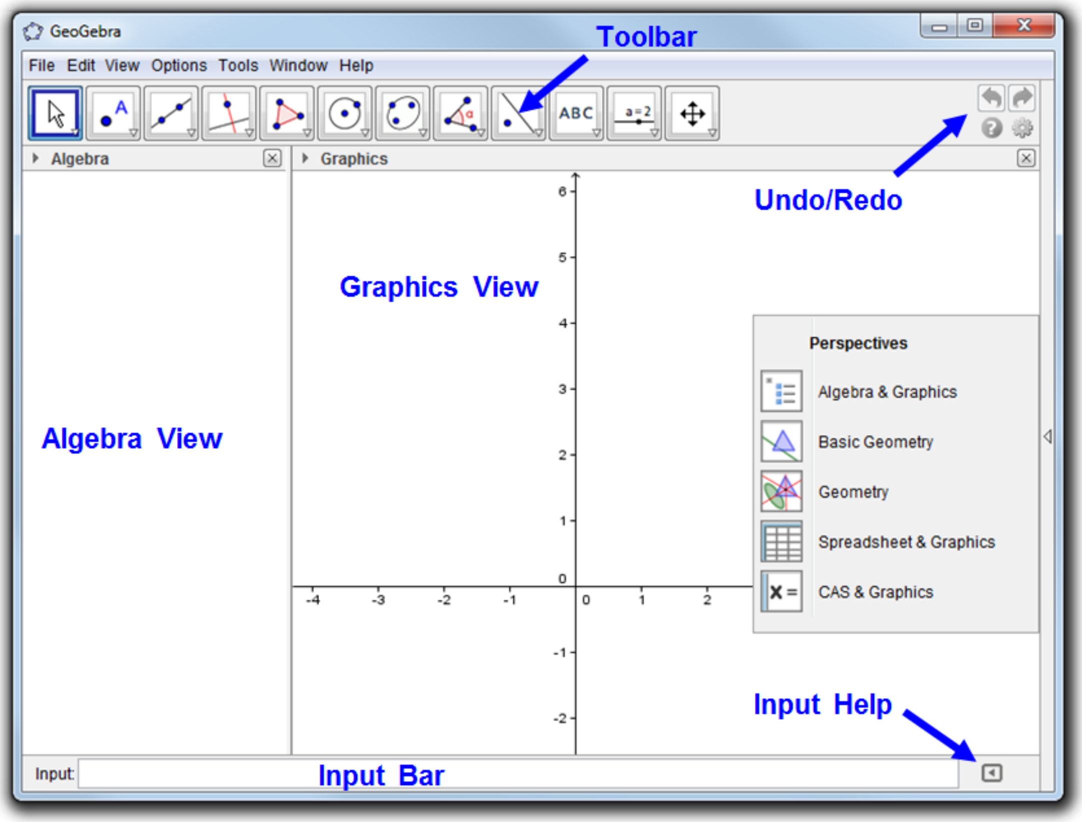


Figure 8: Geogebra 4.2 Window

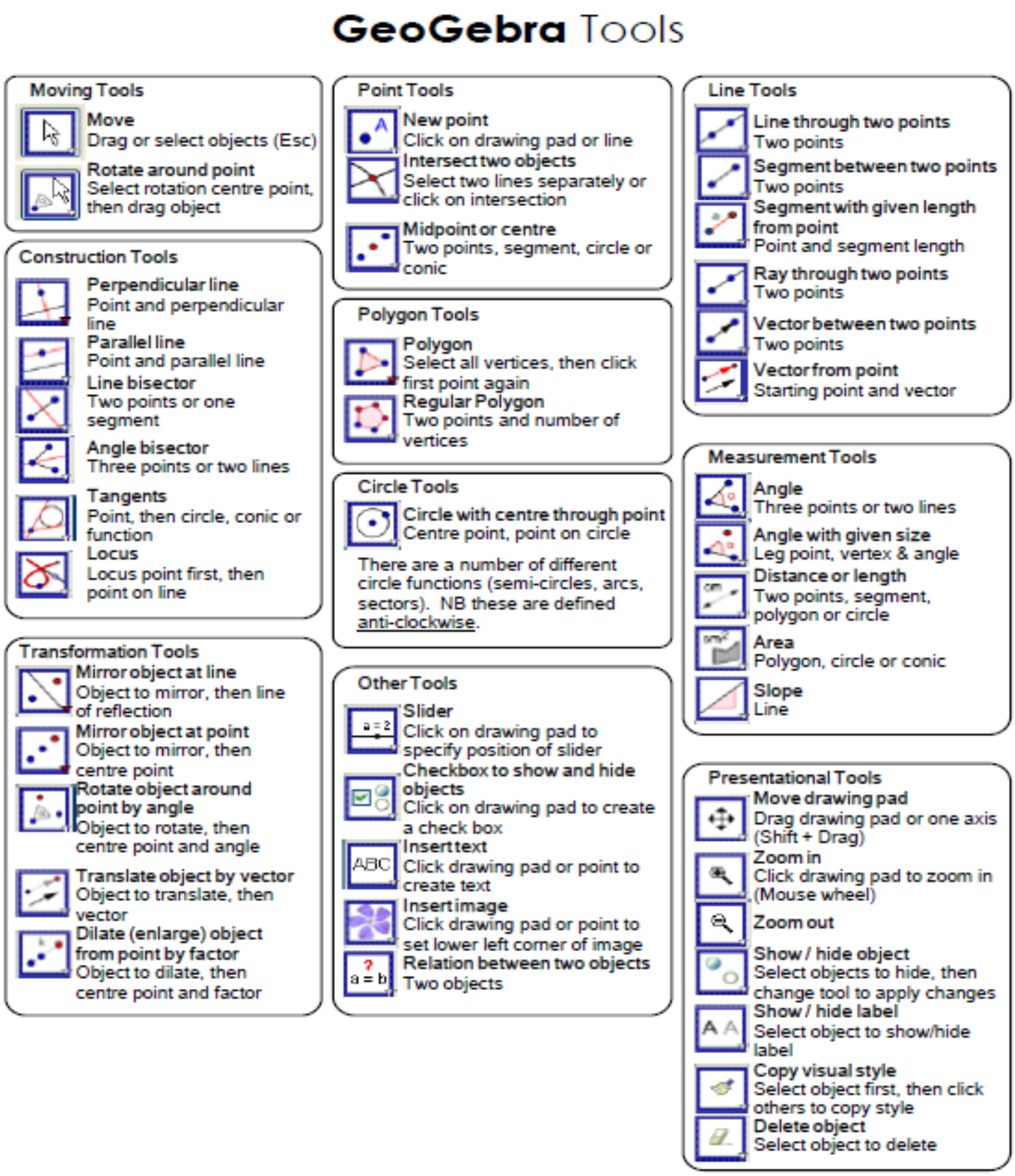


Figure 9: List of all Geogebra tools (Chrysanthou, Geogebra, 2008, p. 29)

3.5.2 Geometer's Sketchpad

Geometer's Sketchpad is developed by Jackiw (1995), dynamic geometry software that uses exploratory approach in mathematics. This software allows teachers and students to use the construction and the animation of an interactive mathematics model (Nordin, 2008).

With Sketchpad, students at all levels get the chance to learn mathematics in a tangible, visual way because it increases their engagement, understanding, and achievement. Elementary school students, for example, can manipulate dynamic models of fractions, number lines, and geometric patterns. Middle school students may discover ratio and proportion, rate of change, and functional relationships through numeric, tabular, and graphical representations in this software, thus getting better prepared for algebra. Finally, in the hands of high school students, Sketchpad is suitable for the construction and transformation of geometric shapes and functions, from linear to trigonometric, promoting deep understanding. Sketchpad, as such, is an optimal tool for interactive whiteboards. It is sure to make teacher's job easier and more colourful as well as more instructive as it appeals to both teachers and students visually (The Geometer's Sketchpad).

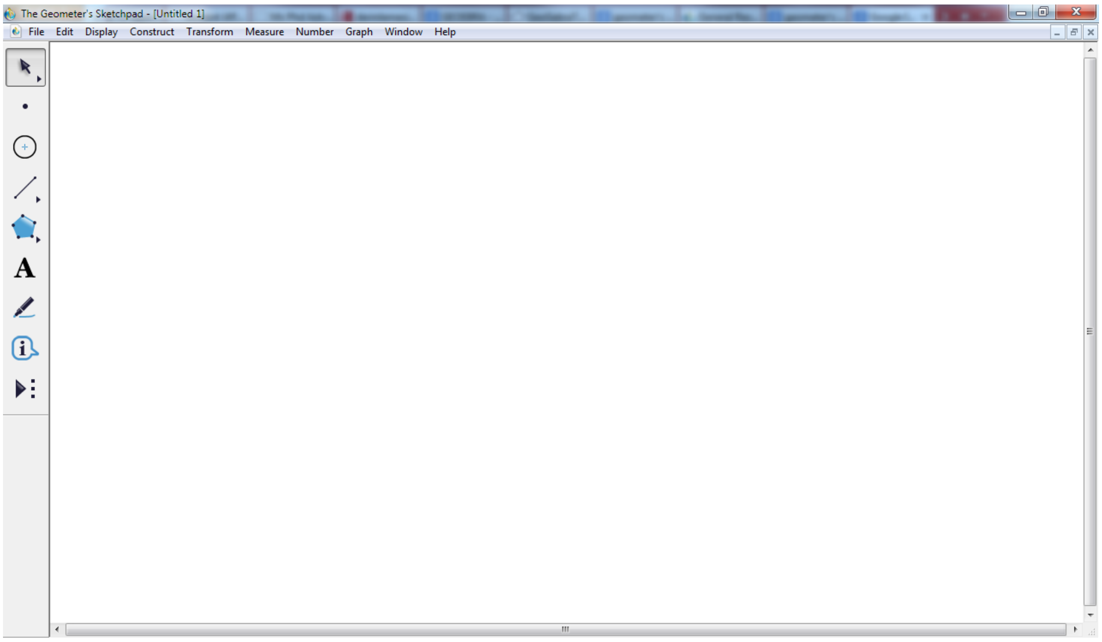


Figure 10: Geometer's Sketchpad 5.0 Window

3.6 Data Collection Procedure

To conduct a usability study, tasks which could be completed in an hour at most were given for each study. While forming these tasks, we made use of the tutorial prepared by Geryl Stahl and his VMT (Visual Math Team) project team (Stahl & The VMT Project Team, 2012). The tasks we used in this study were related to the use of the basic features of the system. We had not expected the users to reach excellent mathematical solutions in this study. We just sought to find out if they could construct an acceptable dynamic geometry presentation and, if yes, how much effort they made in constructing it.

3.6.1 Study 1

In the usability test, subjects were asked to complete 6 specific tasks by using GeoGebra and Geometer's Sketchpad. In terms of the number of features one needs to use to complete each task, two of them were easy, two of them had medium degree of difficulty and two of them were difficult. First two of them were basic task. After doing these basic tasks, the difficulties of other tasks increased. The tasks were;

Table 4: Tasks of First Study

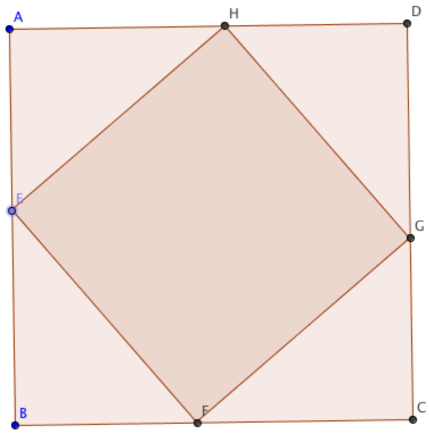
Task 1:	Draw any triangle, show its angle and edge length and add any edge length of this triangle.
Task 2:	Draw any irregular polygon, show its angle and calculate its circumference and area.
Task 3:	Draw a straight line passing through the A (5, 0) and B (0, 2) points and indicate the equation of the line.
Task 4:	Draw a graph of the equation $y = 3x^2 +5$.

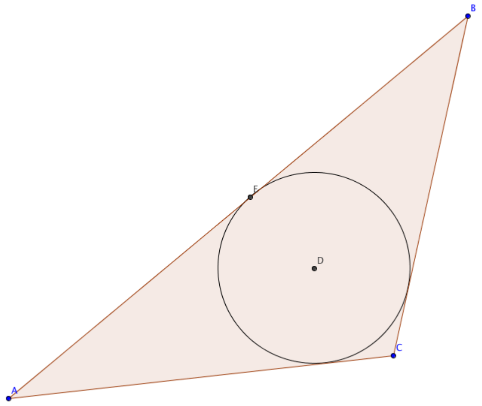
Task 5:	$F(x) = 2x^3 - x^2 + 6x + 4$ Take the derivative of the function. Draw a graph of a derivative.
Task 6:	Draw any circle; calculate its circumference, the radius and area. Create a table of values found by changing the radius of the circle. Draw a graph from the data in this table.

3.6.2 Study 2

Ten tasks were given to the participants. They were asked to complete the 5 of the tasks by using a Mouse and the other 5 tasks by using a Touchpad Pen. The tasks were;

Table 5: Tasks of Second Study

1.	Without using polygon tool form a square. Prove that drawn shape is a square (Çokgen aracını kullanmadan bir kare oluşturunuz. Oluşturduğunuz şeklin kare olduğunu ispatlamaya çalışınız.)
2.	Form a square within a square as shown below, The square inside needs to touch corners of the square other square. (Şekilde görüldüğü gibi kare içinde kare oluşturunuz. İç kısımdaki karenin köşelerinin dıştaki karenin kenarlarını ortalaması gerekmektedir.)
	
3.	Using only points, lines, segments and a circle draw an isosocleses triangle and prove it. (Sadece nokta, doğru, doğru parçası ve çember kullanarak ikizkenar üçgen oluşturunuz. Oluşturduktan sonra bu üçgenin ikizkenar olduğunu ispatlamaya çalışınız.)
4.	Form an equilateral triangle and find its center point prove that it is the center. (Bir eşkenar üçgen oluşturunuz ve bu üçgenin merkez noktasını bulunuz. Bulduğunuz noktanın merkez nokta olduğunu ispatlayınız.)
5.	As shown below draw a circle within a triangle that should pass tangentially in three points. (Şekilde görüldüğü gibi bir üçgen içine 3 noktadan teğet olacak şekilde bir çember çiziniz.)

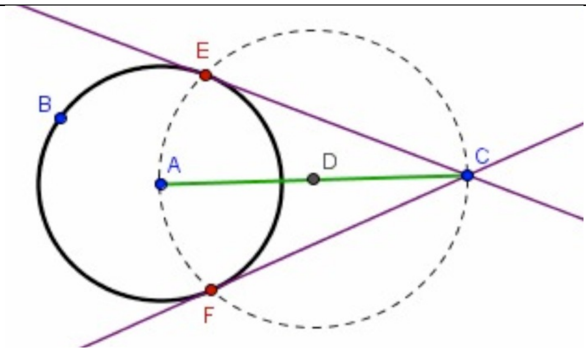


6. Form a parallelogram and prove that it is a parallelogram. (Paralelkenar oluşturunuz. Oluşturduğunuz şeklin paralelkenar olduğunu ispatlayınız.)

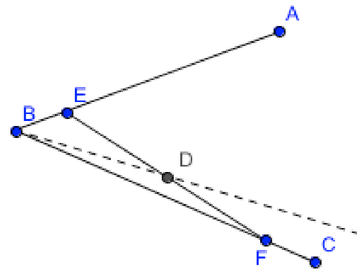
7. Using only circles and segments draw and prove a hexagon. (Sadece çember ve doğru parçası araçlarını kullanarak düzgün altıgen oluşturunuz. Oluşturduğunuz şeklin düzgün altıgen olduğunu kanıtlayınız.)

8. Draw three parallels and forms an equilateral triangle, which should touch the parallels at its corners. (3 adet paralel doğru çiziniz. Her bir köşesi bir doğruda olacak şekilde bir eşkenar üçgen oluşturunuz. Üçgenin eşkenar olduğunu kanıtlayınız.)

9. Draw a circle and create a point outside this circle. As shown below from the point within the circle without using the tangent tool, draw a tangent. (Bir çember ve çember dışında bir nokta belirleyiniz. Şekilde görüldüğü gibi çember dışında belirlediğiniz bu noktadan teğet aracını kullanmadan çembere teğet çiziniz.)



10. As shown above form a ABC angle and draw a EF segment and specify a D point which equally divides the EF segments and prove it. (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.)



3.6.3 Study 3

Six tasks were given to ten participants in the third usability study. Subjects used the Geogebra's mobile version for Ipad to complete the tasks. Half of the tasks were chosen from Study 1 and half of them were chosen from Study 3.

Table 6: Tasks of Third Study

Task 1:	Draw any triangle, show its angle and edge length and add any edge length of this triangle.
Task 2:	Draw a straight line passing through the A (5, 0) and B (0, 2) points and indicate the equation of the line.
Task 3:	Without using polygon tool form a square. Prove that drawn shape is a square
Task 4:	Draw a graph of the equation $y = 3x^2 +5$.
Task 5:	Draw three parallels and forms an equilateral triangle, which should touch the parallels at its corners.
Task 6:	Using only circles and segments draw and prove a hexagon.

3.6.4 Pilot Study

A pilot study was only conducted in study 3, because the mobile eye-tracking stand had not been experimented at our laboratory before. The study was carried out on only one participant from the department of Cognitive Science. The aim of this pilot study was to see whether there are any hitches somewhere in the experimental setting. According to this pilot study, order of the task was confusing and the calibration of eye tracking was poor. Since poor calibration causes the missing results, we redesigned our experimental setup (Bojko, 2013).

3.6.5 Before Experiments

In the first study, before the experiments, e-mail was sent to Mathematics Education Department students in order to reach participants. In this e-mail, the students were informed about the aim of this study, where it will be implemented, and how long it would take. Moreover, in the second and third experiments, IS/COGS students and undergraduate university students were invited to participate in the study personally. People who accepted the invitation were chosen as participants. In all three studies subjects filled a questionnaire containing demographic questions about gender, age, educational background, computer usage skills and experience about GeoGebra and in the first study experience of Geometer's Sketchpad prior to the experiment.

3.6.6 Experimental Setup

In the single user study group, 6 tasks were given to 6 participants who study in math as master and doctorate students to do. Those participants were requested to solve these tasks with GeoGebra and Geometer's Sketchpad, and eye tracker used to record participants' eye movement to analyze.

10 geometry problems were determined In the second study, we try to analyze the usefulness of GeoGebra examining in a computer supported physical environment using face to face collaborative method with 6 pairs' problem solvıng processes and understand to effects of developing technology product such as Touchpad Pen. The participants' dialogues, screens and body gestures were recorded in the study. Collective all data was examined with Synchronized way to produce dialogues' transcripts. According to these transcripts we observed the usefulness of GeoGebra and its effects on collaborative problem-solving process, analyzing breakdowns in participations communication because of GeoGebra software properties.

In the third study, 6 tasks were given to 10 single users who study in Information Systems and Cognitive Science. Before they started to solve these geometry problems, each participant trained for approximately 10 minutes. The Geogebra tools used frequently while solving geometry problems and an example for constructing an equilateral triangle using circles were presented.

3.6.7 After Experiments

In the first study, a survey was applied including System Usability Scale and a questionnaire about usability. In the second study, participants responded the questionnaire which was about their age, sex, field of study, their knowledge of basic math and level of computer skills and experience of Geogebra and open-ended questions were asked about software and get participants' comments. In the Third Study same questionnaire given and open-ended questions asked. Moreover, System Usability Scale was applied.

According to all study data, the results present about using GeoGebra software in a different environment and devices and discussed.

3.7 Data Analysis

3.7.1 Study 1

In this study mixed research method approach was employed for the analysis of usability differences between Geogebra and Geometer's Sketchpad for the first study.

First we analyzed the survey descriptively. Descriptive statistics were used to discover the distributions of participants' gender, age, educational level, computer usage skills, Geogebra experience and Geometer's Sketchpad experience.

After the experiments, data gathered from eye-trackers were analyzed quantitatively. For this analysis, area of interest of the eye movements considered, time to total visit duration, mouse click count records of the participants exported by Tobii Studio Software.

Firstly, task analysis was conducted for both programs. Then total visit duration, mouse click count, which are eye-tracking data, were statistically compared to obtain and evaluate the results.

Additionally, the results of the questionnaire and SUS scale applied for Geogebra and Geometer's Sketchpad were calculated and assessed.

3.7.2 Study 2

In this study mixed research method approach was employed for the analysis of usability issues involved with Geogebra in a collaborative problem-solving context that requires more complex geometric constructions and the touchpad interface compared to the mouse-based standard interface of Geogebra for building more complex geometric objects.

First, we analyzed the survey descriptively. Descriptive statistics were used to discover the distributions of participants' gender, age, educational level, computer usage skills, and Geogebra experience.

Secondly, this experiment has data obtained from two different environments. To begin with, the screen video captures of the computers used by the participants were extracted. These videos also contained audio records. These videos were divided into tasks by using Camtasia Studio program, a separate video file was formed for each task.

Afterwards, video records obtained from the video camera were divided into tasks, using the windows Movie Maker program. For each task, a separate video file was formed. Then Transana Program was used to synchronize these two videos, using the sounds of the participants. In this program, data were transformed into transcripts.

First of all, task analysis was done to see whether the tasks were conducted. Then the current tasks were classified according to the input devices such as mouse or touchpad pen. Breakdown analysis was carried out to find out the causes of breakdowns and whether they could be solved. It was also determined how many breakdowns were experienced in each of these tasks. And they were assessed for usability. The acquired data were calculated statistically via two-way ANOVA test and the results were obtained.

Lastly, data were obtained from the open-ended questions applied after the experiment.

3.7.3 Study 3

In this study mixed research method approach was employed for the analysis of usability issues involved with the tablet version of Geogebra.

Similarly study 2, first we analyzed the survey descriptively. Descriptive statistics were used to discover the distributions of participants' gender, age, educational level, computer usage skills, and Geogebra experience.

After the experiments, data gathered from eye-trackers were analyzed quantitatively. For this analysis, area of interest of the eye movements considered, time to total visit duration, mouse click count, Percentage of time spent on an AOI, Number of fixations prior to first fixation on an AOI, Percentage of participants who fixated the target at least once, records of the participants exported by Tobii Studio Software. Moreover, data were transformed into transcripts.

First of all, task analysis was conducted for both programs. Then eye-tracking data were statistically evaluated.

SUS results were calculated and results were obtained for the GeoGebra mobile version. In addition to them, the users were asked open-ended questions after the experiment and they were asked to determine the difficulties they had.

3.8 Assumptions of the Study

For this study, the following assumptions are stated:

- Participants responded correctly to questionnaires, open-ended questions and SUS.
- The measures used in the study were reliable and acceptable.
- The recorded, collected and analyzed data were accurate.
- The transcripts of conversations in study were correct.
- The environment of study was under normal circumstances.

CHAPTER 4

RESULTS

4.1 Study 1

Subject demographics are briefly specified in the Methodology part. We examined each distribution in detail in this chapter.

4.1.1 Subject's Demographics

4.1.1.1 Age

The average age of participants is 27 years (range between 23-32). Two of them were 23 years old. One of them was 27, one of them was 28, one of them was 29, and one of them was 32 years old.

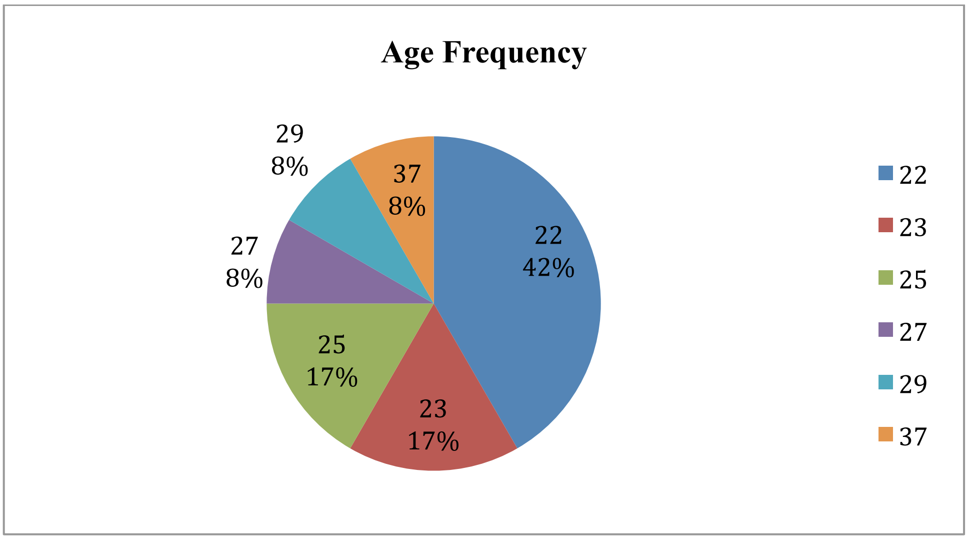


Figure 11: Age Frequency of First Study

4.1.1.2 Sex

All participants were female.

4.1.1.3 Educational Level

Education level of the participants varies between university B.S. students and doctoral students. Majority of the participants were master students (4 participants 67 % respectively) and 2 participants (33%) were Ph.D. students in Mathematics. 5 of them were Research Assistants at Math Education Department. One of them was a student in Mathematics.

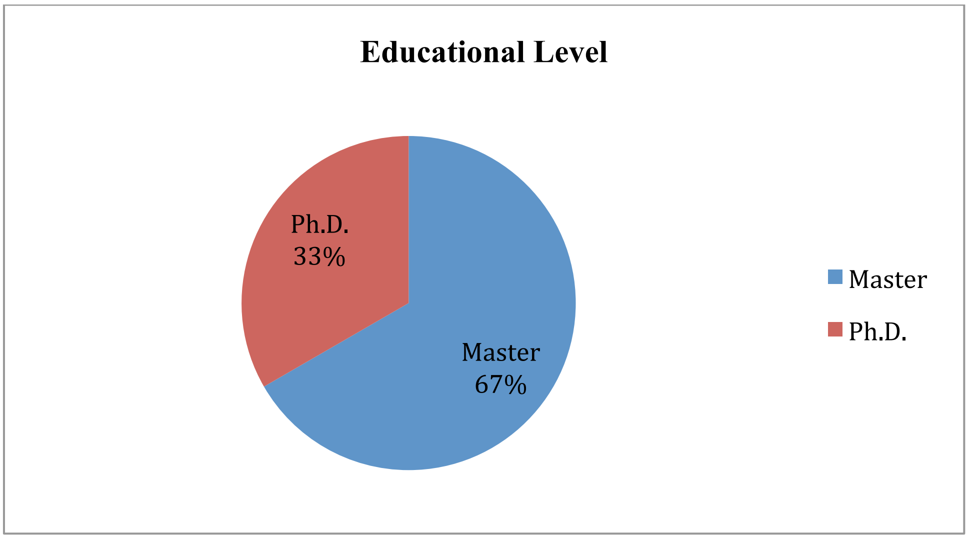


Figure 12: Educational Level of First Study

4.1.1.4 Computer Skills

In this part of questionnaire, participants rated their computer skills between 1- 9. The average of participants Computer Skills was 7. Four of them rated their skills with 7(66, 7%). One participant rated her skills with 5 (16, 6%) and one of them rated her skills with 8 (16, 6%).

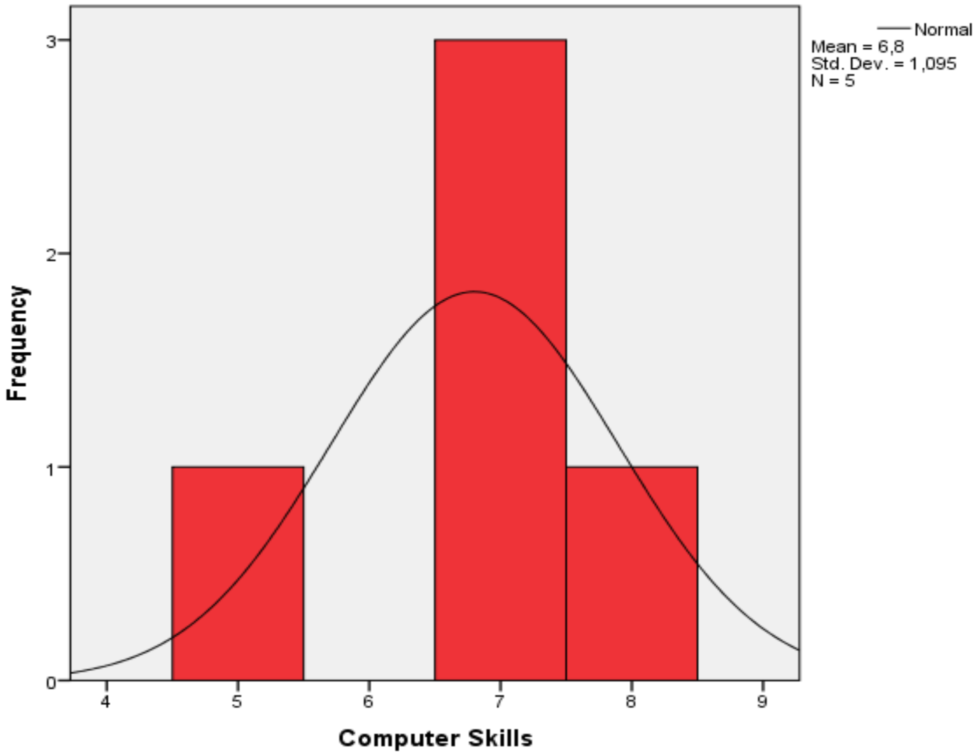


Figure 13: Computer Skills of First Study

4.1.1.5 Geogebra Experience

3 of the participants stated that they never used the GeoGebra program before; the others stated that they had an experience with Geogebra. One of them indicated she uses GeoGebra a few times a week. One of them stated she uses Geogebra once a week and one of them stated she uses GeoGebra once a month.

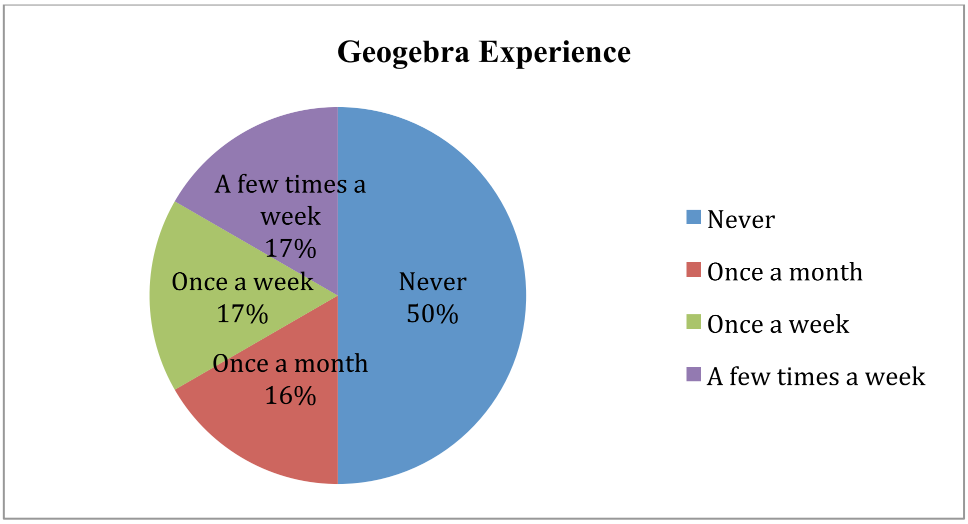


Figure 14: Geogebra Experience Level of First Study

4.1.1.6 Geometer's Sketchpad Experience

2 of the participants stated that they never used the Geometer's Sketchpad program before; the others stated that they had an experience with Geometer's Sketchpad. Three of them indicated she use Geometer's Sketchpad. One of them stated she uses Geometer's Sketchpad once a week.

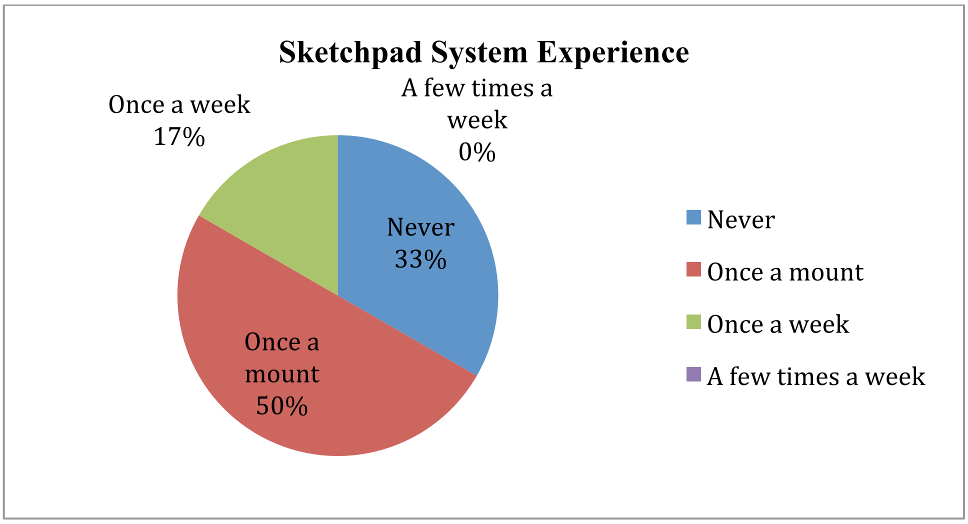


Figure 15: Geometer's Sketchpad Experience Level of First Study

4.1.2 Quantitative Results

Firstly, we compared Geogebra and Geometer's Sketchpad in terms of task accuracy (Table 7). All participants using Geometer's Sketchpad completed all tasks. However, half of the participants could not complete Task 6 in Geogebra. In Task, 6 we wanted the participants to draw a circle and calculate its circumference, radius and area. Then, we wanted them to create a table of values found by changing the radius of the circle, and expected them to draw a graph using the data in the table. The first level of the Task, which was drawing a circle and showing its area, circumference, and radius was completed by the attendants smoothly. Geometer's Sketchpad allowed the participants to create the table using these data and moreover, Geometer's Sketchpad was the table itself. For Geogebra, the participants had to create the table showing the change of the data using Spreadsheet themselves. Those who hadn't used Geogebra ever before or had less experience, had difficulty in drawing a table at Geogebra Spreadsheet window and eventually were not able to complete this task.

Table 7: Fulfillment of the Tasks in the First Study

	Geogebra						Geometer's Sketchpad					
Participants	T1	T2	T3	T4	T5	T6	T1	T2	T3	T4	T5	T6
1	✓	✓	✓	✓	✓	-	✓	✓	✓	✓	✓	✓
2	✓	✓	✓	✓	✓	✓	✓	✓	✓	✓	✓	✓
3	✓	✓	✓	✓	✓	✓	✓	✓	✓	✓	✓	✓
4	✓	✓	✓	✓	✓	✓	✓	✓	✓	✓	✓	✓
5	✓	✓	✓	✓	✓	-	✓	✓	✓	✓	✓	✓
6	✓	✓	✓	✓	✓	-	✓	✓	✓	✓	✓	✓

4.1.2.1 Eye Tracking Results

We obtained time to first fixation, total visit duration, mouse click count, and time to first mouse click records of the participants from the Tobii Studio software. We calculated the time to first fixation for each task for each software and analyzed the average time to first fixation. Then, we considered total visit duration time for each task. Next, we calculated mouse click counts for each task to compare both interfaces in terms of the average number of steps it took users to complete each task. Lastly, we calculated time to first mouse click for each task. To compare both interfaces in terms of these measures, we used paired-samples t-tests. Significant differences were observed only for the total visit duration and mouse click measures, which are further described below.

4.1.2.1.1 Total Visit Duration Results

Tables 8 and 9 show the distribution of total visit duration observed for each task on Geogebra and GSP interfaces respectively.

Table 8: Geogebra Total Visit Duration (In Seconds)

User	Task 1	Task 2	Task 3	Task 4	Task 5	Task 6
1	110,71	181,35	18,60	18,70	368,77	1536,86
2	200,56	137,60	24,37	13,47	96,10	624,82
3	42,50	41,59	26,46	3,63	77,63	330,86
4	101,73	136,65	38,49	59,06	531,89	482,56
5	201,41	484,21	20,85	83,66	61,40	264,40
6	36,86	137,76	25,80	8,62	91,58	840,07

Table 9: Geometer's Sketchpad Total Visit Duration (In Seconds)

User	Task 1	Task 2	Task 3	Task 4	Task 5	Task 6
1	159,31	127,33	65,78	52,81	176,96	178,36
2	300,59	14,54	37,21	34,76	59,28	163,64
3	100,54	72,78	34,29	99,65	62,91	207,44
4	158,60	231,22	106,35	23,25	46,33	158,83
5	257,97	91,12	42,06	62,89	46,80	116,81
6	146,01	45,25	42,94	26,55	40,51	129,71

Figure 16 below shows the bar chart corresponding to the total visit duration values summarized in Tables 8 and 9.

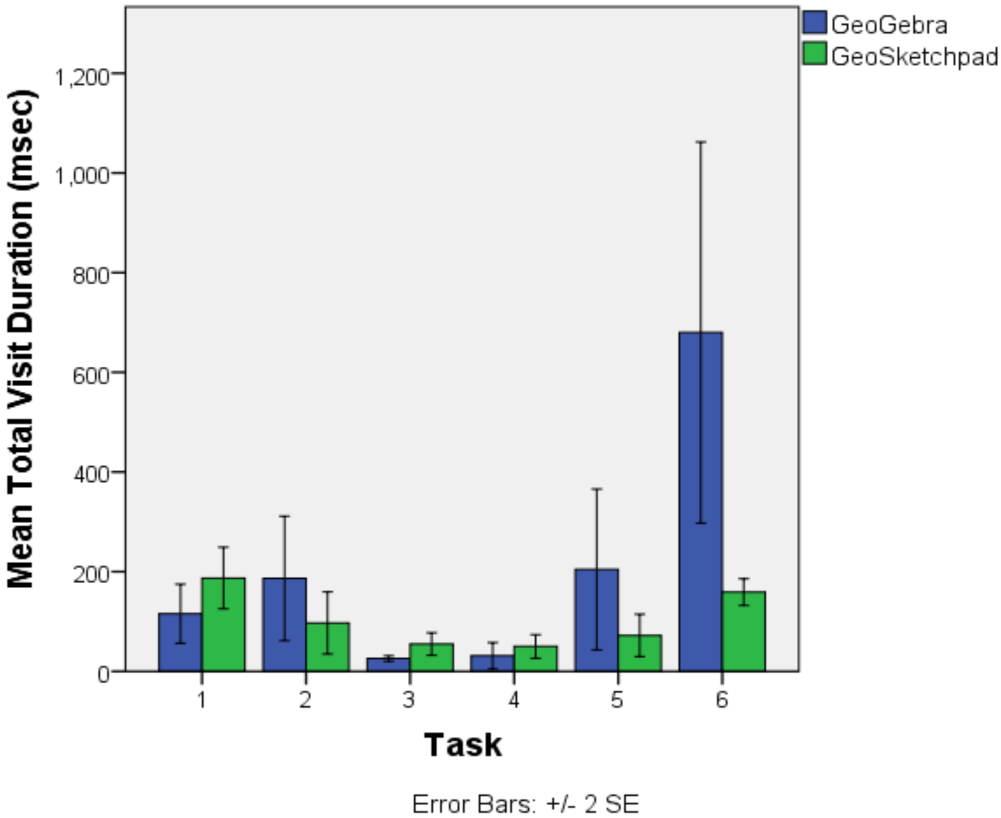


Figure 16: Distribution of mean total visit duration times of each task across both interfaces. The whiskers represent twice the standard error.

The total visit duration observed during each task for both interfaces was compared separately via paired-samples t-tests. Table 10 below summarizes the results of these pairwise comparisons.

Table 10: Results of paired differences

		Paired Differences							
					95% Conf. Interval of the Diff.				
		Mean	Std. Deviation	Std. Error Mean	Lower	Upper	t	df	Sig. (2-tailed)
Task 1	GeoGebra - GeoSketchpad	-71.54	25.98	10.61	-98.80	-44.28	-6.746	5	**.001**
Task 2	GeoGebra - GeoSketchpad	89.49	169.12	69.04	-87.99	266.97	1.296	5	.252
Task 3	GeoGebra - GeoSketchpad	-29.01	23.46	9.58	-53.63	-4.39	-3.029	5	**.029**
Task 4	GeoGebra - GeoSketchpad	-18.80	46.37	18.93	-67.46	29.87	-.993	5	.366
Task 5	GeoGebra - GeoSketchpad	132.43	185.33	75.66	-62.06	326.92	1.750	5	.140
Task 6	GeoGebra - GeoSketchpad	520.80	464.17	189.50	33.68	1007.91	2.748	5	**.040**

A significant difference in total visit duration was observed between the two interfaces for tasks 1, 3 and 6. In tasks 1 and 3, GeoGebra had a significantly shorter total visit duration time ($t(5) = -6.75$, $p<.01$ and $t(5) = -3.03$, $p<.05$ respectively). Geometer's Sketchpad had a significantly shorter visit duration in task 6 ($t(5) = 2.75$, $p<.05$). This results shows that Total visit duration in the task for Geometer's Sketchpad was longer than GeoGebra except task 6. The reason why task 6 took longer was due to the problems participants experienced while using the spreadsheets in Geogebra, which ultimately caused some participants fail to complete Task 6.

4.1.2.1.2 Mouse Click Count Result

The distribution of total mouse clicks are summarized in Tables 11 and 12 below for both interfaces.

Table 11: Geogebra Mouse Click Count

User	Task 1	Task 2	Task 3	Task 4	Task 5	Task 6
1	42,00	60,00	7,00	8,00	122,00	496,00
2	85,00	36,00	8,00	18,00	63,00	197,00
3	16,00	25,00	5,00	4,00	10,00	71,00
4	27,00	38,00	10,00	12,00	100,00	144,00
5	65,00	183,00	6,00	21,00	22,00	89,00
6	11,00	44,00	9,00	4,00	26,00	246,00

Table 12: Geometer's Sketchpad Mouse Click Count

User	Task 1	Task 2	Task 3	Task 4	Task 5	Task 6
1	100,00	69,00	15,00	17,00	40,00	74,00
2	162,00	20,00	23,00	12,00	17,00	84,00
3	53,00	44,00	8,00	14,00	29,00	60,00
4	85,00	161,00	39,00	9,00	26,00	59,00
5	153,00	58,00	12,00	25,00	11,00	61,00
6	86,00	30,00	26,00	13,00	22,00	69,00

Figure 17 below shows the bar chart corresponding to the total mouse click values summarized in Tables 11 and 12.

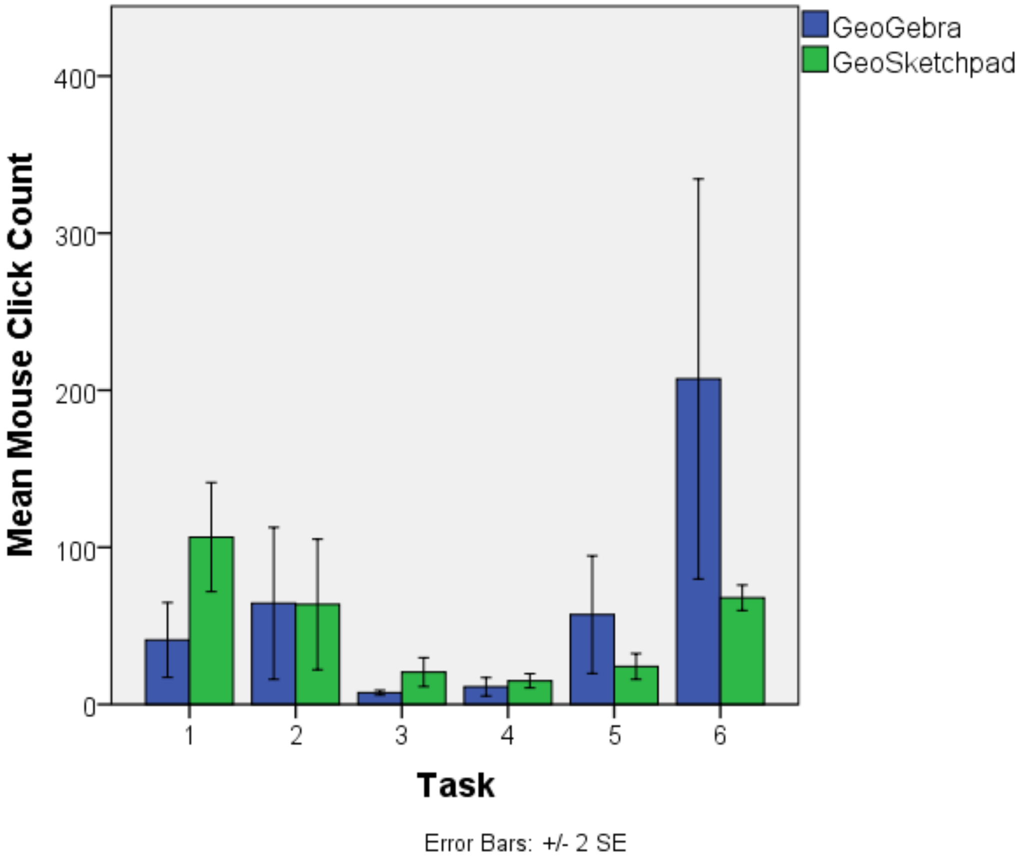


Figure 17: Distribution of mean mouse click counts of each task across both interfaces. The whiskers represent twice the standard error.

The mouse click counts observed during each task for both interfaces were compared separately via paired-samples t-tests. Table 13 below summarizes the results of these pairwise comparisons.

Table 13: The results of pairwise comparisons

		Paired Differences							
		Mean	Std. Deviation	Std. Error Mean	95% Conf. Int. of Difference Lower	Upper	t	df	Sig. (2-tailed)
Task 1	GeoGebra - GeoSketchpad	-65.50	18.19	7.42	-84.58	-46.42	-8.823	5	**.000**
Task 2	GeoGebra - GeoSketchpad	0.67	79.56	32.48	-82.82	84.15	.021	5	.984
Task 3	GeoGebra - GeoSketchpad	-13.00	9.49	3.87	-22.96	-3.04	-3.357	5	**.020**
Task 4	GeoGebra - GeoSketchpad	-3.83	6.85	2.80	-11.03	3.36	-1.370	5	.229
Task 5	GeoGebra - GeoSketchpad	33.00	40.69	16.61	-9.71	75.71	1.986	5	.104
Task 6	GeoGebra - GeoSketchpad	139.33	150.88	61.60	-19.01	297.68	2.262	5	.073

A significant difference between GeoGebra and Geometer's Sketchpad in terms of total mouse click counts was observed for tasks 1 and 3 only ($t(5) = -8.82$, $p<.01$ and $t(5)=-3.36$, $p<.05$ respectively). In both cases GeoGebra elicited smaller number of clicks as compared to Geometer's Sketchpad. This suggests that users performed smaller number of steps in GeoGebra as compared to GSP for these particular tasks.

4.1.2.2 SUS

The last analysis made according the SUS (System Usability Scale) System Usability Scale (SUS) a reliable, low-cost usability scale that can be used for global assessments of systems usability (Brooke, 1986). SUS involves 10 Likert-scale questions that address different aspects of user satisfaction.

4.1.2.2.1 Scoring SUS

After the experiments subjects were asked to evaluate the system by completing the SUS instrument. Tables 14 and 15 summarize the SUS scores obtained for both interfaces. The following steps were taken while processing raw SUS responses to each item:

- For odd items: subtract one from the user response.
- For even-numbered items: subtract the user responses from 5
- This scales all values from 0 to 4 (with four being the most positive response).
- Add up the converted responses for each user and multiply that total by 2.5. This converts the range of possible values from 0 to 100 instead of from 0 to 40.

Table 14: System Usability Scale for Geogebra

	1	2	3	4	5	Score
1- I think that I would like to use this system frequently.		✓✓	✓	✓	✓✓	**15**
2- I found the system unnecessarily complex.	✓✓	✓	✓	✓✓		**15**
3- I thought the system was easy to use.		✓	✓	✓✓✓	✓	**16**
4- I think that I would need the support of a technical person to be able to use this system.	✓	✓✓	✓	✓✓		**14**
5- I found the various functions in this system were well integrated.		✓✓	✓✓✓	✓		**11**
6- I thought there was too much inconsistency in this system.	✓	✓✓✓	✓	✓		**16**
7- I would imagine that most people would learn to use this system very quickly.		✓	✓✓✓	✓✓		**13**
8- I found the system very cumbersome to use.	✓	✓✓	✓		✓✓	**13**
9- I felt very confident using the system.		✓✓✓		✓✓✓		**12**
10- I needed to learn a lot of things before I could get going with this system.	✓	✓✓✓	✓	✓		**16**
Total						**140**
SUS Total	**140*2.5=**					**350**
SUS (Average)	**350/6**					**58,33**

Table 15: System Usability Scale for Geometer's Sketchpad

	1	2	3	4	5	Point
1- I think that I would like to use this system frequently.			✓✓	✓✓✓✓		**16**
2- I found the system unnecessarily complex.	✓✓	✓✓✓	✓			**19**
3- I thought the system was easy to use.			✓	✓✓✓	✓✓	**19**
4- I think that I would need the support of a technical person to be able to use this system.	✓✓	✓	✓	✓✓		**15**
5- I found the various functions in this system were well integrated.			✓✓	✓✓✓	✓	**17**

6- I thought there was too much inconsistency in this system.	✓	✓✓✓	✓✓			**17**
7- I would imagine that most people would learn to use this system very quickly.			✓✓✓	✓✓	✓	**16**
8- I found the system very cumbersome to use.	✓✓	✓✓✓	✓			**19**
9- I felt very confident using the system.		✓	✓	✓✓✓✓		**15**
10- I needed to learn a lot of things before I could get going with this system.	✓✓	✓✓✓	✓			**19**
Total						**172**
SUS Total	**172*2.5=**					**430**
SUS (Average)	**430/6=**					**71,66**

Tables 14 and 15 show that Geometers Sketchpad's SUS score (M=71.67, SD=12.21) was higher than Geogebra's SUS score (M=58.75, SD=19.09). However, a paired-samples t-test conducted over SUS scores did not find a significant difference between Geogebra and GSP, t (5) =-1.014, p>0.05.

4.1.2.3 Questionnaire Results

The other quantitative analyzed was conducted on the second questionnaire which included more fine grained questions about interface features. The paired-samples t-test was used to compare the ratings of each user. The test did not reveal a significant difference between Geogebra (M=6.1917, SD=1.81), and Sketchpad (M=7.22, SD=0.94), t (5) = -0.984, p>0.05.

To sum up, study 1 was conducted as a preliminary study to develop insights regarding usability issues common to dynamic geometry environments. The results suggest that there were no major differences between Geogebra and GSP in terms of the usability of the features they provide for constructing basic dynamic mathematical objects. However, participants ran into issues when they were attempting some of the tasks (as evidenced in performance measures), and their responses to questionnaires indicate a moderate level of user satisfaction. Even though the performance evaluation is based on a small sample of 6 users each attempting 6 tasks over both interfaces, the findings highlight the need for further refinements and improvements to support the construction of dynamic representations. Touchscreens may help resolve some of the issues involved with mouse controlled drawing actions, since they offer a more naturalistic drawing interface with potentially higher level of precision. In the next studies we tried to test to what extent touchscreen support can help users develop dynamic geometric constructions in a more effective way.

4.2 Study 2

4.2.1 Subject's Demographics

4.2.1.1 Age

The average age of participants is 27 years (range between 22-37). 5 of them were at 22 years old. Two of them were at 23 years old, two of them were at 25 years old, one of them was 27 years old, one of them was 29 years old, and one of them was at 37 years old.

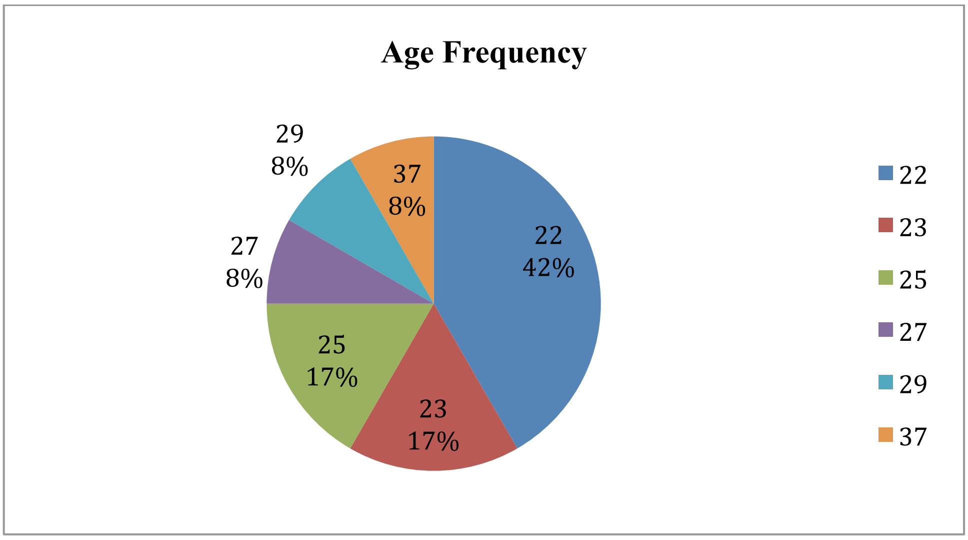


Figure 18: Age frequency distribution of second study

4.2.1.2 Sex

Majority of the participants were male (7 participants, 58, 3%) and minority were female (5 participants, 41, 7%).

4.2.1.3 Educational Level

Education level of the participants varies between university (B.S. students) and doctoral (PhD. students). Majority of the participants were Bachelor of Science (B.S.) student (8 participants 67 % respectively) and 3 participants (33%) were Master of Science (M.Sc.) students and 1 of them was doctoral (Ph.D.) student.

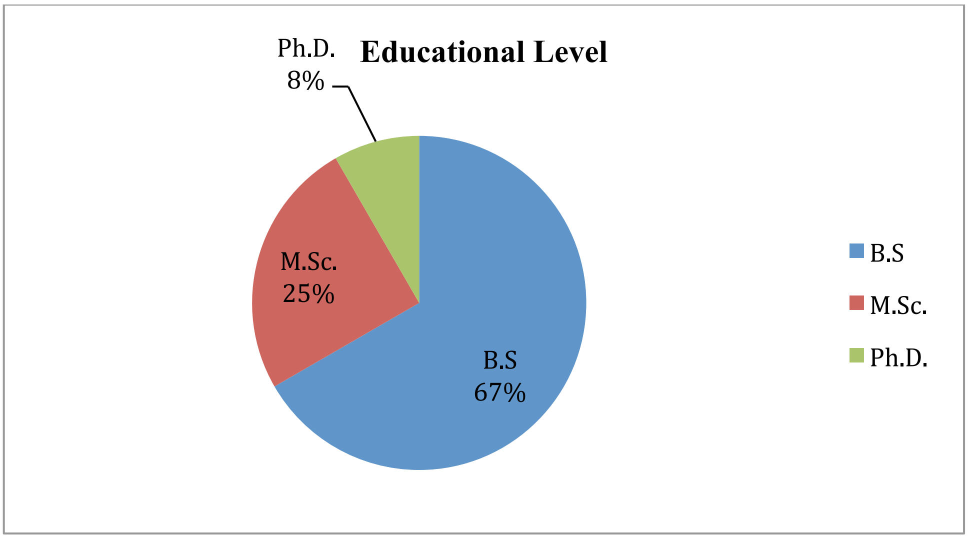


Figure 19: Educational Level of Second Study

4.2.1.4 Department

Subjects from several different specialty areas in field participated. There were 7 participants with Basic Sciences background such as Math, Statistic. There were 3 participants enrolled in a degree program in Engineering Sciences. There was a single participant with an Educational Sciences background and one of them was from a medical informatics major.

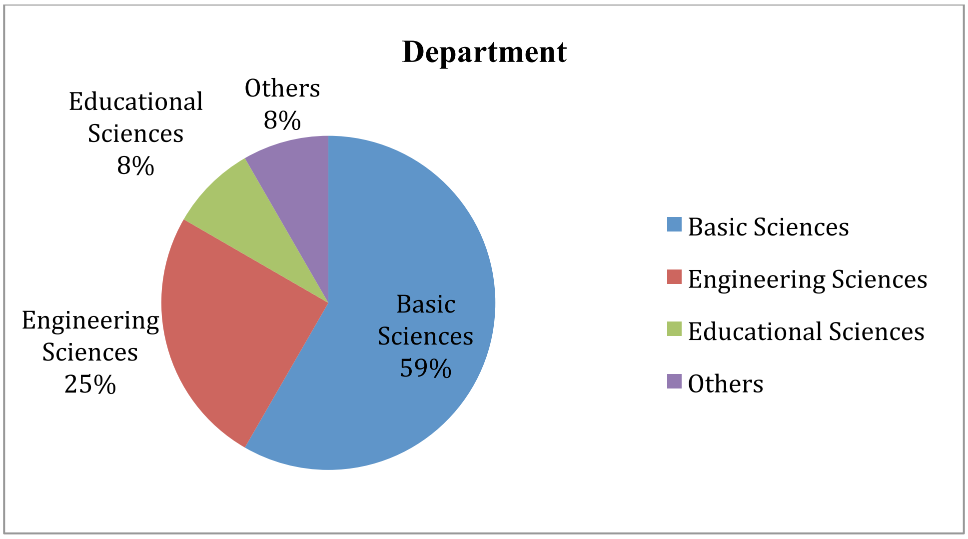


Figure 20: Departments of Participants in the Second Study

4.2.1.5 Computer Skills

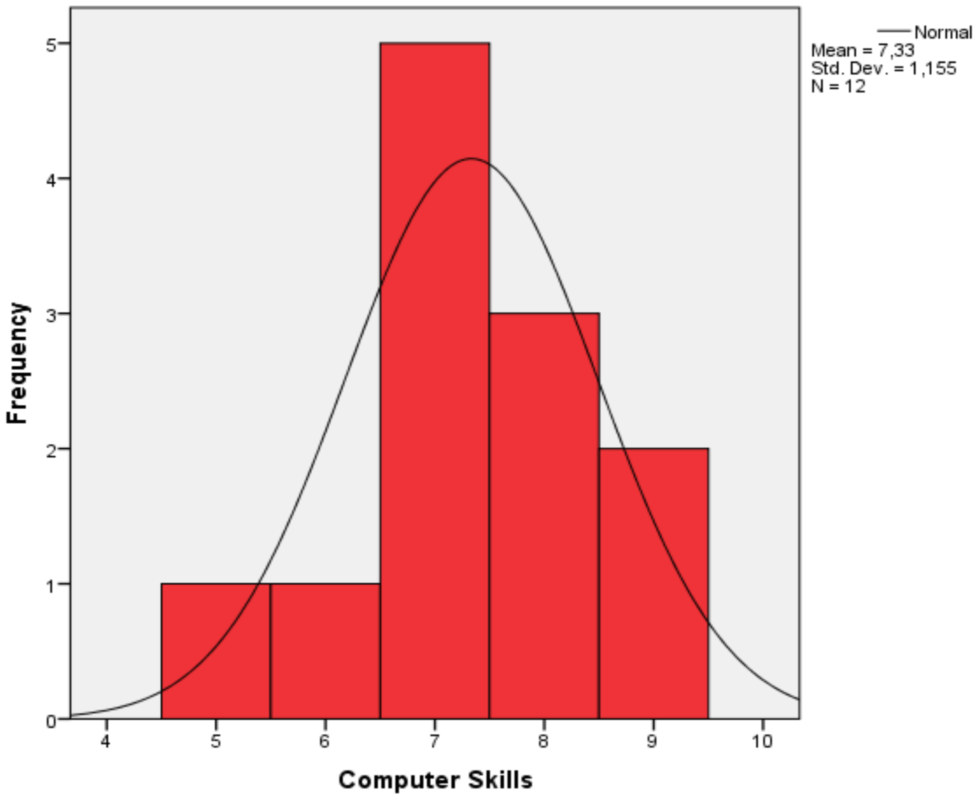


Figure 21: Computers Skills of Second Study

In this part of questionnaire, participants rated their computer skills between 1- 9. The average of participants' Computer Skills was 7. Five of them rated their skills with 7 (41, 7%). Three participants rated their computer skills with 8 (25%). Two of them rated their computer skills with 9 (16, 7). One participant rated his/her computer skills with 5 (16, 6%) and one of them rated his/her skills with 6 (8, 3%).

4.2.1.6 Math Skills

In this part of questionnaire, participants rated their basic math skills between 1- 9. The average of participants with basic Math Skills approximately was 8. Five of them rated their skills with 8 (41, 7%). Five of them participants rated his/her math skills with 9 (41, 7 %). One of them rated his/her math skills with 6 (8, 3). One of them rated his/her skills with 7 (8, 3%).

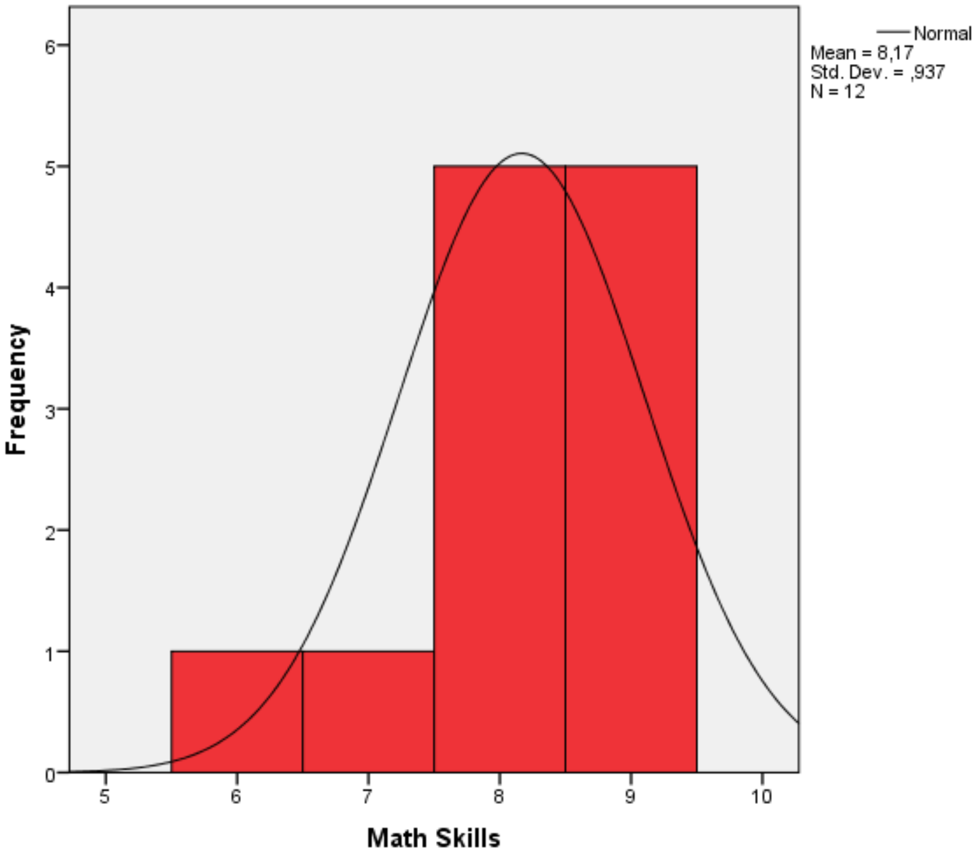


Figure 22: Math Skills of Second Study

4.2.1.7 Geogebra Experience

In this study nobody has GeoGebra experience. This study was the first meeting with Geogebra for participations.

4.2.2 Quantitative Results

In this study, ten tasks were given to participants. They did five tasks by using Mouse, and five tasks by using Touchpad Pen. We divided participants into two groups as A and B. Group A used the Mouse first then used the Touchpad Pen. On the other hand, group B used the Touchpad Pen first, and then the Mouse. First we looked the fulfillment of the Tasks.

Table 16: Fulfillment of the Tasks in Study 2

	Pair 1	Pair 2	Pair 3	Pair 4	Pair 5	Pair 6
Task 1	✓	✓	✓	✓	✓	✓
Task 2	✓	✓	✓	✓	✓	✓
Task 3	✓	✓	✓	✓	✓	✓
Task 4	✓	✓	✓	✓	✓	✓
Task 5	✓	-	✓	✓	✓	✓
Task 6	✓	✓	✓	✓	✓	✓
Task 7	-	✓	-	✓	-	✓
Task 8	✓	✓	-	✓	✓	✓
Task 9	✓	✓	-	✓	✓	✓
Task 10	✓	✓	✓	-	✓	✓

All participants attempted all the tasks, but only one pair could complete all 10 tasks. Half of the teams couldn't finish task 7, who were all in the A group where they attempted task 7 by using the Touchpad Pen. On average participants spent approximately 8 minutes 40 second in this question. Only pair 2 failed to complete Task 5, where they were using the Touchpad Pen. Similarly, Pair 3 was the only group who did not complete task 8 and task 9 because they got bored of using the Touchpad Pen. There is only one task that could not be completed by using the Mouse. Figure 23 below shows the distribution of completed and not completed tasks across both interface conditions. A chi square test conducted on this distribution indicated that there were significantly more incomplete tasks in the touchpad condition than the mouse condition, χ^2 (1) =4.043, $p<0.05$.

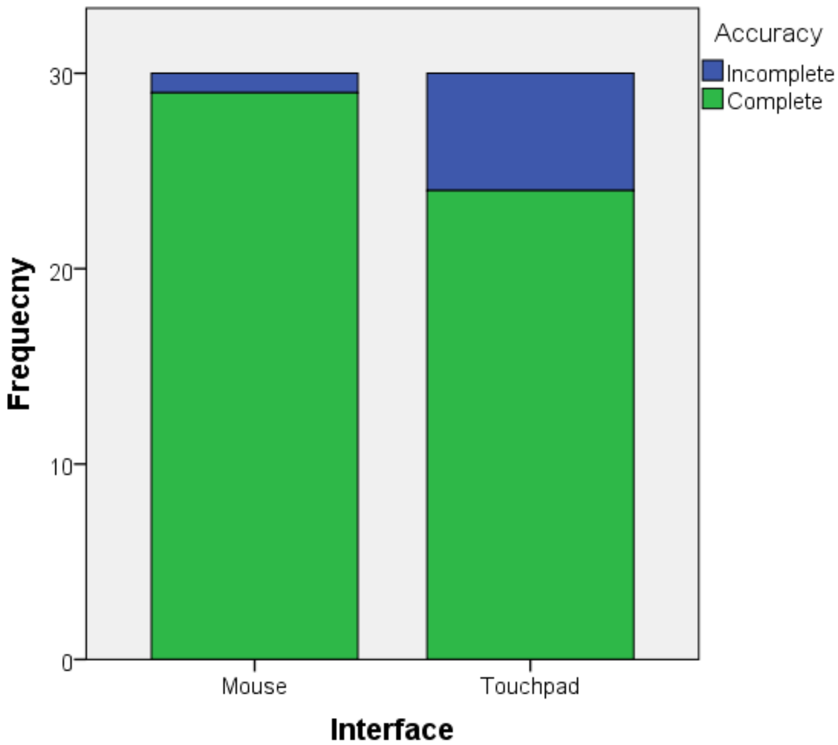


Figure 23: The distribution of completed and not completed tasks across mouse and touchpad conditions

Table 17 below summarizes the task completion times observed during the second study.

Table 17: Time spent on tasks (in seconds)

	Pair1	**Pair2**	**Pair3**	**Pair4**	**Pair5**	**Pair6**
Task 1	260	135	370	755	213	187
	Mouse	Touchpad Pen	Mouse	Touchpad Pen	Mouse	Touchpad Pen
Task 2	14	355	360	140	290	73
	Mouse	Touchpad Pen	Mouse	Touchpad Pen	Mouse	Touchpad Pen
Task 3	247	238	224	62	460	229
	Mouse	Touchpad Pen	Mouse	Touchpad Pen	Mouse	Touchpad Pen
Task 4	790	660	703	297	400	730
	Mouse	Touchpad Pen	Mouse	Touchpad Pen	Mouse	Touchpad Pen
Task 5	199	630	166	38	287	160
	Mouse	Touchpad Pen	Mouse	Touchpad Pen	Mouse	Touchpad Pen
Task 6	209	85	356	136	176	97
	Touchpad Pen	Mouse	Touchpad Pen	Mouse	Touchpad Pen	Mouse
Task 7	500	718	692	332	620	179
	Touchpad Pen	Mouse	Touchpad Pen	Mouse	Touchpad Pen	Mouse
Task 8	335	115	110	234	480	352
	Touchpad Pen	Mouse	Touchpad Pen	Mouse	Touchpad Pen	Mouse
Task 9	255	109	266	183	175	150
	Touchpad Pen	Mouse	Touchpad Pen	Mouse	Touchpad Pen	Mouse
Task 10	204	191	310	530	425	137
	Touchpad Pen	Mouse	Touchpad Pen	Mouse	Touchpad Pen	Mouse

Figure 24 below shows the distribution of task completion times across tasks and interfaces for the successfully completed tasks. In tasks 3, 4, and 5 pairs who attempted the problem with the touchpad took less time than the pairs who were using the mouse. Moreover, in tasks 1,6,8,9 and 10 the pairs using the mouse took less time as compared to the touchpad group. However, a two-way ANOVA on task completion time where the interface and task are treated as independent variables, did not find a significant difference between interface types, $F(1,34) = 0.388$, $p>.05$. The interaction was not significant either, $F(8, 34) = 0.748$, $p>0.05$. There was a significant effect of task type, $F(9, 34) = 3.98$, $p<0.01$, which indicates that some of the tasks took significantly more time to complete

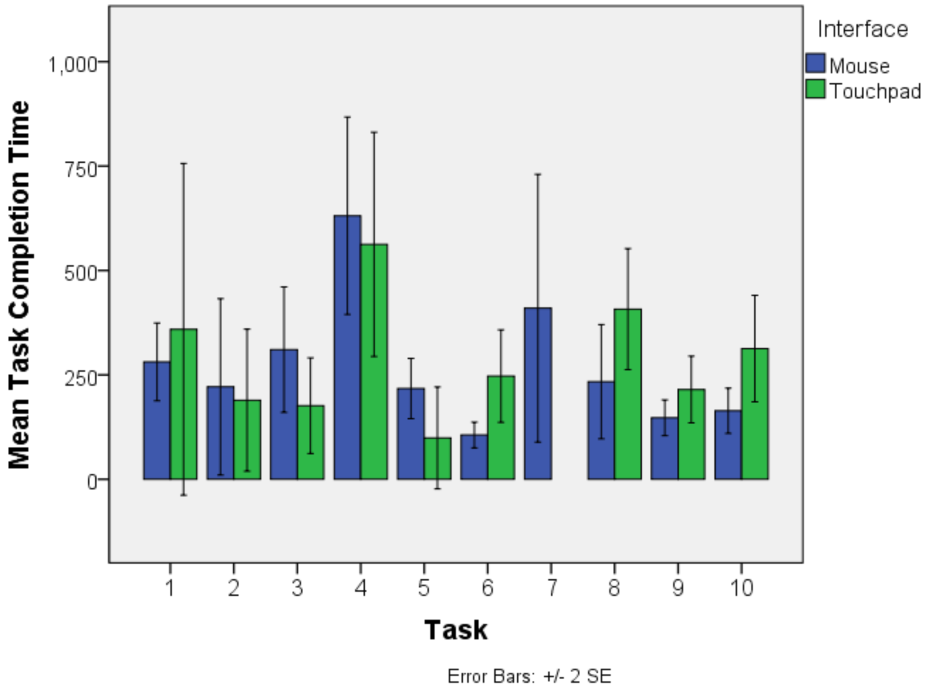


Figure 24: Average task completion times for completed tasks. Since none of the pairs could complete task 7 by using the touchpad interface, no data is presented.

The order in which participants get familiarized with the environment could be another factor on the distribution of task completion times. Figure 25 shows the distribution of task completion times detected for each task. A two-way ANOVA on the task completion time with order and interface type as independent variables did not find a significant order effect, $F(1,56) = 1.389$, $p>0.05$, so the order in which each interface type was introduced to the partners did not seem to effect the distribution of response times.

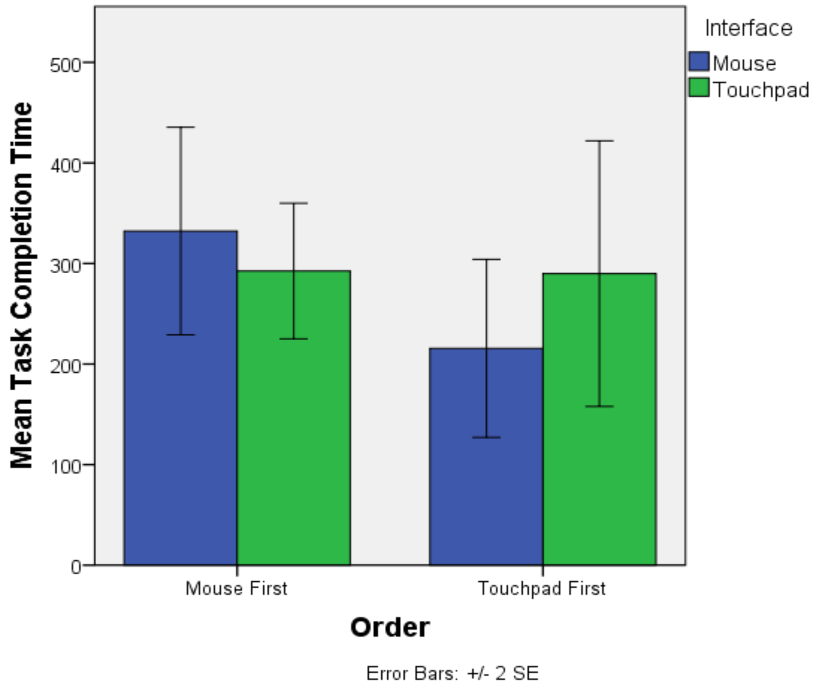


Figure 25: Based on input device order, task completion time.

4.2.2.1 Breakdown Analysis

In order to empirically test the CA method, we videotaped six pairs as they used dynamic geometry software called Geogebra. We used a dialogue-based approach to observe the breakdown in users' dialogues and map the mismatches between users' action and software behavior. With this perspective, we investigated the usefulness of Geogebra. Totally we observed 204 breakdowns in users' dialogues. 71 of them occurred when users used Mouse to interact with the program, 133 of them occurred with Touchpad pen. We categorized the breakdowns according to reasons. Except lack of mathematical knowledge and communication gap, mostly breakdowns occurred because of software behaviors.

4.2.2.1.1 Mouse/Touchpad Pen

The participants faced 204 breakdowns in total. 71 of them occurred while they were using the Mouse, whereas 133 of them occurred while they were using the Touchpad Pen. We divided users into two groups. The first group that was called A used the Mouse interface for the first 5 questions and then they used the Touchpad Pen for the last 5 questions. The second group that was called B used the Touchpad Mouse in the first five questions, then for the last 5 questions they used the Mouse. Table 18 shows the distribution of breakdowns detected during each task performed by the 6 pairs.

Table 18: Question Groups

		1.Group Questions						2.Group Questions						
	Pairs	Q 1	Q 2	Q 3	Q 4	Q 5	Total	Q 6	Q 7	Q 8	Q 9	Q10	Total	Total
A	Pair 1	4	0	0	3	2	9	4	9	4	4	1	22	31
	Pair 3	5	5	3	4	2	19	1	10	1	0	3	15	34
	Pair 5	2	5	8	3	3	21	3	26	8	1	4	42	63
	Total	11	10	11	10	7	49	8	45	13	5	8	79	128
B	Pair 2	1	5	0	7	7	20	0	3	0	0	1	4	24
	Pair 4	14	2	1	1	0	18	2	4	4	0	5	15	33
	Pair 6	4	0	3	7	2	16	1	0	2	0	0	3	19
	Total	19	7	4	15	9	54	3	7	6	0	6	22	76
A+B	Total	30	17	15	25	16	103	11	52	19	5	14	101	204

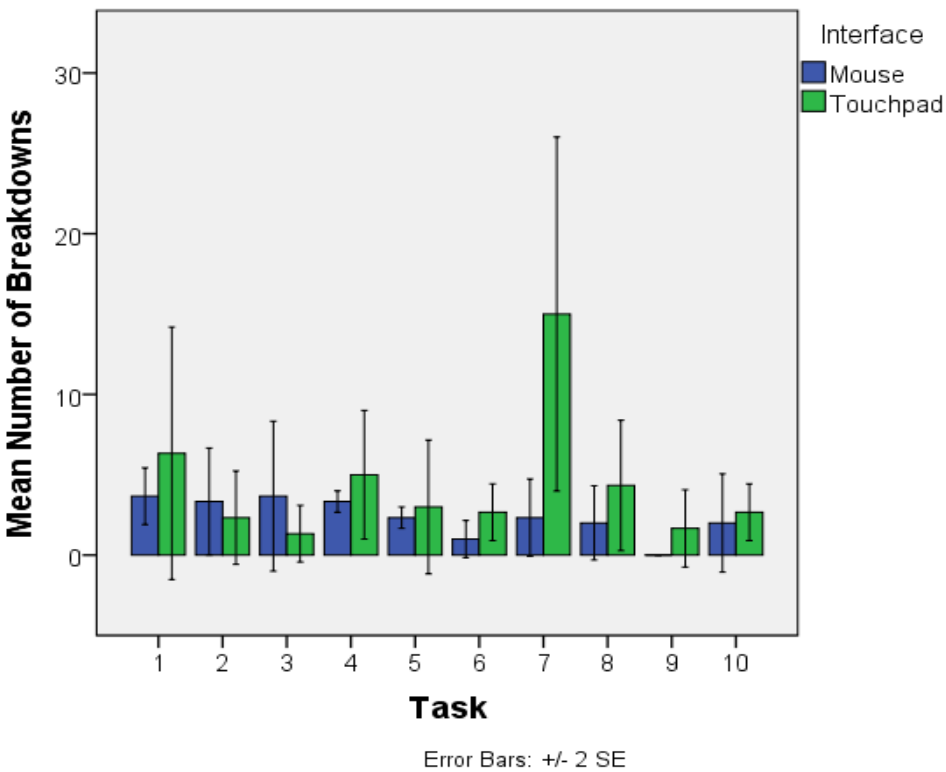


Figure 26: The distribution of breakdowns detected for each task

Figure 26 shows the distribution of breakdowns detected for each task. Except tasks 2 and 3, the mean number of breakdowns observed during each task was smaller in the case of mouse interface as compared to the touchpad interface. A two-way ANOVA on number of breakdowns revealed that significantly higher number of breakdowns occurred in the touchpad condition, $F(1, 40) = 5.422$, $p<0.05$. Tasks also significantly differed from each other in terms of the number of breakdowns observed, $F(9, 40) = 2.414$, $p<0.05$. In particular, Task 7 stood out among other tasks with the highest number of breakdowns. The interaction was not significant, $F(9, 40) = 2.059$, $p>0.05$, suggesting that the pattern of relationship is similar across tasks, where touchpad brings on average higher number of breakdowns across all tasks.

The order in which participants get familiarized with the environment could be another factor on the distribution of breakdowns. The Figure 26 compares the distribution of breakdowns for the groups who started with the mouse interface first with the groups who started with the touch pad interface. A two-way ANOVA on the number of breakdowns with order and interface type as independent variables did not find a significant order effect, $F(1,56) = 2.794$, $p>0.05$, so the order in which each interface type was introduced to the partners did not seem to effect the distribution of breakdowns. On average more breakdowns occurred in the touch pad case. This suggests that providing touch screen features without taking adequate advantage of their unique features may not automatically translate into gains in usability.

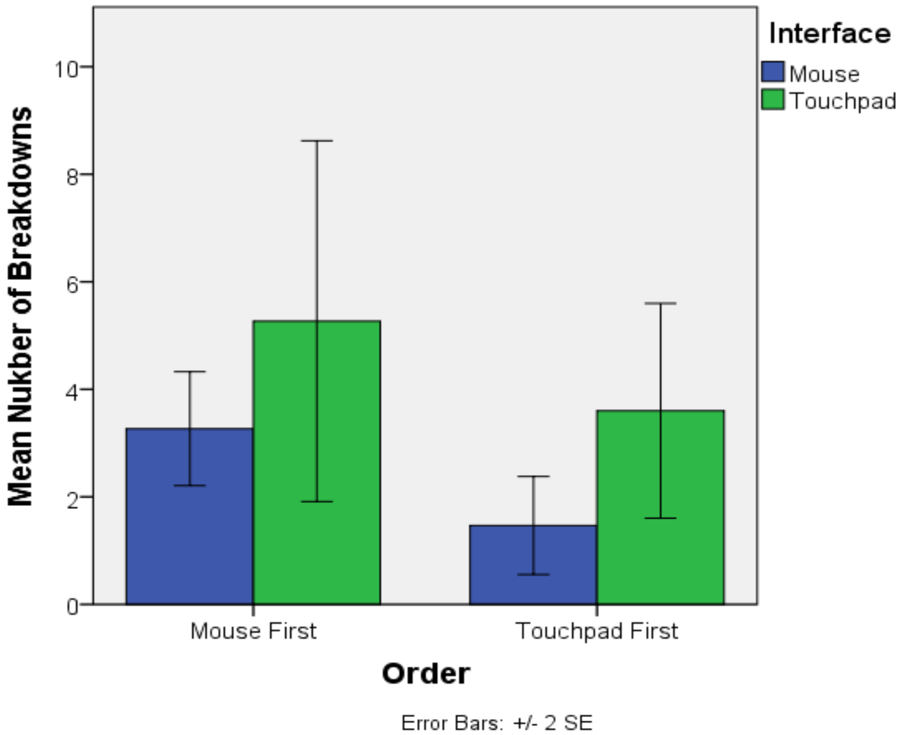


Figure 27: Based on input device order, number of breakdowns

The following tables provide more details about the distribution of different types of breakdowns associated with key GeoGebra functions. The types of breakdowns are labeled based on the specific feature that the pairs attempted to use as part of their collaborative problem solving session. Each breakdown type will be further illustrated over excerpts following the tables.

Table 19: Breakdowns with Mouse

BREAKDOWN TYPE	Device	1.Exp	3.Exp	5.Exp	2.Exp	4.Exp	6.Exp	Total
Confusing	Mouse	1						**1**
Move	**Mouse**	**3**				**1**		**4**
Create a circle	**Mouse**	**1**	**3**	**1**				**5**
Angle	**Mouse**	**1**	**5**	**5**	**1**	**3**	**2**	**17**
Math Error	Mouse	1			1	2		**4**
Algebra Window	Mouse		1	1				**2**
Segment	Mouse	2	2					**4**
Line	**Mouse**		**2**					**2**
Parallel Line	**Mouse**			**1**				**1**
Perpendicular Line	**Mouse**			**1**				**1**
Polygon	**Mouse**		**1**	**1**		**1**		**3**
Carelessness	Mouse		1	1		1		**3**
Delete/Erasing	Mouse		1	1	1			**3**
Selecting	Mouse		1					**1**
Tangent	**Mouse**			**4**				**4**
Bad experience	Mouse			1				**1**
Perpendicular Bicestor	**Mouse**					**2**		**2**
Communication	Mouse					2		**2**
Length	Mouse			2	1			**3**
Click	Mouse					2		**2**
Point	Mouse			1				**1**
Control	**Mouse**		**3**			**1**	**1**	**5**
Total		**9**	**20**	**20**	4	15	3	**71**

Table 20: Breakdowns with Touchpad-Pen

BREAKDOWN TYPE	Device	1.Exp	3.Exp	5.Exp	2.Exp	4.Exp	6.Exp	Total
Segment	Pen	2	1	1	1	1	1	**7**
Pen Click	**Pen**	**4**	**1**	**4**		**3**	**2**	**14**
Angle	**Pen**	**1**	**3**	**10**	**4**		**2**	**20**
Polygon	Pen							**0**
Tangent	**Pen**	**3**		**1**	**1**		**1**	**6**
Point	Pen	2		1			2	**5**
Right Click	Pen						1	**1**
Communication	Pen	2		2				**4**
Delete/Erasing	Pen	1						**1**
Line	**Pen**				**1**			**1**

Parallel Line	**Pen**	**2**	**1**	**1**		**1**		**5**
Perpendicular Line	**Pen**			**5**	**1**	**4**	**1**	**11**
Move	**Pen**	**2**	**1**	**5**	**5**	**3**	**1**	**17**
Carelessness	Pen	1	1	2	2	1	1	**8**
Circle	**Pen**	**1**			**3**		**1**	**5**
Orientation	Pen					1		**1**
Graphics Window	Pen			2				**2**
Perpendicular Bicestor	Pen			1				**1**
Selecting	Pen		1	1				**2**
Using Pen	Pen		1					**1**
Math Error	Pen			2				**2**
Segment with Given Length	Pen			1		1		**2**
Algebra Window	Pen				1	1		**2**
Input Window	Pen			1	1	1		**3**
Pen Control	**Pen**		**2**	**2**			**3**	**7**
Invalid Value	Pen		2					**2**
Not knowing limits of program	Pen		1					**1**
Shifting	Pen	1						**1**
Environment	Pen					1		
Total	Pen	**22**	**15**	**42**	**20**	**18**	**16**	**133**

4.2.3 Interaction Analysis Results

4.2.3.1 Drawing Line Tool

The first major problem that was observed 47 times came out when user tried to create a line. 3 of them occurred when drawing a line, 8 of them were about tangents and 12 of them were while using the Perpendicular Line Tool, 6 of them were encountered while using the Parallel Line Tool. 3 of them were about the Perpendicular Bicestor Tool. 12 of them were about Segment with Tool, 2 of them were about Segment with Given Length from Point Tool.

4.2.3.1.1 Perpendicular Line

Example 1:

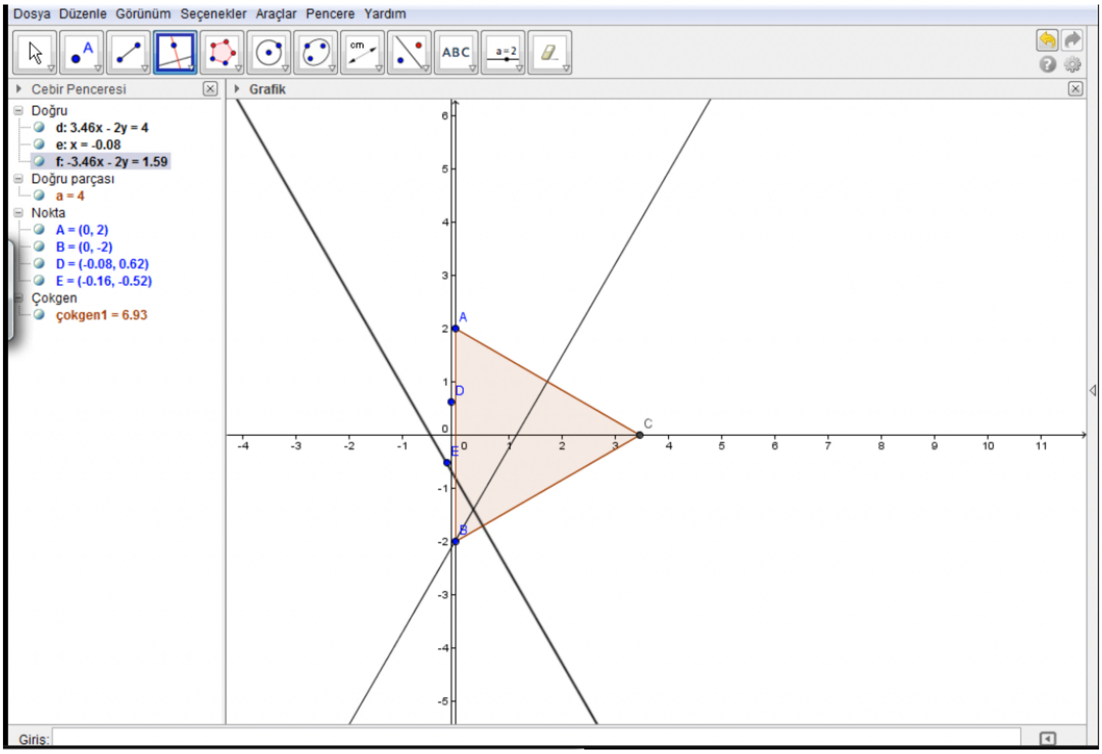


Figure B 1: Perpendicular Line Breakdown

1. A: Ohhhh there is a perpendicular line!!! . (Haaah, dik doğru var.)
2. B: Now from here click to A. Now do the same thing for the others. (Ordan, A ya tıkla şimdi. Tamam diğerlerine de koy.)
3. A: Do we know this a perpendicular line? (Bunun dik olduğunu biliyormuyuz?)
4. B: It is a perpendicular line. Also if you wish we can check for the perpendicular angel. Now do it for the other three. (Draws a perpendicular line on the screen) dik doğru. İstersen dik açıyada bakarızda. Diğer üçünede koy. (Eliyle dik doğru çiziyor)
5. A: Isn't there another one? (Diğeri yok mu ya.).
6. B: Click on that click on the Line thing, on the AC straight. (Pupil A erases all the information on screen and hand the pen over to Pupil B) (08:36)).
7. A: Here. (Al.)
8. A: If we drew a tangential circle to this (Points to the triangle on screen) wouldn't it be with its thing??? (Buna teğet geçen bir çember çizsek (Ekrandaki üçgeni gösteriyor) onun şeyiyle olmazmı acaba?
9. B: Maybe?????? (Belki olur)
10. A: There are three dotted circles (points to the on screen for this), they will pass through a tangent but we can't find it. (Points to the screen)(Üç noktadan geçen çember var (Ekranda bu aracı gösteriyor), teğet olacak noktalar ama bulamayız. (Ekranı işaret ediyor))
11. B: How about here. (Tries to draw a perpendicular line)(Ya şurdan. (Dik doğru çizmeye çalışıyor)
12. **A: Don't you realize it's not happening!! (Olmuyor farkında mısın)**
13. Reseacher: There are Perpendicular Bicestor and etc. (kenarortay falan var.)
14. A: Don't help us with this experiment. The bisector is already with the median equilateral triangle. Draw one already. (Sen yardım etme bu deney. Açıortay zaten kenarortay eşkenar üçgende. Çiz zaten bir tanesi şey)
15. B: **It always draws to the same place. We only couldn't find one that draws angel A. (Hep aynı yere çiziyor zaten ya. Bir tek A köşesini çizeni bulamadık haa.)**

16. A: Done!!!! (Haaah olduuu.)
17. B: Pfffff. (haaah olduuu.)
18. A: Now we didn't draw C. (Points to the screen) (şimdi C dekini çizmedik. (Ekranı işaret ediyor))
19. B: It's already on axis. (O eksende.)

In this task participants tried to draw three perpendicular lines. They easily drew two perpendiculars, but in the last one, they experienced a breakdown. In line 12, they noticed that they could not draw it. In Line 15, they tried again but they could not. When they tried to draw, the program put points not a line. As can be seen in the figure above, they draw a perpendicular line, which did not pass through the corner A of the equilateral triangle. To overcome this breakdown they deleted all the objects on the screen and drew again. After they tried a few times, they could draw the last perpendicular line. In this example, this breakdown was not that significant. However, some participants who had similar breakdowns gave up using this tool. Designers should pay a lot of importance to this tool. They should change the usage of this tool. For instance, when they first click a point and then second click is an edge, the perpendicular tool should draw the line, not put a new point.

4.2.3.1.2 Segment Breakdown

Example 2:

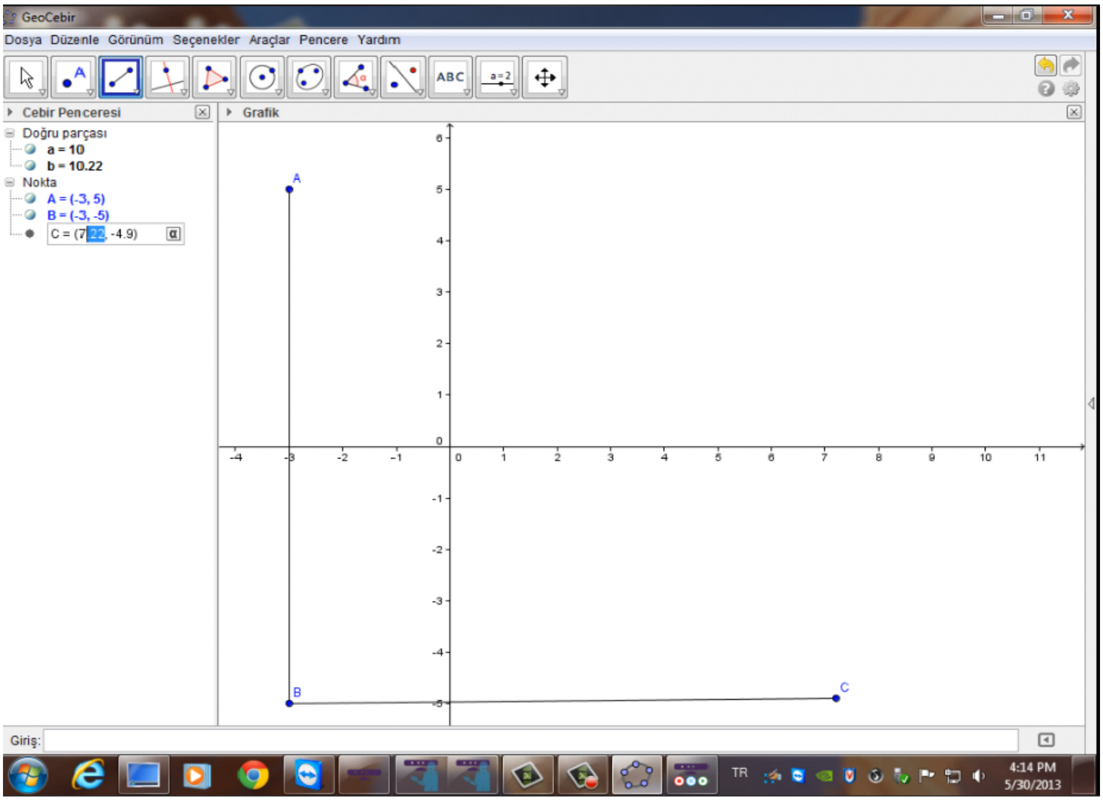


Figure B 2: Segment Breakdown

1. A: If we could form a square and show that its angel is 90 degrees? (Kare, doğrularla oluşturup aradaki açının 90 derece olduğunu gösterebilirsek)
2. B: A straight that passes from two points? (2 noktadan geçen doğru mu?)
3. A: Something like that (öyle birşey oluyor)
4. B: A straight line passing from two points. What is this a straight passing from two points (2 noktadan geçen doğru parçası. neymiş bu iki noktadan geçen doğru parçası)

5. A: Yeah for example draw from there (Points by hand). 2 by 2(hıı, ordan mesala çiz (Ekranı eliyle işaret ediyor). 2 ye 2 lik)
6. B: Ok let one point be like this. (Tamam bir nokta böyle olsun.)
7. A: Come till 3. (3 e kadar gel.)
8. B: Are we on 5? (Kaçtayız 5 miyiz?)
9. A: Not exactly 5(5 tam değil)
10. B: Exact 5 let it be exact 5(5 tam 5 olsun). .
11. A: OK. (Hı hı)
12. B: Let's take this from here to here also (bunu burdan da alalım).
13. A: From 5 till 5. Come on draw it."(5 ten 5 e. Hadi çiz.")
14. B: How many units from here 10 units? (Burdan kaç birim 10 birim mi?)
15. A: 5 again. 10 units come to 8. (Yine 5 e. 10 birim 8 e geliyor)
16. B: 7
17. **A: 8, ummm, 7. Ohhh see that isn't exactly 10. (Points to the screen with his hand). The angle didn't become 90. See it came there. (Points to the screen with his hand)(A: 8, ıı, 7. Haa tam 10 olmadı bak. (Eliyle ekranı işaret ediyor). Açı 90 olmadı. Bak şu noktaya geldi ya. (Eliyle ekrandaki noktayı işaret ediyor).**
18. B: Which point? (Hangi nokta)
19. A: Look it creates points for you such as A, B points, (shows points A and B with his hand) here is 7,23(shows the algebra window)(bak noktalar belirliyor sana A, B noktası, (A ve B noktasını eliyle gösteriyor) burası 7,23(cebir penceresini gösteriyor)
20. B: Don't we correct it from here (Mentioning the algebra window) şurdan düzeltemiyormuyuz (Cebir penceresinden bahsediyor)
21. A: Here (Show with his hand the screens drawing space)(şurdan (Eliyle ekran çizim alnını gösteriyor)
22. B: Ohhh here it is (Corrects the co-ordinates at drawing screen)(tamam burda varmış (çizim pencersinden noktanın koordinatlarını düzenliyor)
23. A: 7, 10 units (7, 10 birim olucak)

The participants had 16 breakdowns while drawing a line. In this example, the task was drawing a square. To this aim, firstly, they tried to draw a straight line whose length was 10, through point A and point B. But they could not do it easily. There is a breakdown in Line 17. They recognized that the angle was not 90 degrees and the line length was not 10. They wanted to stop at 7 point; however, the line stopped at 7.23 point. They overcame this type of breakdown in lines 20, 21, 22. When they noticed that they have drawn a line which they did not want, they tried to correct line's length using Algebra View.

4.2.3.1.3 Tangent

Example 3:

The users had tangents breakdown 8 times.

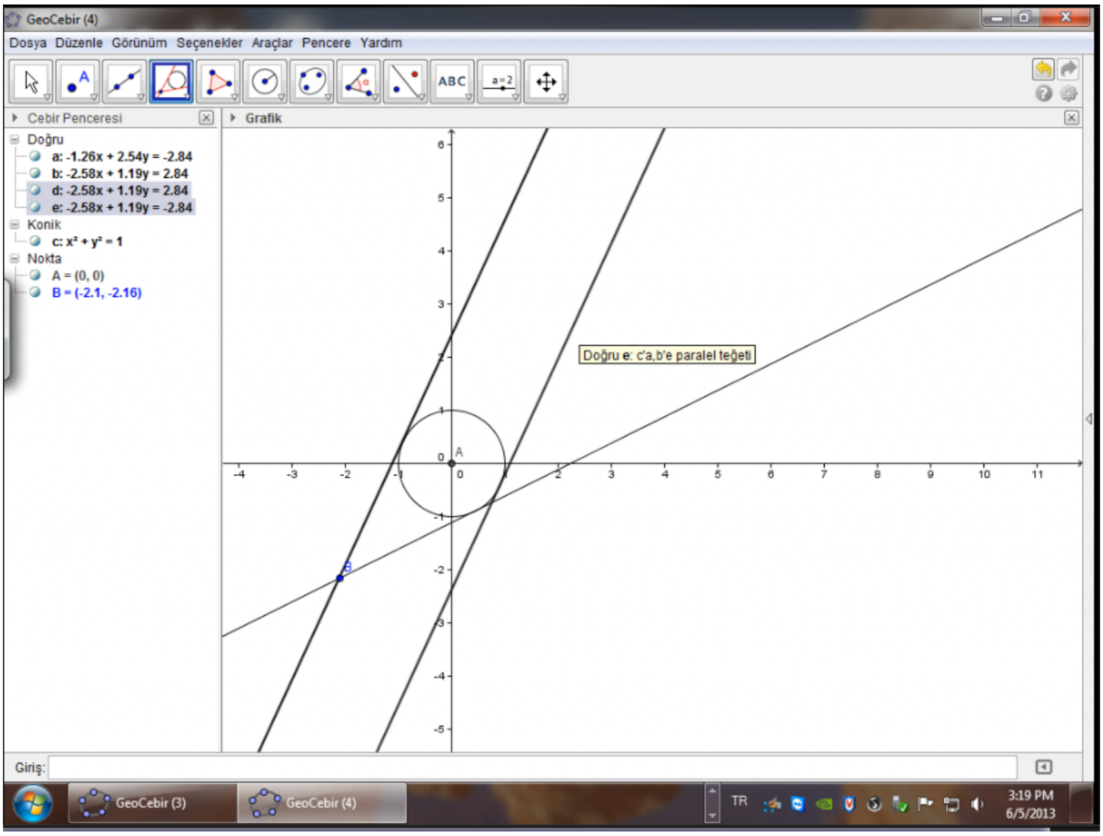


Figure B 3: Tangent Breakdowns

1. B: Ok then I will do it like this? A circle with a center given point right? (Tamam, o zaman şöyle geliyorum demi? Merkezle bir noktadan geçen çember değil mi?)
2. A: Yes. (Evet)
3. B: Lets also call the radius 1(şöyle diyim, yarıçapına da bir diyelim)
4. A: One it is. (Bir diyelim.)
5. B: Ok we drew this now let select another point. (Tamam bunu çizdik ondan sonra şurdan bir nokta seçiyim.)
6. A: We can select three points on the circle. (Çember üzerinde üçtane nokta seçeriz.)
7. B: There I selected a point from the circle. Let me select another one from here (Şöyle Bir tane nokta seçtim burdan. Bir tanesi şöyle bir yerde seçeyim)
8. A: Ok (tamam)
9. B: I will pick another one from here. And draw a perpendicular line passing from all these points. Right so later these two points will pass by from these two or perhaps I should draw a tangent line? A point passing by from that tangent? (Bir tanesini de şöyle bir yerde seçeyim. Bu üç noktadan geçen doğru çizeyim. Değil mi ondan sonra bu doğrular, iki noktadan geçer hani direk teğet çizeyim demi? O noktadan geçen çembere bir teğet)
10. A: OK (olur)
11. B: Where was our tangent? (Nerdeydi teğetimiz)
12. A: How about we try to create a polygon again. But directly from the tangent. (Şey yapsak düzgün çokgen işine girsek yine. Ama tamam teğetten gidelim)

13. B: **It won’t matter but I didn’t draw a tangent now. I just said (fark etmez o da olur ama şey yapamadım, teğet çizdiremedim şu anda. Teğet dedim.)**
14. A: Ohhh it wants an external point as it points out here (haa dış noktadan istiyor, burda zaten kopya vermiş.).
15. B: Ok only one (tamam, bir tanesini)
16. A: 1,2,3,4. There are four and one of them is on the triangle (1, 2, 3, and 4. Dört tane var bunlardan bir tanesi üçgenin üzerinde)
17. "B: Yes other ones are outside of it. (Evet, diğerleri dışta.)
18. A: Others out of it. (Diğerleri dışta.)
19. B: Let me pick one from here ok? (Bir tane şurdan şeçeyim olur mu?)
20. A: Ok (Tamam)
21. **B: but let’s do it like this, this doesn’t seem right. As it passes from here, CTRL+Z, like this, how about I pick it from somewhere here. Can’t I draw a straight directly passing from the tangent??(Ama burdan şunu şöyle yapalım, bu olmadı sanki bak. Şurda seçip, CTRL+Z, şöyle geçicek ya, demi şöyle geçicekya, şöyle bir yerde seçsem. Şu ikisindne teğet geçen bir doğru çizemezmiyim direk)**
22. A: Ofcourse you can. (Gayette çizersiniz.)
23. B: **I wonder how I can draw it I wonder how. Well I think I was going to draw a straight here but that can’t be it because I have to draw a straight that will tangent the circle.(nasıl çizdiricem acaba, nasıl yapsak onu. Ya bence şöyle bir doğru seçicektim şurda, ama o da olmaz yani beni çemberin üstüne bir doğru ekleyip direk bunu teğet)**
24. A: Yes (hı hı)
25. **B: Ok I should be able to draw a tangent from here, what I don’t understand is this point. I should be able to draw a tangent from this point. It says to me to pick a point outside so we can draw a tangent. (Tamam bu noktadan teğet çizdirebilmem lazım benim, yani şeyini anlayamadım ben şu anda. Bir noktadan geçen teğet çizdirebilmem lazım. O bana ne diyor, dışarıdan bir nokta al diyor demi ordan ordan teğet çizdirelim diyor.)**
26. A: Yes (Hı hı)
27. B: Let’s do it like that. (Tamam öyle yapalım)
28. A: Two of our points are already outside this will be the third one. (Iki tane noktamız dışarıda zaten bu şekilde üçüde dışarda) "
29. B: Ok then I won’t pick one above the circle? (O zaman çemberin üstünden alayım ben olur mu)
30. A: Sure, (tamam),
31. B: One point from here and another from here. (Şurdan bir tane nokta alayım, şurda şöyle bir nokta alayım.)
32. A: Good (Çok güzel)
33. B: And now tangent. (Sonrada teğet diyim)
34. "A: I don’t think we should do that. Ohhhh it did it. (Onu demeyin bence. Aaa yaptı)
35. B: It happened right. (Oldu demi)
36. A: Ok. (Tamam)
37. B: Now we need to draw another one tangent to the circle (Şimdi de şurdan yine çembere teğet şekilde bir tane daha çizmem lazım)
38. A: Right (Hı hı)
39. "B: I click on tangent it doesn’t work. I hit Ctrl+z. Ohhh we never did this before. Actually for the second question we could do a polar tangent and straight central straight edge and a circle with a radius. (Teğet diyorum, olmadı. Ctrl+z yapıyorum. Bunu aha önce yapamamıştık. Aslında 2. Soruya teğet, kutupsal ve, doğru, kenar orta dikme, merkezi yarıçaplı çember)
40. A: We already did Compass straight line tangent, tangent (Pergel, dik doğru, teğet, teğet yapmıştık az önce)

41. B: Tangent only (teğet yaptık)
42. A: What will happen if we tried again? (Bir daha denesek ne yapacak ki)
43. B: Tangent will appear like this and like this, (Teğet olur yani, şöyle şöyle,)
44. A: ... Is there a tangent? .... I wish we could do a tangent, but because of something (.... teğet var mı? ... teğet yapsak keşke ama, birde şu yüzünden)
45. B: We need to draw another tangent. (Şöyle bir teğet daha çizmemiz lazım.)
46. A: And it needs to pass above the circle.
47. B: Right I wonder how we will do it. We opened it like this, for ourselves one, what's on there, separate the line from point, point on the object, crossing of two objects, mid-point or center. I mean if I put a central location and then drew a straight to them. (Aynen öyle nasıl yapıcaz acaba onu. Şöyle açtık, Kendimiz şöyle bir, şurda ne varmış, noktayı bağla ayır, nesne üzerinde nokta, iki nesnenin kesişimi, orta nokta veya merkez. Yani şöyle bir nokta belirlesem, sonrada onları bir doğru çizsem)
48. A: I think it would be awesome. (Çokda güzel olur bence.)
49. B: I hope it will work. What does it say? (Olmaz mı oldu bence. ne diyo bu)
50. A: That's it. (Bu Kadar.)
51. B: That's it. (Bu Kadar.)
52. B: Ohhhh that's already the central point (haa, merkez noktası o zaten.)

In this example, the task was drawing a triangle and constructing a circle in it. Firstly, Using Circle with Center through Point Tool, they constructed a circle, and then they tried to draw tangents that were perpendicular to the circle. In Line 13, they had a breakdown drawing a tangent. Another participant suggested that taking a point outside of the circle and drawing a tangent might be the solution. They overcame this first Breakdown. But it was not the last one for them. She tried to draw another tangent but she encountered another tangent Breakdown in Line 21. She undid the last step she did. She tried to draw a line which passed through the tangents. In Line 23, she did not know how she could draw the other tangent. In line 25 she tried out taking 3 points outside of the circle. According to Line 34, they drew the second tangent. Moreover, they needed a third tangent to display. But they went through another Breakdown again, in Line 39. They tried the steps that they did before, but it did not work. In Line 47, she changed her mind and decided to create a new point and draw a line that passed through this point. The other participant also agreed with her. First, she drew a line then she drew the tangent from this line to circle. In Line 50, they drew the last tangent for this task. In short, they wanted to draw three tangents, each time they faced Breakdowns. Although they overcame these breakdowns, this situation indicates a problem from the usability perspective.

4.2.3.1.4 Parallel Line

Example 4:

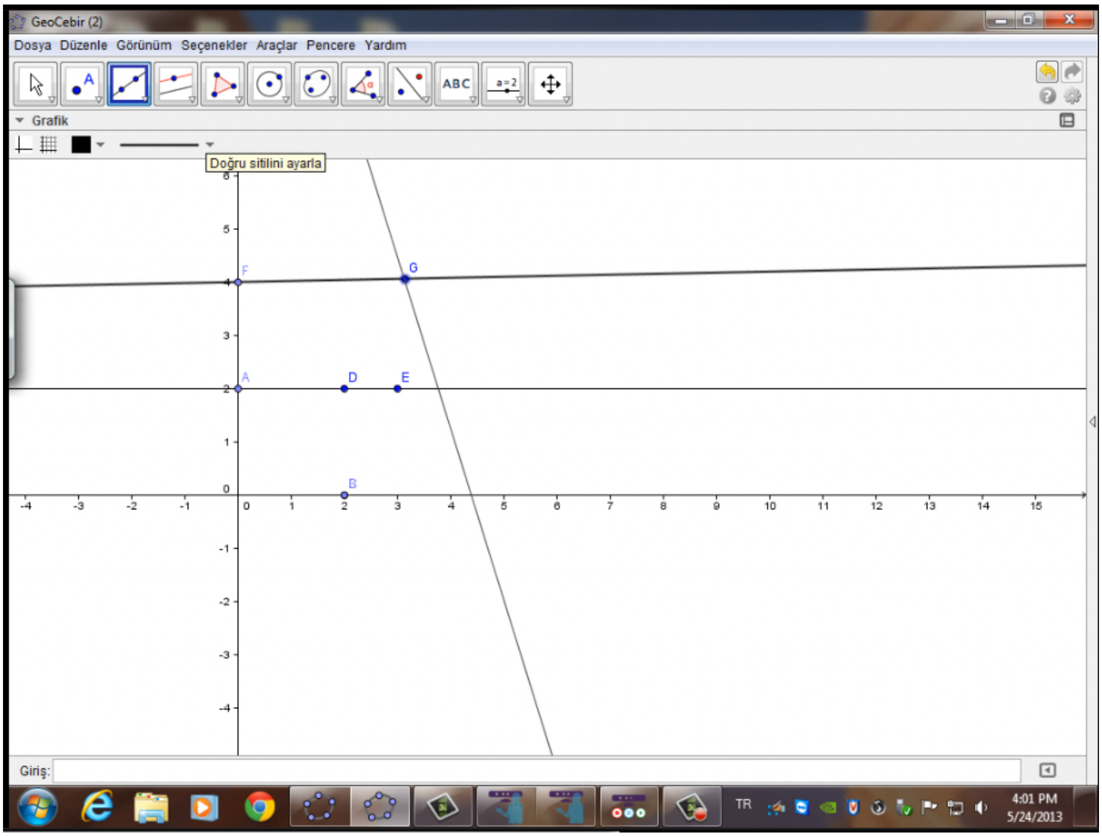


Figure B 4: Parallel Line Breakdown

1. A: We need to draw two straights that are parallel to each other. (Iki tane doğru çizicez paralel olucaklar birbirine)
2. B: It says three (3 tane diyor)
3. A: Two oh right three (2 doğru haaa 3 tane)
4. B: 1, 2, 3 (draws straights on screen with the mouse)(1, 2, 3 (ekranda Mouse ile doğrular çiziyor))
5. A: This one should be the axis (biri şu eksen olsun)
6. B: Ok (Tamam)
7. **A: One should be an axis. Let's draw the parallels towards this axis. Draw one. (Biri eksen olsun. Eksene doğru çizelim paralel. Çiz bir tane)**
8. **B: Hmmm why didn't it do it (hımm niye olmadı)**
9. A: How did we manage it last time? (Nasıl çizmiştik bundan öncekinde)
10. B: I don't know (bilmiyorum ki)
11. A: (Erases the points) Clicks on 2 towards the parallels on X-axis the parallels are formed. (Çizilen noktaları siliyor) 2 ye tıklıyor, paralel doğruya tıklıyor, x ekseninde paralel doğru oluşuyor.)
12. B: Ohhhhh (haaaa)
13. A: I couldn't do it (Tries to carry the X-axis towards the point (0, 2)) it can't be understood from here. Why doesn't it draw? (Beceremedim (x eksenindeki doğruyu (0, 2) noktasına taşımaya çalışıyor) anlaşılacak bir şey mi şurdan. Niye çizmiyor.)
14. B: Let's draw it normally. Leave that point let's do ummmm. Remember how we used to draw it longly (From point A they drew a parallel and put three points on it

(0,2)) Ok it does say three (normal çizelim şurdan şöyle. Noktayı bırak şey yapalım. Uzun uzun çiziyorduk ya (A (0, 2)) noktasından bir paralel doğru oluşturup üzerine 3 ayrı nokta koydular.) Tamam 3 tane diyo ya)

15. A: This is 1. (şu 1)
16. B: This is 2 and 3 I wonder if it's a parallel? (şu 2)
17. A: Come on. Oh we drew these (They drew a line from (0, 4) and put three points on it) (hadi be. Ha şimdi şunları çizdik ((0,4) noktasından geçen bir doğru ve üzerine üç ayrı nokta koydular)

In this example, the task was to draw three parallel lines and to create an equilateral triangle using these lines. In Line 7, firstly, they tried to draw a line parallel to the x-axis but in line 8 they had a breakdown related to drawing a parallel line. They tried to remember how they could do it. In line 11, they undid everything and drew a line on the x-axis. They wanted to move this line to (0, 2) point. In line 13, they could not move it. There was another breakdown about moving the object. In this section, Move Breakdown is examined in detail. Because of this breakdown they gave up moving the line. In Line 13, they tried to draw a parallel line. In Line 14, one of the participants suggested drawing a parallel line. In Line 15, she followed the instructions and drew the parallel lines. Parallel line breakdowns were not a crucial problem for users as they overcame this situation. However, from the usability perspective, this is still a problem.

4.2.3.1.5 Line

Example 5:

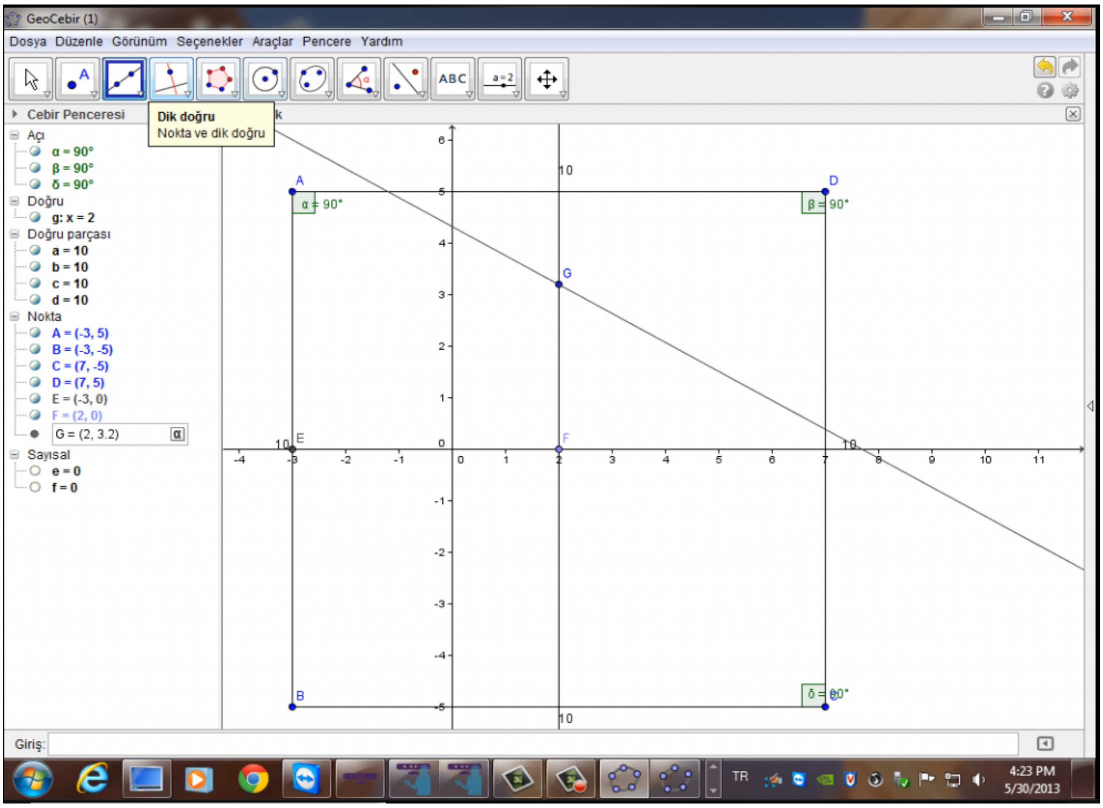


Figure B 5: Line Breakdown

1. A: It makes 4 points from here...(Touches the screen with his hand says some vague words which I couldn't understand)(4 nokta yapıyor burdan...(Eliyle ekrana dokunuyor birşey söylüyor anlamadım)

2. B: Ohhhh ok. You need one here and another one here of those things (haa. tamam. Bir tane burda bir tane şurda şeylerin olmalı)
3. A: Come back one more. Select it from there (Points with its hand) is it trying to select from 2(Bir tane daha geri gel. Seç ordan (Eliyle gösteeriyor) acaba tam 2 den seçmeye mi çalışıyor.)
4. B: Let me draw one from here (önce bir tane şuraya doğru çizeyim ya)
5. A: If you drew a straight yes it would be correct, but the vertical straight is (2, 0) exact. Ok ok. Now it's correct, but the G spot isn't correct (points the G spot with his hand) 2 by 32. Right there (Points the screen). My F point is 2 by 0, now you pick from here (Doğru çizsen çok mantıklı evet, dik doğru ama tam şu an (2, 0) tam. Tamam, tamam. Oldu şimdi, olmamış ama G noktası (Eliyle gösteriyor G noktasını) diyor 2 ye 32. Tamam orası (Eliyle ekranı işaret ediyor) olsun. Benim F noktam 2 ye 0, sen şimdi seç şurdan)
6. B: Ok G doesn't have an importance now. (Tamam, G nin önemi yok zaten.)
7. A: You can erase that later right. The perfect polygon is done now. (Onu sonra silersin zaten değil mi. Düzgün çokgen tamam)

In this task the participant tried to draw a straight line from where the straight line and the square met however instead of this, an unwanted point G was formed and they drew the straight line from here. The participants easily overcame this breakdown by reversing their previous works to draw the straight line they desired.

4.2.3.1.6 Perpendicular Bicestor Tool

Example 6:

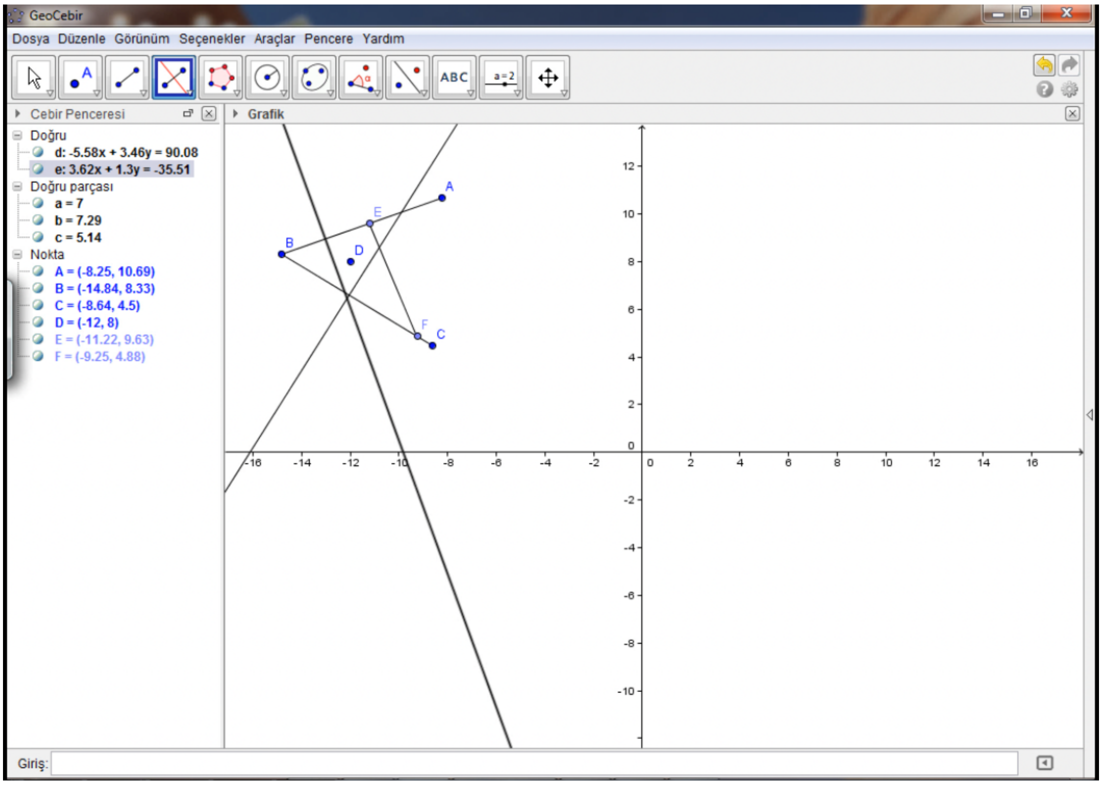


Figure B 6: Perpendicular Bicestor Tool

1. B: Let's draw a perpendicular bisector from B to EF, and put D on top of it. (Draws a perpendicular bisector from point B till EF with his hand on the screen)(Kenarortay çizelim B den EF ye, D yi de üstüne koyalım. (Ekranda B noktasından EF ye kenarortayı eliyle çiziyor)

2. A: Ok we are doing that. And we shall do it like that. (Tamam işte öyle yapıyoz.öyle yapıcazda)
3. B: There you go a perpendicular bisector (tamam işte kenarortay)
4. It still says Perpendicular bisector. This is very strange it very hard to control. (Tries to insert a perpendicular bisector)(Kenarortay dikmesi diyor yaa.çok garip ya, kontrol edilmesi çok güç. (Kenarortay dikmesi koymaya çalışıyor))
5. B: Shall I also try to make it closer? (Az daha yakına. Deniyim bende?)
6. A: I think that's ok (smiles for not being able to do it)(oldu bence tamam (yapamadığı için gülüyor)
7. B: So what? (Ne yani)
8. A: What has happened has happened. Give me second. Here you go here you wanted this. (Ne olduysa oldu, Allah allah. ya tamam şunun, dur bi dakka. Al Sana o zaman, sen istedin bunu.)
9. B. I wanted it? (Ben mi istedim)
10. A: The vector in between two points, multi-straights, with fixed parts. Here you go parts with fixed length. Ok look (iki nokta arasındaki vektör, çoklu doğru, sabit uzunluklu kesim. Al sana sabit uzunluklu kesim. Peki bak)
11. B: So (eee)
12. A: **No so's. Is nothing happened? Delete, Ok, iptal. Delete, Delete For goodness sake Delete .Why can't we delete it. Isn't this 5, 14. This E, and this is how are we going to find the midpoint of those? (Eee si yok, bişe olmadı.İptal, OK, iptal. İptal, Allah Allah, iptal. İptal edemiyoz ya. Bu neymiş 5, 14, değil mi.Şimdi şu E, şu F bu ikisinin orta noktasını nasıl bulucaz ki?**
13. B: We could have done it easier through an equilateral triangle, (Points to the triangle on the screen.) if we had done this equal to this then we could have brought them down perpendicular to this .Now let's try it like it that. (Kolaydan eşkenar yapsaydık şunu, (Ekrandaki üçgeni gösteriyor.) şunu şuna eşit yapsaydık dik indirirdik. Bulurduk öyle. Şimdi bence öyle yapalım)
14. A: We cannot use the perpendicular bisector. (Şeyi kullanamıyoruz ki kenarortayı.)

In this task, the participants tried to draw a perpendicular bisector line, which passed through point D. But they had a breakdown using it. In Line 4, users told that this tool was very hard to control. As can be seen in the figure above, they drew an unnecessary line which did not help them draw the suitable perpendicular line. Because of this breakdown they gave up using this tool as seen as in Line 12. This type of breakdown occurred three times. However, it was a big problem for users. Designers of this software should design this tool to help participants use and control it in a simple way.

4.2.3.1.7 Segment with Given Length from Point Tool

Example 7:

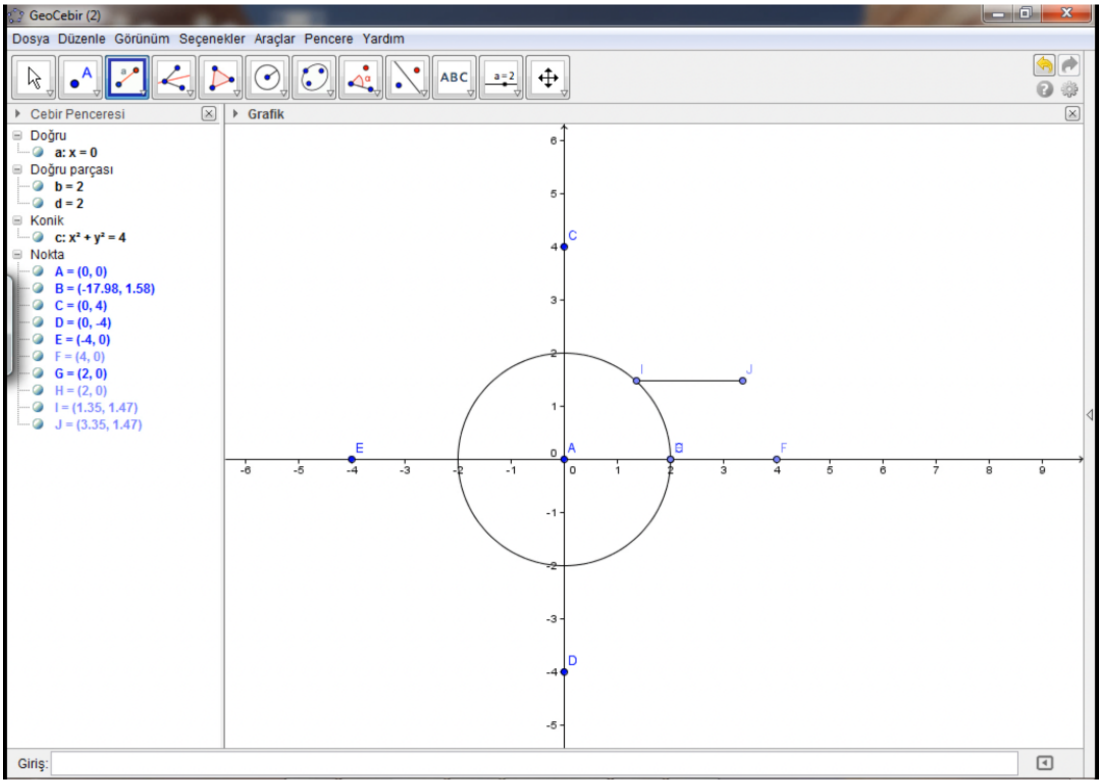


Figure B 7: Segment with Given Length from Point Tool Breakdown

1. A: hmmm a given angle, if we did like this but we have to draw a straight why would I need an angle is I supposed to draw a line from here? A line passing from two points (hıı, verilen ölçüde açı, şöyle yapsak ama çizgi çizicez açı ne yapayım kardeşim biz buradan çizgi çizicez.. iki noktadan geçen doğru)
2. B: **Ok I got it now, (at (09:53) retakes the control of the pen from participant A) (ha tamam bi saniye buldum ben buldum, ((09:53) te kalemin kontrolunu A şahsından geri alıyor)**
3. B: **I said we should have cut it at a fixed length I came from here so my length is supposed to be 2, right? Ok then I said 2 I picked this from here and put it here as it's supposed to be 2 and clicked ok but I wonder if it's the length that isn't what if I picked this and put it to here. (Sabit uzunluklu kesim dedim burdan geldim uzunluğum benim kaç 2 olacak dimi 2 tamam dedim sonra 2 bunu aldım burdan şuraya koydum 2 olacak şekilde tamam dedim bunun uzunluğu iki değil mi acaba bunu alıp böyle)**
4. A: Not really (pek değil)
5. B: If we took here and here and joined with here … Oh it said invalid okay okay. (Hani alıp acaba şöyle şurayla şurayı birleştiricek. Geçersiz dedi tamam okay tamam)
6. A: Ctrl-Z (Kontrol Z)
7. "B: How can we do it if we entered 2 and clicked okay????? I mean how can we do it, if I corrected this and made it an angle that passed from two points but these two have to be equal with each other we are going to do it like this inside the angle perhaps yani (nasıl yapsak acaba, doğru çizcez, 2 deyip tamam desem????? yani nasıl yapabiliriz acaba, şunu düzeltiyim iki noktadan geçen açı bi şöyle yapsak ama

işte şurayla şuranın birbirine eşit olması lazım aynı şeyi bunun içinde yapıcaz bunu açıdan bi bakalım)

This type of breakdown was a minor breakdown compared to the other line tool breakdowns. In this example, the task was to create a hexagon using circle, segment and line. The participants tried to use Segment with Given Length from Point Tool. They tried to draw a segment whose length was 2 the same as the circle's radius, in Line 3. In Line 5, they had a breakdown, the segment was drawn outside of circle not inside the circle, for this reason they gave up using it. The reason of this breakdown was the misusage of the tool by participants. They had chosen the point first, and then they draw it. They could not realize it.

4.2.3.2 Angle Breakdown

The major problems that were observed 37 times came out when user tried to display the angles. Two major reasons for angle breakdowns were displaying exterior angles instead of interior angles and difficulties in creating an angle with a given size.

Example 1:

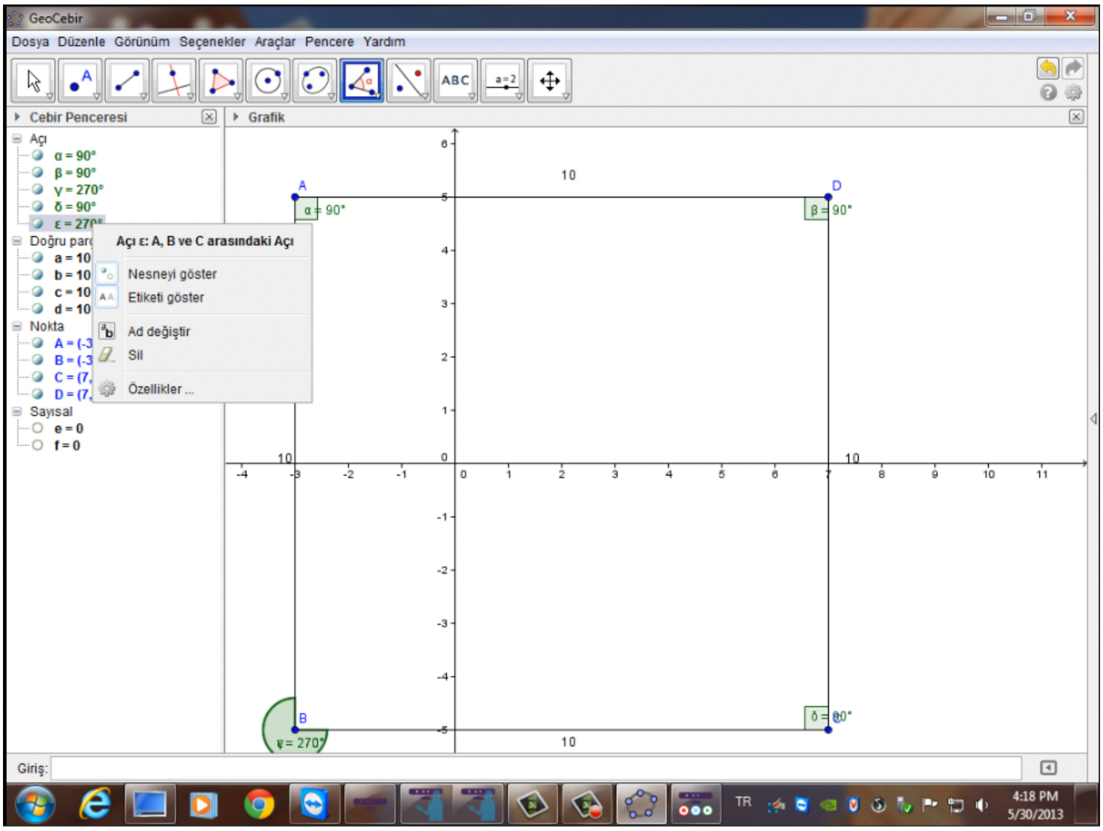


Figure B 8: Angle Breakdown

1. B: It is okay now (tamam şimdi oldu.)
2. A: Draw them (onlarıda çiz)
3. B: How much from there? (Ordan da kaça kadar?)
4. A: Come till 5. Hold it like this a little. (Makes a straight line with his hand in the air). That is supposed to be from 5 till 7 and to 5. Now show the angle from here. (Points to the angle tool) (5 e kadar gelicen. Azcık şöyle tut. (Eliyle dik çizgi yapıyor havada). Orası 5 olucak 7 den 5 e. Şimdi şurdan açıyı göstereceksin. (Açı araç çubuğunu gösteriyor))
5. B: The angle? (Açı yı mı?)

6. A: How else would you prove it if it's a square? You need to prove that these are equal (Show the sides of the square), the length of its sides and its angle is 90 (kare olduğunu ispatlarsan nasıl ispatlarsın? şuraların eşit olduğunu ispatlaman lazım (Eliyle karenin kenarlarını gösteriyor), kenar uzunluklarını birde açısını 90)
7. B: The angle is 90, between this and this, and this and that (Açısı 90, bunla bunun arasındaki açı, bunla bunun arasındaki açı,)
8. **A: Reverse it from there. (Şurdan geri al.)**
9. **B: Then, (sonra)**
10. **A: That's the reverse angle. That's 270, if so isn't there 90? (Ters açı aldın. orası 270, orasıda 90 değil midir?)**
11. B: Ok isn't that the same thing? (Tamam aynı şey değil mi?)
12. A: Yeah now make that point inside (shows the point) (hıhı, o noktayı şey yap (Noktayı eliyle gösteriyor) şu içeriyi)
13. B: It doesn't get inside (A comment on the usage) (içerde alınmıyorki (Kullanımla ilgili yorum))
14. A: You should do this like that (Show with his hand). Reverse it (şurayı böyle yapacaksın (Eliyle gösteriyor) Geri al.)
15. B: I will select this from here, because I can't select anything else from here (şurdan şeyi seçeyim, burdan başka birşey yapılmıyor ki)

First problem is encountered 33 times when participants tried to display interior angles. In this example, the task was to draw a square without using the rectangle tool. Firstly they drew a polygon using the line tool. In this task users need to prove the polygon that they had drown was a square. In line 8, a user suggests displaying the angle to prove it. To do this, they needed to use the angle tool of Geogebra. In Line 10, they tried to display the interior angles but they could not. Instead of interior angle they displayed exterior angle that was 270°. But this was not a big problem for users as they used the geometric theorem indicating that the summation of interior and exterior angle is 360. Hence, by subtracting the degrees of the exterior angle from 360, they calculated the measure of interior angle. The reason for this breakdown is that angle tool has a specific step for the measurement of angles. GeoGebra always creates angles with mathematically positive orientation, in other words with a counterclockwise direction. Therefore, this requires an order for selection of lines or points. However, the participants didn't follow this order since they didn't know of this property and the program didn't show any hints. This type of breakdown was not a big problem for users since they overcome it using the exterior angle. In Line 11, according to the user exterior angle was same interior angle.

4.2.3.2.1 Angle with a given size

Example 2:

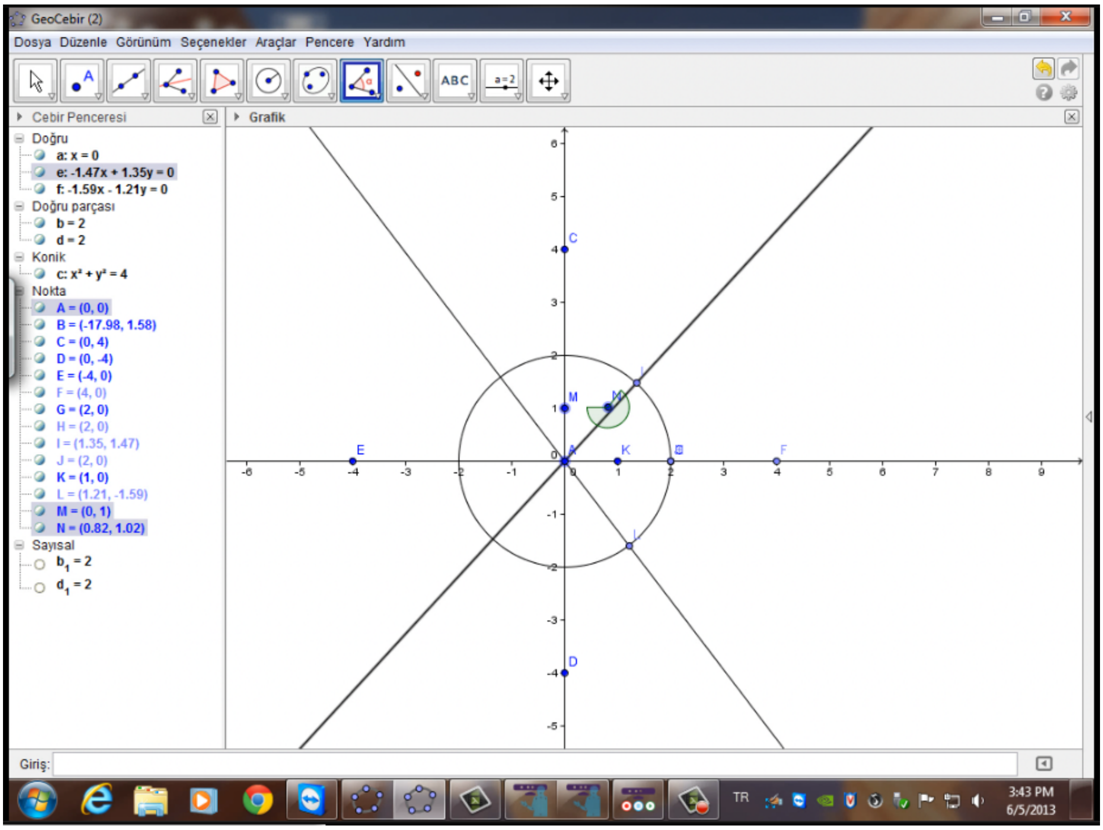


Figure B 9: Angle with a given size Breakdown

1. **A: 45 90 180. 360 divided by 6 60. Now bro this is a 60 degree and this is a 30 degree triangle (Show the degree with his hand and forms a triangle) (45 90 180. 360 bölü 6 60. Hocam şimdi 60 derecelik şurda bir açı, şurası 30 derecelik bir üçgen (Eliyle açıyı gösterip, üçgeni oluşturuyor)**
2. A: so if it needs some lines trough inside, we should draw these lines, which suit the angle. Then, we should compound it these lines' tops. Click, click, and click. (Yani böyle bi kaç tane içinden kaç tane eee doğru geçmesi gerekiyorsa. O açıya uygun olarak o doğruları yapalım. Ondan sonra o doğruların tepelerine tık tık tık tık tık birleştirelim – (draws what needs to be done with his finger on the table)
3. B: Okay to connect those straights we don't need to find those points so they can be equal. (Tamam, işte o doğruları birleştirmek içinde şey yapmamız lazım şu noktaları bulmamız lazım eşit olması için ama)
4. A: Perfect (harika)
5. B: Oh it says it is 60 degrees hold on shouldn't we make that 45(ha 60 derece diyor dur bi saniye, 45 yapmayalım mı bunu)
6. A: No we shouldn't we should cancel out the other one (yok yapmayalım öteki bunu da iptal desek)
7. B: Oh ok Ctrl – Z it didn't happen as we wanted (ha olur kontrol Z istediğimiz olmadı)
8. A: Now from there to here is 60 how do we make that (Points with his finger on the screen and takes the pen from participant B) (08:27) şimdi… şurdan şuraya 60 onu nasıl yapıcaz (Eliyle ekranı işaret ediyor ve kalemin kontrolunu B şahsından alıyor)(08:27)
9. B: Hold on (dur bi bakalım)

Second problem was faced 4 times when users created an angle with a given size. In this example, the task was drawing a hexagon without using the polygon tool. Firstly, the participations drew a circle with the center at point A. A center point of a circle has 360 °angles. They tried to divide this angle into six. For this one of the participants suggested creating an angle with a given size and drawing lines using this angle. For this purpose they used an angle with a given size tool. This tool of the program requires selecting two points but the tool creates the third point automatically. This property causes difficulties for the users since this point is not placed where the user wants it to be. Similarly, there are no hints about this property. To deal with the problem, the participations undid the last step they applied to create angle and tried to do again several times until they gave up using these tools.

As a result, the breakdown the users faced and the quick and dirty solutions that they tried showed that Geogebra is not efficient from the usability perspective. To overcome angle breakdowns, designers should provide hints and use pop-up menu for writing the points which is used in the measurement of angles.

4.2.3.3 Drag Breakdown

The third major breakdown occurred 20 times while they were moving objects on the screen.

Example 1:

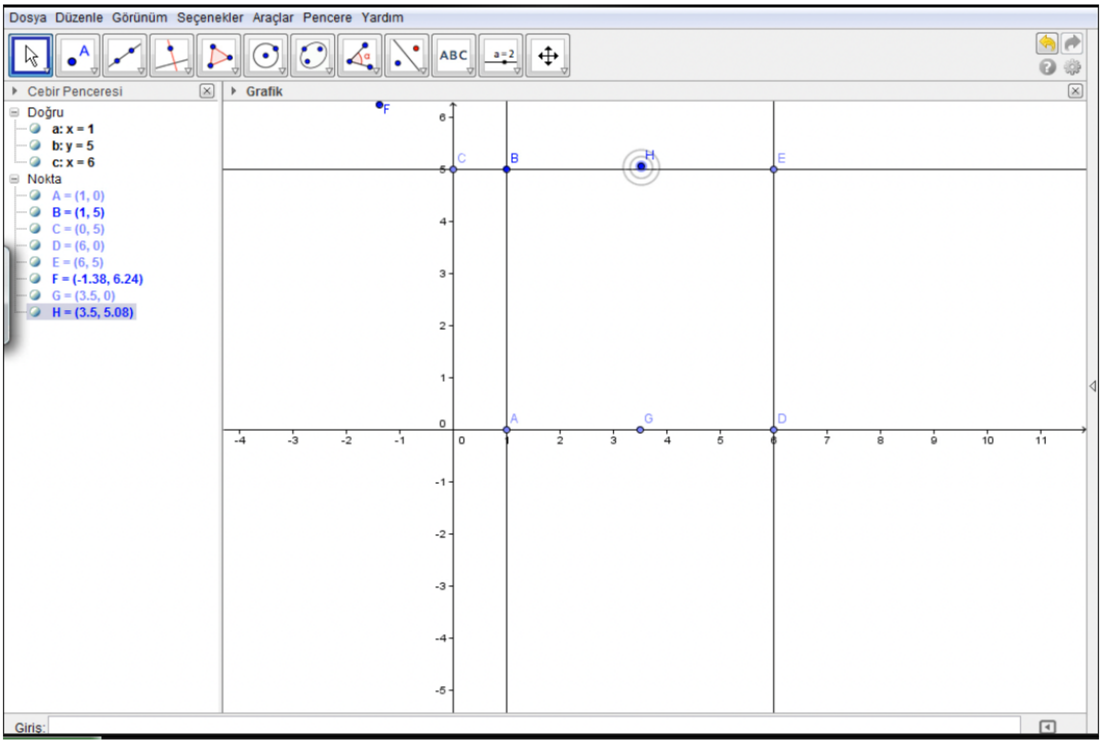


Figure B 10: Drag Breakdown

1. A: Oh so 3.84 didn't work.
2. B: This good this is bad. Ohhh there was move where is the move? (Hover over the tools.)
3. A: I think it was at the beginning
4. B: There you can see it (Mention about point tool in the algebra section)
5. **A: Okay 3,48, 3,50 a little more haa, come on haa. Okay**
6. B: Now let's pick a point from here to here. (Clicks the two intersecting straights from a straight tool)
7. A: Select that directly as one point. Of course (Says "of course" when he clicks it)

8. A: Okkkk now make that 3, 5. When it comes, tam 5 in üzerine gidicen, bak 5, 02, oldu üzerinde.
9. B: Haa. I was looking the thing yaa. (Haaa bende şeye bakıyorum yaa).
10. A: Okay it is 5.No it is 3, 54. (5 oldu. Ama 3, 54 oldu.)
11. A: I will be 3, 5 to 5 on the 5. Haa, it is ok. (5 in üzerinde 3.5 a 5 olucak. Haa oldu.)
12. B: I have just lookeh there not here. (Bende buraya bakmıyorum oraya bakıyorum)
13. A: Ok. Now it is done. Done. Syop. Haah. (Tamam, yine oldu. Oldu, dur. Haaah.)

In this example, the participants tried to move point H on the BE segment, but it was hard for them. As can be seen in the figure above, they experienced a breakdown in Line 6. They tried to move it again. After three trials, they could move it. The reason for this type of breakdown was using the mouse and the Touchpad pen. In this example, it was because of Touchpad Pen.

4.2.3.4 Clicking Breakdown

This type of breakdowns occurred 14 times.

Example 1:

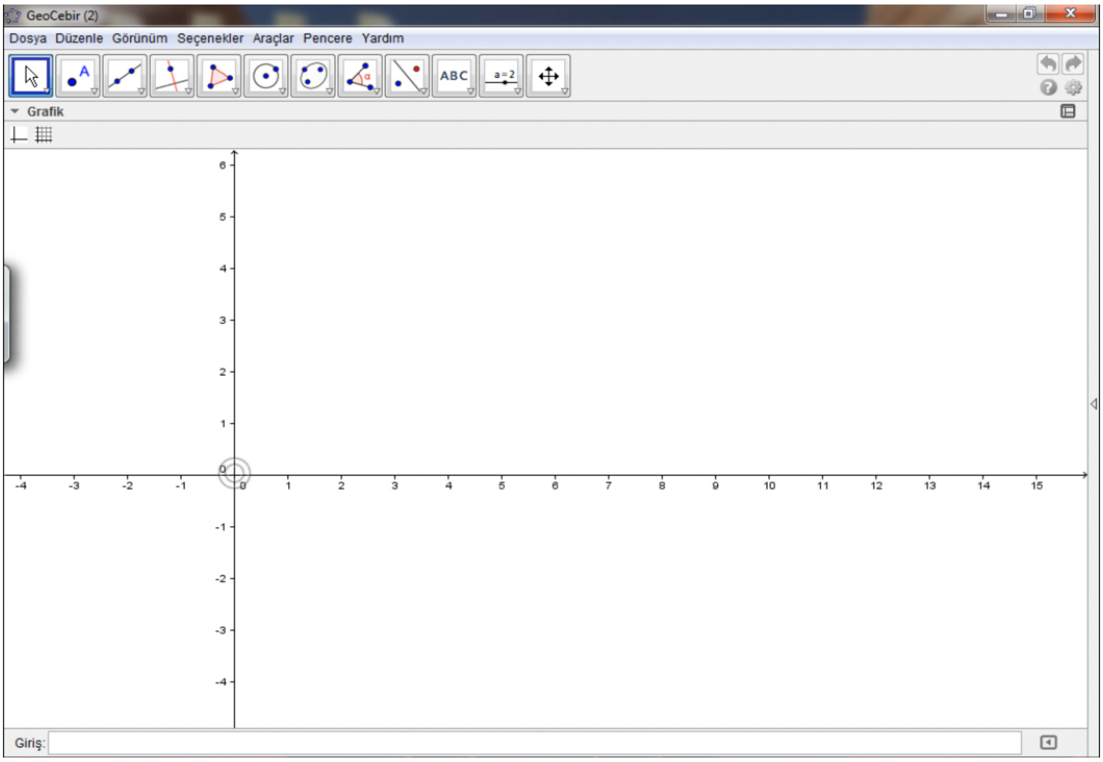


Figure B 11: Clicking Breakdown

1. B: Lets open a new window (ooo, yeni bir pencere açalım)
2. A: The question seem very hard, files … (sorular zor ha, dosya…)
3. B: **It didn’t come the batteries of the pen is dead (gelmediki bu, kalemin pili bitti)**
4. A: Click it (tıklasana)
5. B**: Im but it doesn’t click (tıklıyorum ama tıklanmıyor ki)**
6. A: Click on the screen you can also open it like that…(Ekrana tıklayabilirsin dosya açılıyor)

7. B: hmmmm
8. A: Ok (Tamam)
9. A: What are we supposed to do now? (Re reads the question) I wonder what kind of hexagon it is supposed to. (Şimdi napcaz? (Soruyu tekrar okudu) Altıgen nasıl birşey olacak ki)
10. B: Actually it is an hexagon … Now let's take the center (altıgen aslında… merkezini alalım)
11. **A: Im clicking but … (tıklıyorum ama…)**
12. B: Downsize the hexagon… No, ok continue from 2 by 2 (bence küçült altıgeni… yok tamam 2,2 den git)
13. A: There you go (şimdi bu oldu.)

In this example, the users had a clicking breakdown. She tried to open a new window using touchpad pen. But she could not. She thought that the pen ran out of battery. The partner of the user suggested clicking. She said that she clicked but there was a problem about clicking. First breakdown in this example they overcame, but it was not the last. In Line 11, they had a new clicking breakdown. This type of breakdown gives the participants a hard time. Because of this breakdown the users had another breakdown. The usage of Touchpad pen was hard for clicking any object.

4.2.3.5 Control of Input Device Breakdown

These types of breakdown were occurred 12 times. 7 of them were about touchpad pen. 5 of them were about mouse.

Example 1:

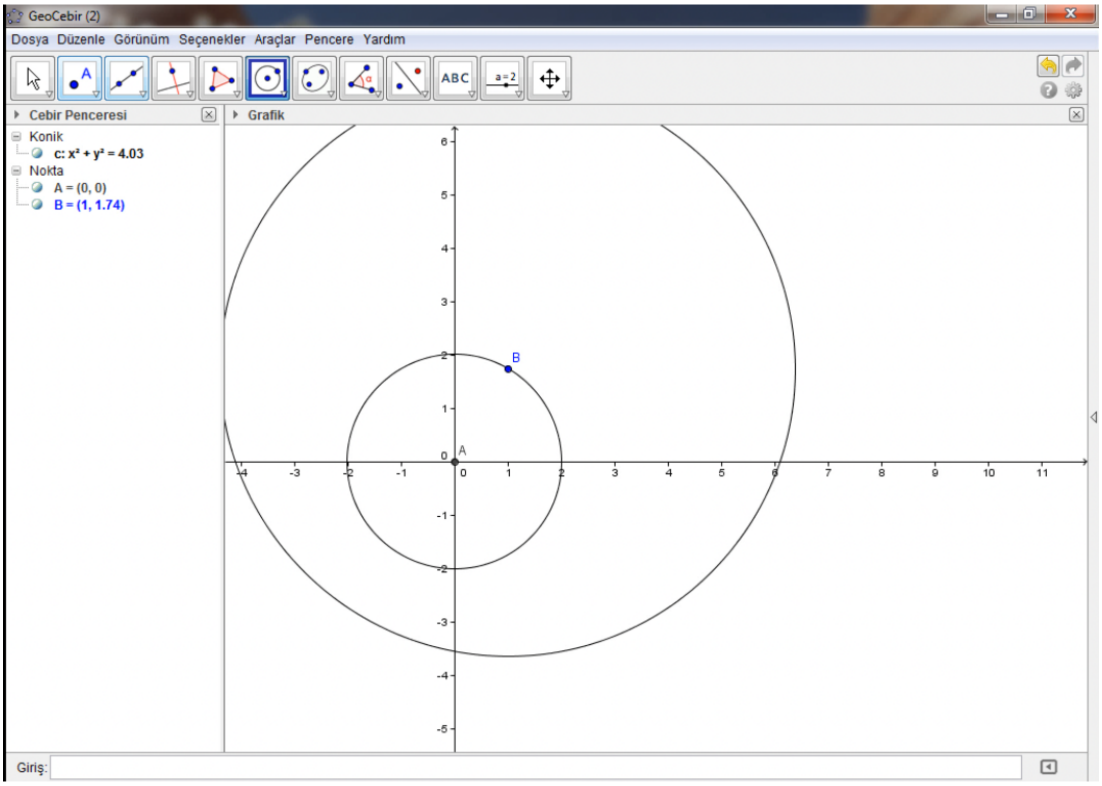


Figure B 12: Control of Input Device Breakdown

1. A: Center and radius (merkez ve yarıçap)
2. B: Let's make that one the center that passes from the radius (merkezden geçen işte. Burası olsun.)

3. A: Not something too big, 2 by 2. Okay, nope (points to the algebra window with his hand) (Çok büyük bişe yapma ... bence 2 ye 2. Tamam, olmadı ama (Eliyle cebir penceresini işaret ediyor)
4. B: What now? (Ne oldu)
5. A: Point B isn't correct; it should be 2 by 2. (B noktası olmadı, 2 ye 2 olucak.)
6. B: ... (Didn't understand it) this tells us the co-ordinates. (... (Anlamadım) bu koordinatını söylüyor.)
7. A: Ohhhh this is the B point. Now a straight … (ha bu B noktası. Haa şimdi bir doğru)
8. B: I can't get out of here!!!(Draws an unwanted circle with the mouse)(A Program related bug.)(Çıkamıyorum burdan yaa (Mouse ile istemeden çember çiziyor) (Programla ilgili bir problem.)
9. A: Aren't we supposed to do it from a straight huh? (Doğru parçasından yapmıcak mıyız haah)

4.2.3.6 Drawing Circle Breakdown

These types of breakdown were occurred 11 times.

Example 1:

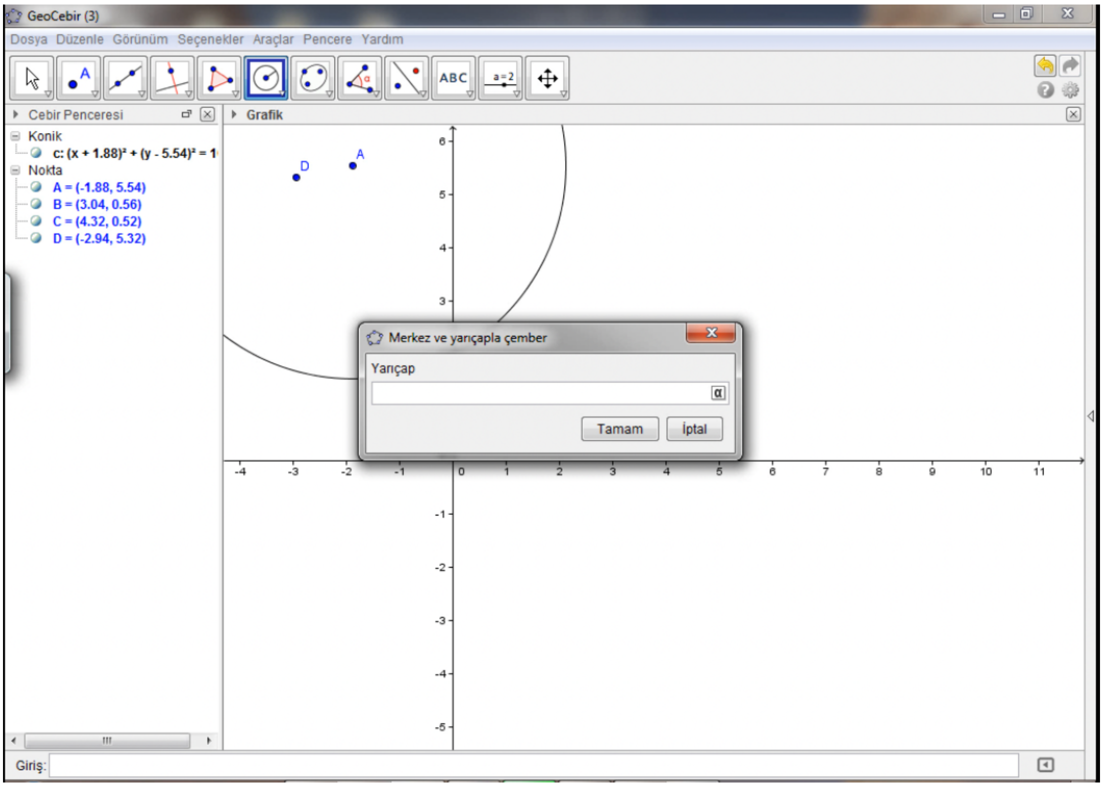


Figure B 13: Drawing Circle Breakdown

1. A: How do you plan to do? Draw a circle? (Çember mi çizcen nasıl yapcan)
2. B: By directly drawing a circle (işte çember çizip direk)
3. A: You could draw a circle and create an angle from there (çember çizip oraya açıdan gidebilirsin)
4. **B: The center is a center at a certain point and the radius which lets make it 4 or do we determine the center first? (Merkez ve bir noktadan merkez ve yarıçapla, yarıçapı 4 olsun, merkezi önceden mi belirliyoz)**
5. **A: Yeah exactly click there (evet aynen oraya tıkla)**
6. **B: I clicked another point instead of A (A yerine başka noktaya tıkladım)**

7. **A: Well if that's 4 by 4 (neyse ya orası 4 e 4 se)**
8. **B: Lets reverse this its radius is 4 (şurayı geri alayım, yarıçapı 4)**
9. A: Ok but change this as well (tamam şurayı da değiştir ya)
10. B: Ok will delete it and if we join those also it is done mi. What does it say now? (Değiştircem ya silcem şuraları birleştirdik mi tamamdır. ne diyor?)

In this example, the participants tried to draw a Circle with the Center and Radius Tool. They wanted to draw a circle whose center was (0, 0) point and radius was 4.However, the program drew the circle with a different center. In the first time, the participants could not overcome this breakdown. They deleted this circle and drew again. This type of breakdown occurred every time when all participants tried to draw a circle. To overcome this type of breakdown, the designers should change the way this tool processes. For example, when user clicks Circle with the Center and Radius Tool, the program should draw the center point then draw the circle later.

4.2.4 Open Ended Questions Results

In this section, the pairs were asked their opinion about experiment.

4.2.4.1 Group 1

Reseacher: What are views on the questions?

A: The questions were very open ended. We had to solve it through assumptions most of the time.

Reseacher: What are your opinions about the first and last 5 questions?

A: The first 5 questions were easy once you get a grip of the program. The last 5 questions required a bit more of thinking.

Reseacher: Did the thinking part spin off due to the usage of the pen or the complexity of the questions?

B: The questions … the questions were also hard but the pen made it more problematic then the mouse.

A: The screen

B: we can't match it to the screen

A: We didn't want to touch the screen but when I did I realized that there wasn't anything then I solved them easier, it seemed as if I was working on my notebook. The pen is also very useful but it seemed a bit problematic it was either because of us or because of the pen.

Reseacher: Thank you for participating

4.2.4.2 Group 2

Reseacher: Ok now what are your opinions?

A: About?

Reseacher: It maybe about the program. Which one was easier to use? Was it easier to use the mouse?

B: The mouse was a lot easier. Now here...

A: My hands shake most of the time so I don't think I can use it

B: You can't control this (The pen), The Mouse is a lot more precise, but here you can't be that precise. So it's definitely the Mouse.

A: Also I’m a very stressful... about being precise and etc.

Reseacher: What do you think about the questions?

B: Oh they were easy

4.2.4.3 Group 3

Reseacher: Now what’s your general opinion?

B: General opinion about what, about the question?

"Reseacher: About the questions and usage of the pen and mouse

"A: No pen. I think you need to be adopted to it first. It’s our first time ever using something like this. But the more you use it the more you adept to it. It’s like these touch-screen phones the more you use it the more you get it.

Reseacher: What do you think about the first and last 5 questions??

B: these were a bit tougher to overcome because it required us to use the pen. Also we didn’t know how to use the pen, which also had an impact on me

Reseacher: Thank you for participating.

4.2.4.4 Group 5

Reseacher: Thanks a lot guys

A: No we thank you

S: May I ask your opinions, I will continue from here due to the empty battery.

B: The usage of the program is very hard, it maybe for you to hard to come by but…

Reseacher: No please do don’t stress yourself out tell us.

B: It definitely can’t replace human interaction. Solving with this program is definitely not the same as solving on a paper what I could have solved in 5 minutes I spend an hour or more.

Reseacher: It was more than an hour

B: Definitely. We have been beating around the bush for 75 minutes just to draw a right

B: We also have faced another problem we couldn’t actually write the equation but if we could I definitely have noticed the equation on the right hand side and its minor differences. But at some point 2, 64 did work didn’t It.?

Reseacher: For example the only thing wasn’t the equation you could also form a certain point. . For example you are going to form a point at (2, 2). If you directly wrote 2, 2 in parenthesis it would have formed that point.

B: Got it, true but if we could write that we could have avoided those minor mistakes while trying to create that 60 degrees but we decided to create that angle on our own since we didn’t know how we could use the keyboard we had to create it manually.

Reseacher: Yes you tried to connect those two by points by shifting them however you could have corrected them by using the keyboard.

B: We didn’t know that but if we did…

Reseacher: Im sorry I took a lot of your time

B: No problem

A: We also took your time.

Reseacher: Thank you

4.2.4.5 Group 6

Reseacher: Would you like to express your opinion?

A: Fun, if you think and know about geometric work around then it really doesn't take much time.

Reseacher: How were the questions?

A: Easy

B: It does provide you with hints from the shapes below

A: This was the exactly it and this question also.

B: The one with the two circles with a tangent

Reseacher: Is there a difference between the Mouse and the Pen?

A: The mouse is definitely easier.

B: Because of habits

A: Habits. Also you have to do the pen like this.

B: Also the screen being so upright is a major problem.

A: Perhaps if the screen was a bit more tilted then it could be a lot easier.

4.3 Study 3

4.3.1 Subject's Demographics

4.3.1.1 Age

The average age of participants is 26.5 years (range between 24 -31). Figure 28 below shows the age distribution of the participants in Study 3.

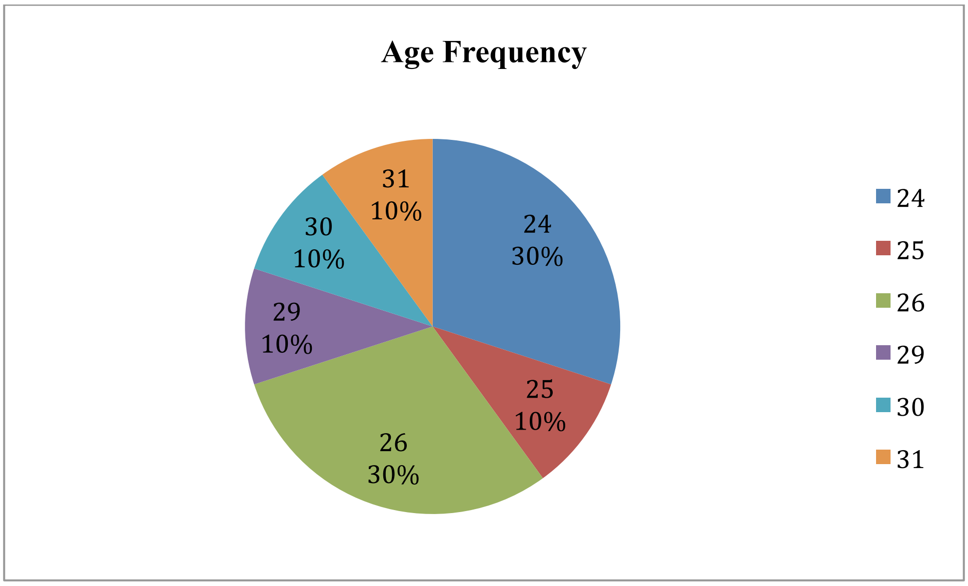


Figure 28: Age frequency of the Third Study

4.3.1.2 Sex

Majority of the participants were female (7 participants, 70 %) and minority were male (3 participants, 30 %).

4.3.1.3 Educational Level

All participants were graduate students at METU. Majority of the participants were Master of Science students (6 participants 60 % respectively) and 4 participants (40%) were doctoral (Ph.D.) students.

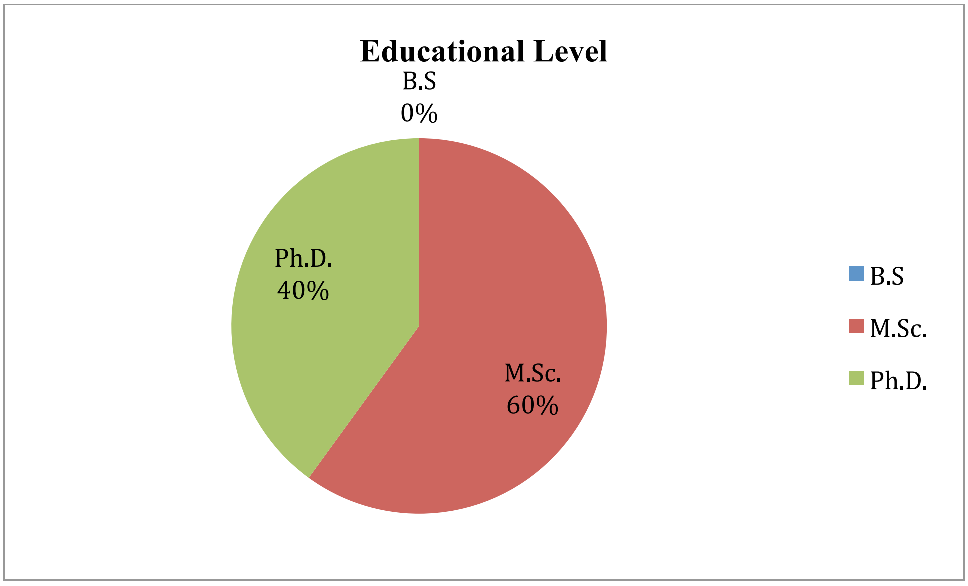


Figure 29: Educational Level of the Third Study

4.3.1.4 Department

Subjects from several different specialty areas in field participated. There were 5 participants with Engineering Sciences background. There were 3 participants enrolled in a degree program in Basic Sciences background such as Math, Statistic. There were two participants with an Educational Sciences background.

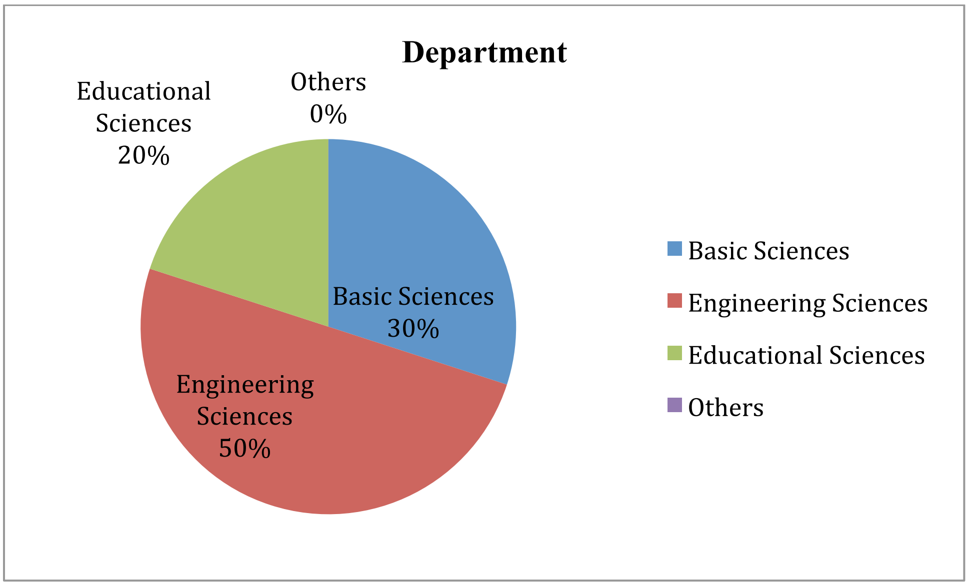


Figure 30: Departments of the Participants in the Third Study

4.3.1.5 Graduate Department

All participants were enrolled in a graduate degree program. 8 of them (80 %) were from Information Systems major, and 2 of them (20%) were from Cognitive Science major.

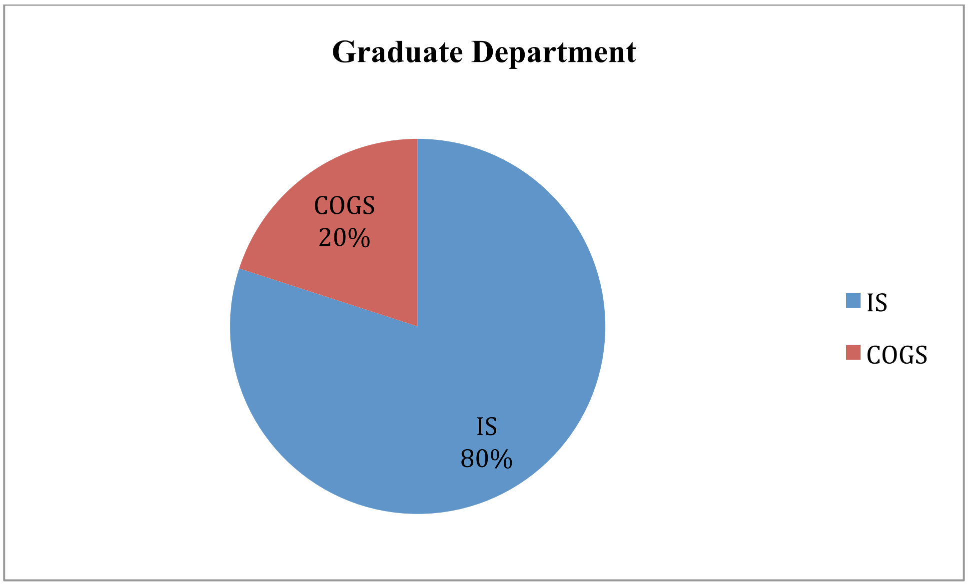


Figure 31: Graduate Department of the Participants in the Third Study

4.3.1.6 Computer Skills

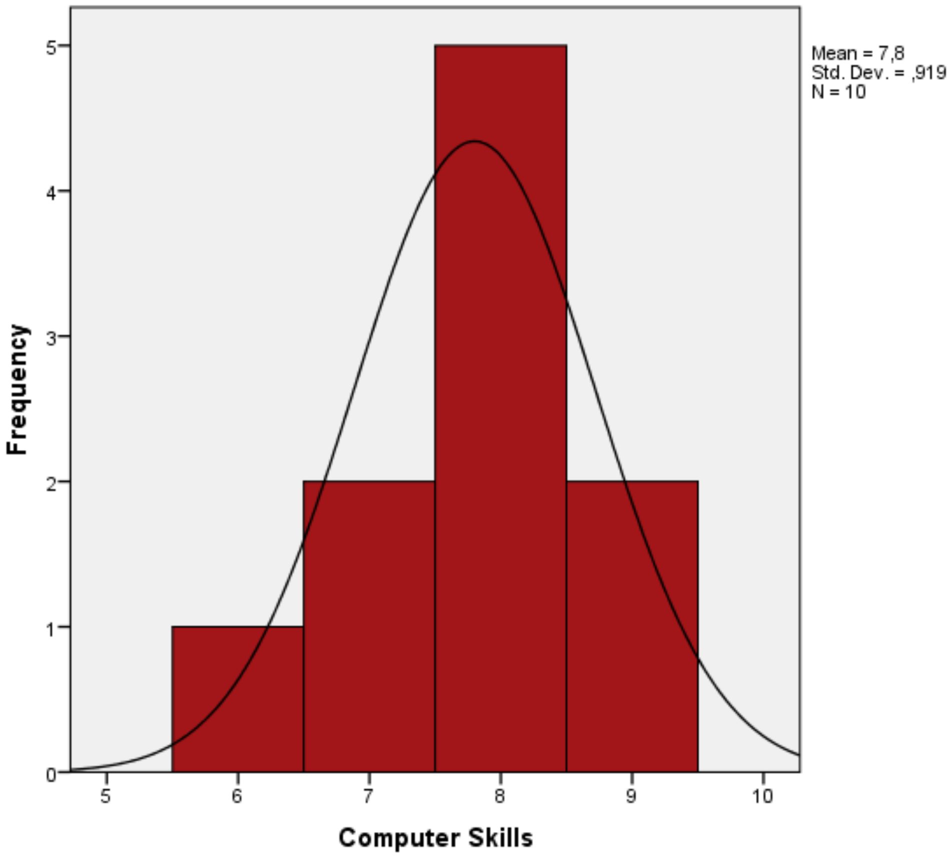


Figure 32: Computer Skills of the Participants in the Third Study

In this part of the questionnaire, participants rated their computer skills between 1- 9. The average of participants' Computer Skills was 7.8. Five of them rated their skills with 8 (50%). Two participants rated their computer skills with 7 (20%). Two of them rated their computer skills with 9 (20%). One participant rated his/her computer skills with 6 (10%).

4.3.1.7 Math Skills

In this part of questionnaire, participants rated their basic math skills between 1- 9. The average of participants with basic Math Skills was 6, 2. Three of them rated their skills with 7 (30 %). Two of them participants rated his/her math skills with 5 (20 %). Two of them participants rated his/her math skills with 2 (20 %). One of them rated his/her math skills with 2 (8, 3). One of them rated his/her skills with 4 (10 %). One of them rated his/her skills with 9 (10 %).

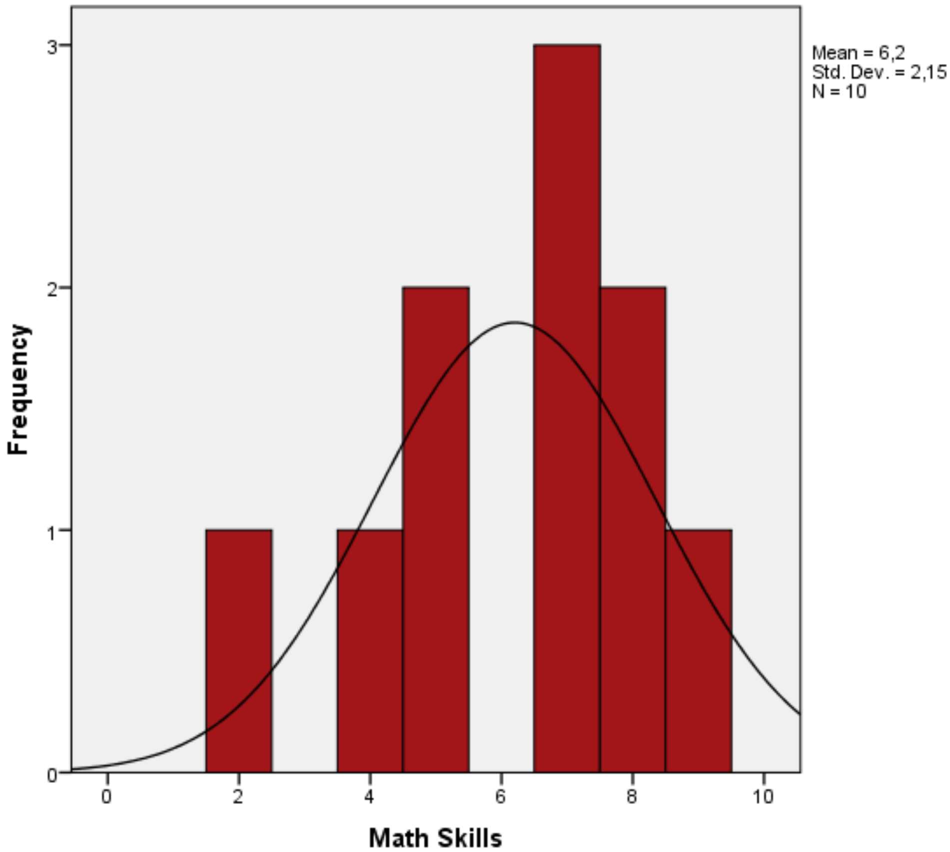


Figure 33: Math Skills of the Participants in the Third Study

4.3.1.8 Geogebra Experience

In this study nobody had prior experience with GeoGebra. This study was the first time they encountered Geogebra.

4.3.2 Scoring SUS

Table 21 summarizes the SUS scale ratings of the participants for the Tablet version of Geogebra. The SUS average for the tablet version (47.0) was lower than the SUS score of the Desktop version (58.3) obtained in Study 1, which highlights issues with user satisfaction

Table 21: SUS scores of the Third Study

	1	2	3	4	5	Score
1- I think that I would like to use this system frequently.	✓✓✓✓✓	✓✓✓	✓✓			**5**
2- I found the system unnecessarily complex.	✓	✓✓✓	✓✓✓✓	✓	✓	**22**
3- I thought the system was easy to use.	✓✓	✓	✓✓✓✓	✓✓✓		**18**
4- I think that I would need the support of a technical person to be able to use this system.	✓✓	✓✓✓	✓	✓✓✓	✓	**22**
5- I found the various functions in this system were well integrated.	✓	✓✓✓	✓✓	✓✓✓✓		**19**
6- I thought there was too much inconsistency in this system.	✓✓✓	✓✓	✓✓✓	✓✓		**26**
7- I would imagine that most people would learn to use this system very quickly.	✓✓		✓✓✓✓	✓✓✓✓		**20**
8- I found the system very cumbersome to use.	✓✓	✓✓✓	✓	✓✓	✓✓	**21**
9- I felt very confident using the system.	✓✓	✓✓✓	✓✓	✓✓✓		**16**
10- I needed to learn a lot of things before I could get going with this system.	✓✓	✓✓	✓	✓✓✓	✓✓	**19**
Total						**188**
SUS Total	**188*2.5=**					**470**
SUS (Average)	**470/10**					**47**

4.3.3 Tasks

The analysis of task performance is carried out in 3 steps. First, overall measures of accuracy and completion times are provided for all tasks. Next, the analysis is elaborated further via a hierarchical task analysis, where the sequence of actions performed by subjects in each task is compared with respect to expected solution steps. Finally, the analysis is further developed with eye tracking measures, which aim to provide further insights regarding the attention resources participants used while attempting the construction tasks.

Figure 34 shows the number of correctly solved and unsolved cases for each task. All participants were able to complete tasks 1, 2 and 4. Participants seemed to struggle the most with tasks 5 and 6. One participant failed to complete task 3.

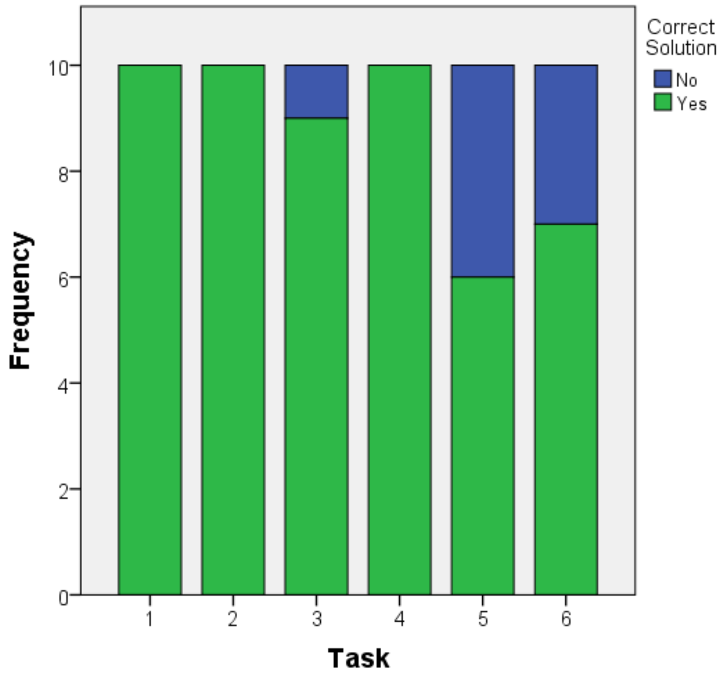


Figure 34: The number of correctly solved and unsolved cases for each task.

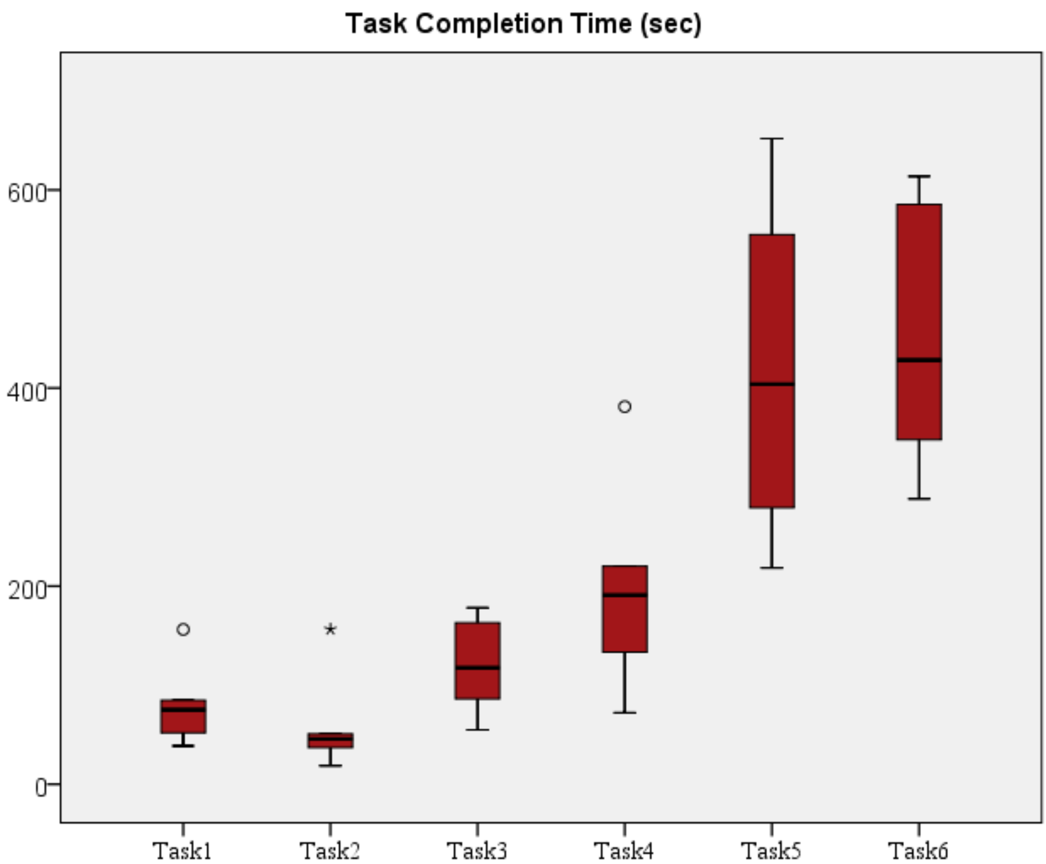


Figure 35: Task Completion Time of Each Task in the Third Study

The box-plot in Figure 35 shows the distribution of completion times measured in seconds for each successfully completed task. The box-plot shows that on average subjects took more time to complete tasks 5 and 6. The length of the interquartile range is also higher for tasks 5 and 6, which indicate a higher level of variability among participants as compared to other tasks. Since the task completion values were not normally distributed, a non-parametric Friedman's ANOVA test was used for statistical comparison. Friedman's ANOVA showed that there is a significant difference among the tasks in terms of their completion times, $\chi^2 = 24.19$, $p<.01$. Follow up pair-wise comparisons with Wilcoxon Signed Rank tests found that the difference between tasks 1 and 4 ($z=-2.70$, $p<.01$), 1 and 5 ($z=-2.19$, $p<.05$), 1 and 6 ($z=-2.37$, $p<.05$), 2 and 3 ($z=2.19$, $p<.05$), 2 and 4 ($z=2.80$, $p<.05$), 2 and 5 ($z=2.20$, $p<.05$), 2 and 6 ($z=2.37$, $p<.05$), 3 and 5 ($z=2.20$, $p<.05$), 4 and 5 ($z=1.99$, $p<.05$), 4 and 6 ($z=-2.37$, $p<.05$) were statistically significant.

In the following sections each task was analyzed further. Each section presents overall performance and eye tracking measures recorded for each participant, including total time spent on task, the number of steps to complete the task, and the total number of fixations logged in that task. Moreover, the typical steps involved with the correct solution of each task were shown with video snapshots. Finally, a detailed transcript of each participant's actions while attempting each task is extracted from the eye tracking videos. The transcripts are presented in Appendix E. These transcripts capture a short description of each move, its time-stamp or time duration, the total number of fixations and the average fixation duration logged during that move.

The transcripts are used for making a more fine-grained analysis of the users' interaction with the tablet version of Geogebra. Each line of action in the transcript is classified into three basic categories; visual search, construction actions, and actions that indicate failure or repair. Visual search refers to those segments where the user visually scans the interface without tapping on any items, indicating that he/she is searching for the relevant system features. Construction actions refer to drawing new objects such as adding a point, line, etc., Repair or failure actions include cases when the user performs an undo, erases an existing part of the dynamic drawing, or decides to quit the task. A total number of 1373 action descriptions were categorized. Figure 35 shows the percent distribution of these action types in the transcripts. Participants spent 22% of their total time on searching for relevant drawing features that they may use to solve the task at hand, 58% of their total time while constructing drawings, and 20% on repairing or erasing existing parts of a drawing.

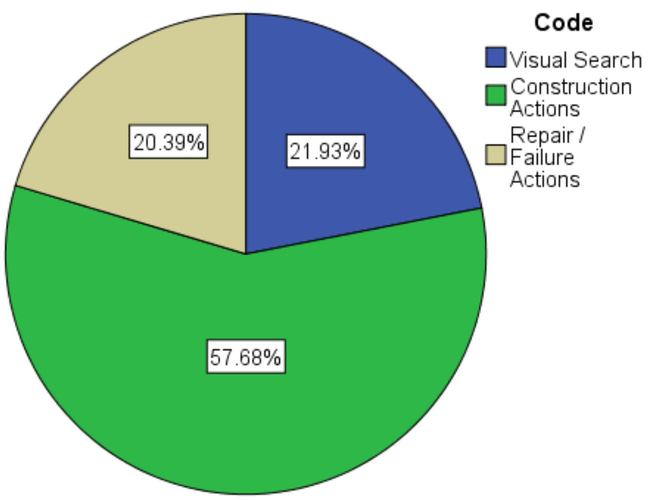


Figure 36: Percent distribution of action categories for Study 3

For each segment categorized as visual search or construction, average fixation duration and number of fixations were also recorded as indicators of efficiency and cognitive workload. Since undo and erasing actions took on average small amount of time, those segments were not subjected to fixation analysis. Figure 37 shows the distribution of average time duration for each visual search and construction action. A two way ANOVA analysis showed that the average time spent on visual search was significantly higher than average time spent on construction actions, $F(1,1013) = 10.093$, $p<0.05$. There was also a significant interaction effect, $F(5,1013) = 2.655$, $p<0.05$. This is due to the fact that the time spent on visual search is especially higher than construction in tasks 3 and 6, which indicates that subjects had more difficulty finding related drawing features in these tasks. There are also cases such as tasks 1 and 5 where visual search and construction actions had similar average time.

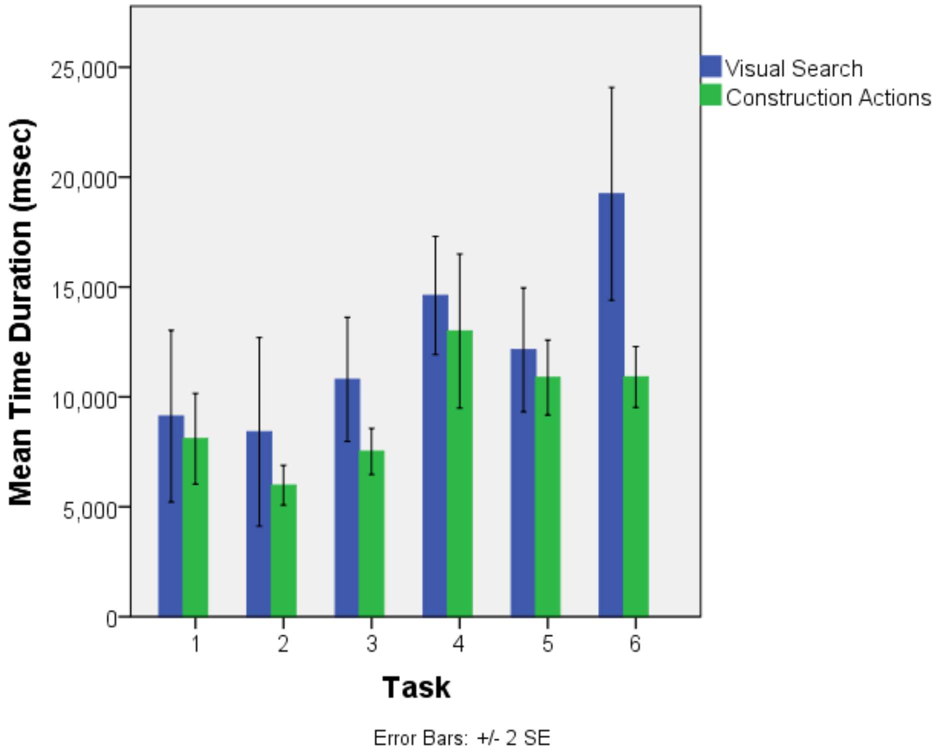


Figure 37: Average time spent on each action of type visual search and construction across all tasks.

Figure 38 shows the distribution of total fixation counts for each segment type across all tasks. A 2-way ANOVA showed that the visual search segments have significantly higher number of fixations as compared to construction segments, $F(1,1008) = 13.472$, $p<0.01$. The difference was particularly high for tasks 3 and 6, which suggest that subjects searched the interface more vigorously in these tasks. The interaction of segment type and task was also significant, $F(5,1008) = 2.280$, $p<0.05$, which is due to the fact that some tasks such as 1 and 4 had almost equal mean fixation counts for search and construction segments.

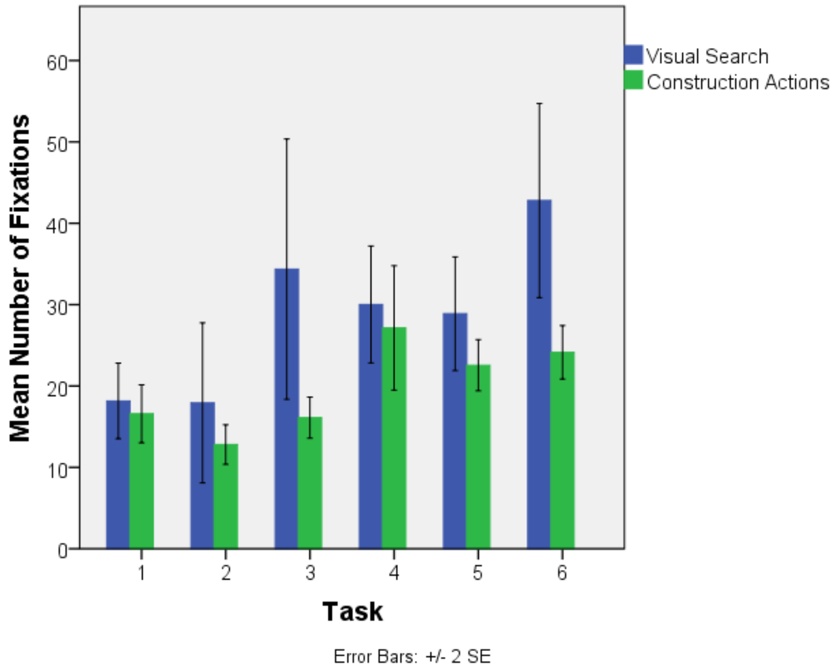


Figure 38: The distribution of mean number of fixations over search and construction segments for each task

Figure 39 below shows the distribution of average fixation duration values observed in search and construction segments for all tasks. A 2-way ANOVA conducted on average fixation duration values showed a significant effect of segment type, $F(1, 1008) = 9.372$, $p<0.01$. Construction segments have higher average fixation values than visual search segments. The interaction effect was not significant, $F(5, 1008) = 0.991$, $p>0.05$, so the pattern of relationship is preserved across different tasks. This suggests that the fixations that guide the construction of dynamic figures tend to elicit higher average duration values than fixations that guide the search process.

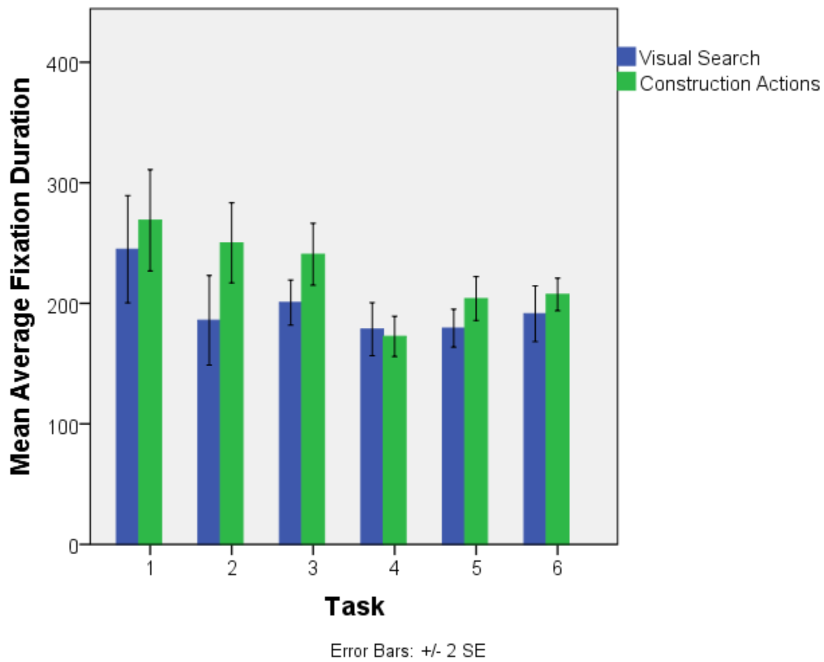


Figure 39: The distribution of average fixation duration values in each segment type across all tasks

The following section will focus on each task separately to provide qualitative observations possibly underlying the results summarized in this section. The qualitative analysis will also aim to elaborate on specific usability issues participants had when they were searching for and executing specific drawing actions.

4.3.3.1 Task 1

Task: Draw any triangle; show its angle and any edge length of this triangle.

Table 22: Task 1 Eye tracker Results of the Third Study

Participants	Spent Time on Task (milliseconds)	Steps Count to Complete the Task	Total Fixation Count
Participant1	156265	28	380
Participant2	94286	14	249
Participant3	130812	16	253
Participant4	74596	6	197
Participant5	42429	6	41
Participant6	84687	9	118
Participant7	52000	6	117
Participant8	76202	6	57
Participant9	38788	6	95
Participant10	75594	10	185

The participants were asked to draw a triangle and show its angles and segments. All of them completed the task. In this task, the participants were free to use all the tools. However, they mostly used point, line, polygon, segment and circle tools to construct the triangle. To show the angles, all of them used the angle tool. Two of them used the circle tool to construct a triangle; however, they failed. The problem with this tool was that they could not intersect the circles, so they gave up using this tool. One of them used the line tool for triangles but she deleted the lines because she could not show the angles correctly. Four of them used the segment tool to create a triangle. And six of them used the polygon tool to construct a triangle.

In this task, Participant 1 had more difficulties than the others so we examined her experiences during throughout in detail. The participant first used the line tool while completing the task and constructed a triangle by drawing three lines. He used the angle tool to show the measurement of one angle of the triangle, and showed the external angle five times. He restarted the question by deleting everything on the screen and used the circle tool this time. He attempted twice to construct a triangle by intersecting the circles and he could not do it. Finally, he gave up solving the question. Then the participant used the segment tool to construct a triangle. He could construct a triangle by intersecting the segments. The biggest problem faced by the participant while completing this task was the showing of the internal angles. The participant who tried to show the angles by using the angle tool first showed the external angle and the internal angle.

There were probably four ways to complete this task. The cause of the differences had something to do with creating a triangle. The first step had four different four ways. The second and third steps were similar for all participants. First steps:

1. Create a triangle via polygon tool.

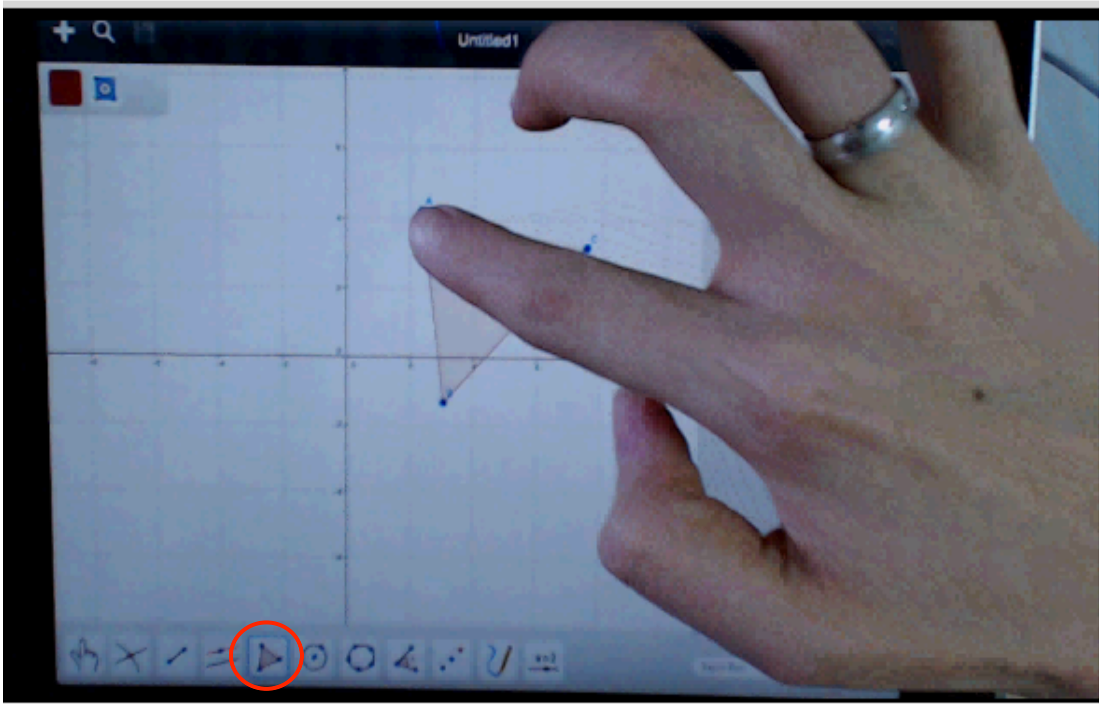


Figure GM 1: Creating a triangle via the polygon tool.

2. Creating a triangle using line tool.

Figure GM 2: Creating a triangle via line the tool

3. Creating a triangle via point tool.

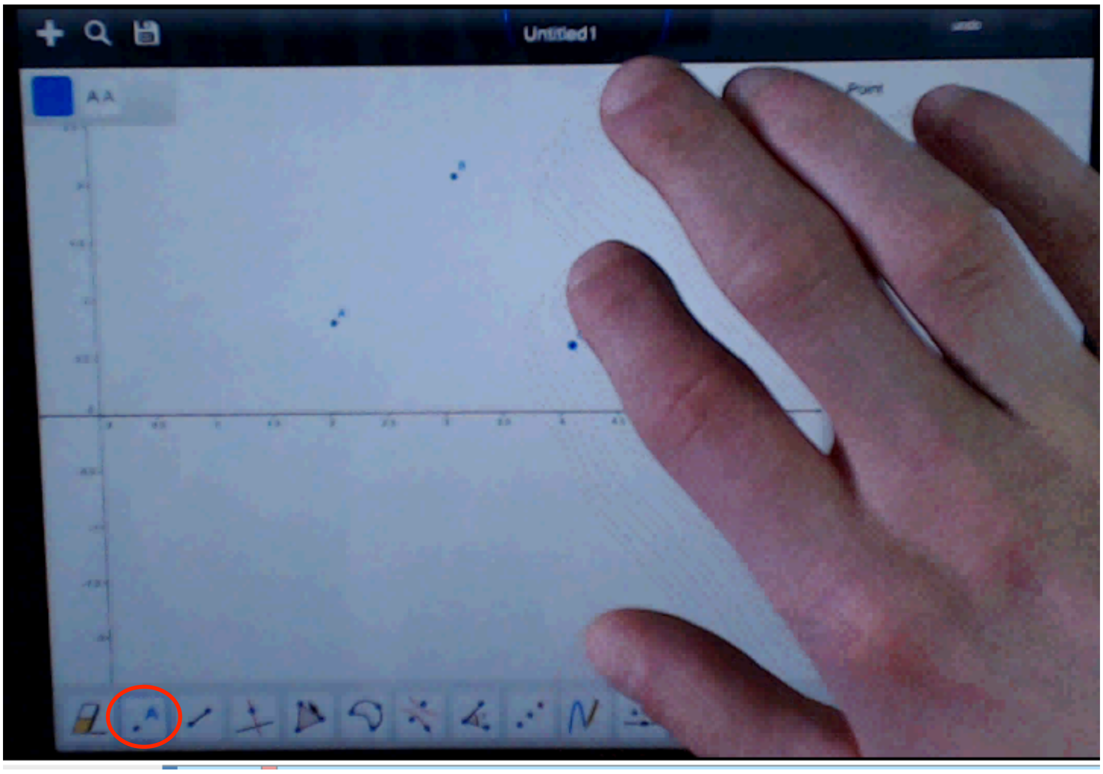


Figure GM 3: Creating a triangle via the point tool.

4. Creating a triangle via the circle tool.

Figure GM 4: Creating a triangle via using the circle tool.

2. **Second Step:** Showing internal angle via the angle tool

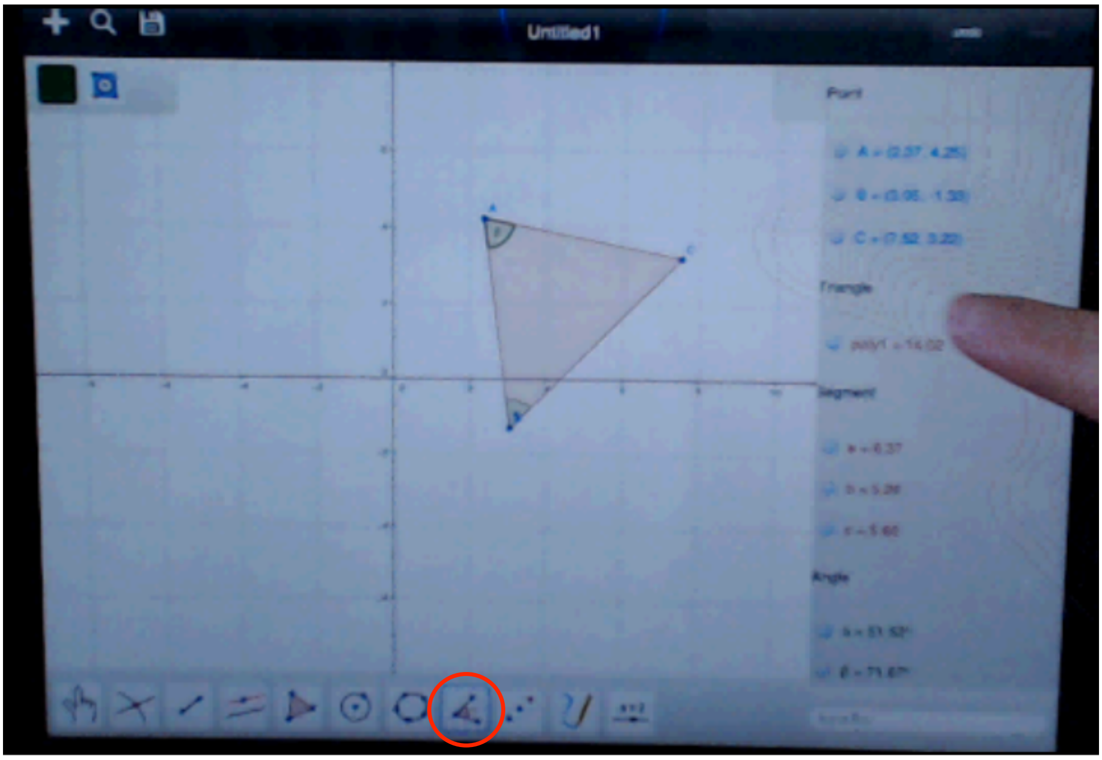


Figure GM 5: Showing internal angle via the angle tool

3. **Third Step:** Noticing the segments' length on algebra pane.

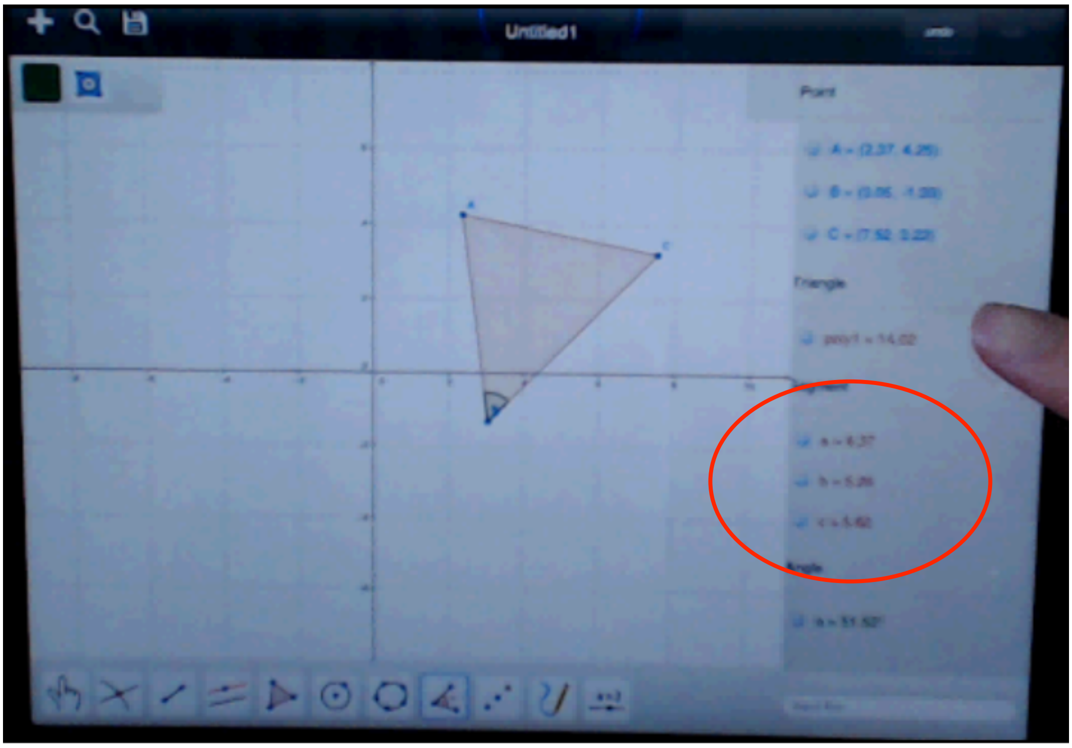


Figure GM 6: Noticing the segments' length on algebra pane.

Main usability problems and suggestions:

The participants had problems to show internal angles. Four of them firstly showed external angles. One of them showed internal triangle after 6 attempts. One of them faced this problem twice. The other two participants faced this problem once.

Since almost all participants struggled with having Geogebra to display the interior angle in the desired place, there is a serious usability issue with the angle tool. The current design expects the user to press on the three points that define the angle in clock-wise order to define where to display the angle. However, no explicit hints or messages are provided on the interface about this expectation. Alternatively, the system could allow users to select the location of the angle with a hand gesture similar to how we draw angles on paper by drawing a small arc connecting two existing line segments. In this new feature, after the user selects the angle button, he will draw a short arc touching on both segments between which the angle should appear. Until the user lifts his finger from the screen, the system can display a visual feedback by highlighting the line segments implicated and the anticipated area where the angle will appear. Such a feature would simplify defining angles by eliminating the need to identify 3 points in a specific order, and providing a more naturalistic method the users are familiar with drawing.

Another problem was intersection the circles. To intersect the circles properly, the program could provide automatic zoom when they clicked the intersection tool.

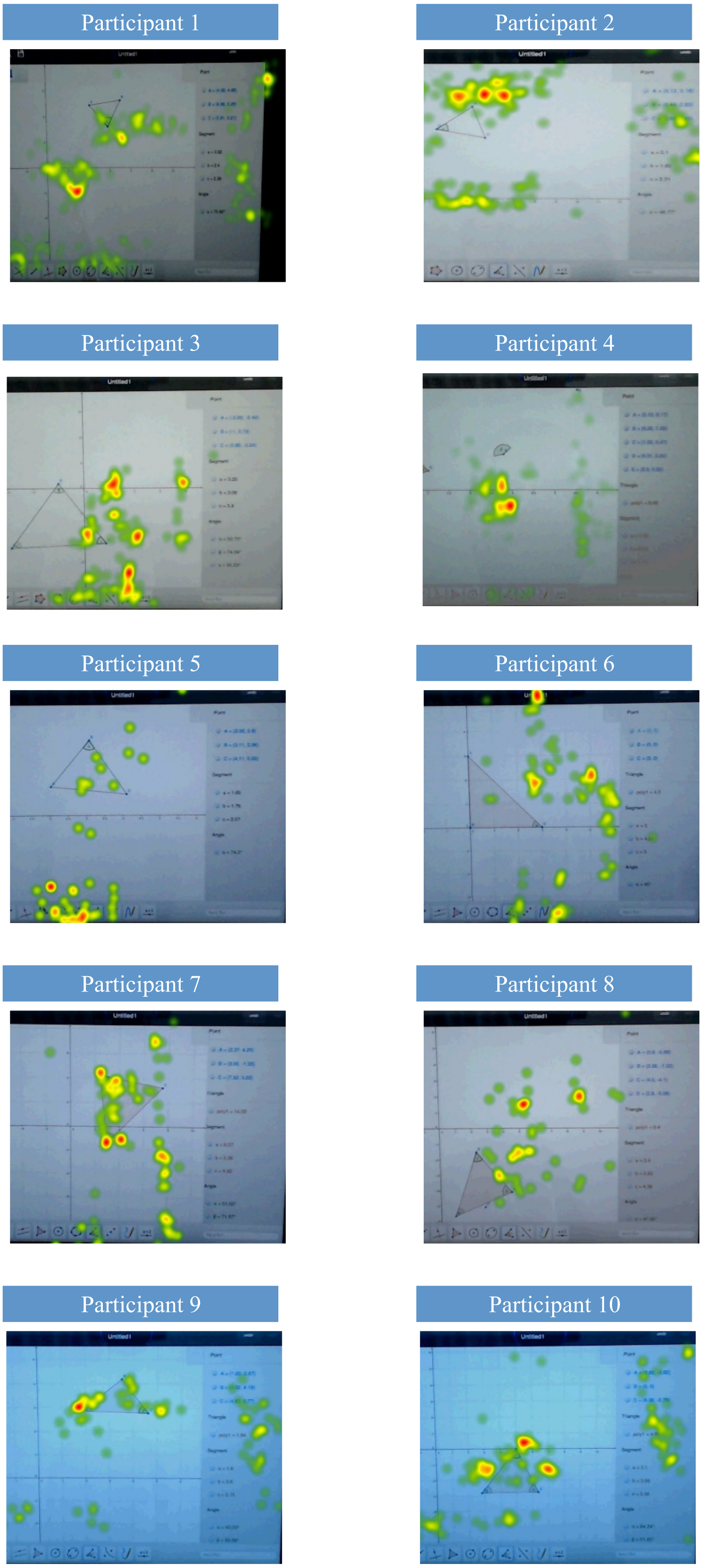


Figure 40: Task 1 Heatmaps

4.3.3.2 Task 2

The task: Draw a straight line passing through the A (5, 0) and B (0, 2) points and indicate the equation of the line.

Table 23: Task 2 Eye-Tracker Results of the Third Study

Participants	Spent Time on Task (milliseconds)	Steps Count to Complete the Task	Total Fixation Count
Participant1	37050	8	92
Participant2	93949	17	249
Participant3	43750	9	101
Participant4	49848	6	115
Participant5	22898	5	29
Participant6	41697	9	56
Participant7	156500	21	348
Participant8	85313	10	115
Participant9	18586	3	28
Participant10	50823	8	131

All participants completed the task. In this task, participants were free to use all tools. However, they mostly used line, point, segment, and slider, undo and move tools to draw the graph. All of them used line button, half of them used point button, four of them used undo button, four of them used move button, one of them pressed on parallel line button but could not use it properly and two of them pressed on slider button but they could not use it.

In this task, Participant 7 had more difficulties than the others so we examined her experiences during throughout in detail. The participant was trying to draw a line passing from the points that he liked, but it was not that easy for him to choose the desired points. To draw a line as he liked to, he had to repeat the procedures eight times. Putting an unwanted point each time, the participant could draw a line but the coordinates of the point where this line passed were not he desired ones. He deleted it and redrew and even zoomed in the page. He was able to draw the line passing from the wanted points in his eighth attempt.

There are probably two ways to complete this task. These two ways are similar. The second way has more steps than one way.

First way

1. Step: Using the Line tool and draw the line.

Figure GM 7: Using the Line tool and draw the line.

Second way

1. Step: Using the point tool and and put two points.

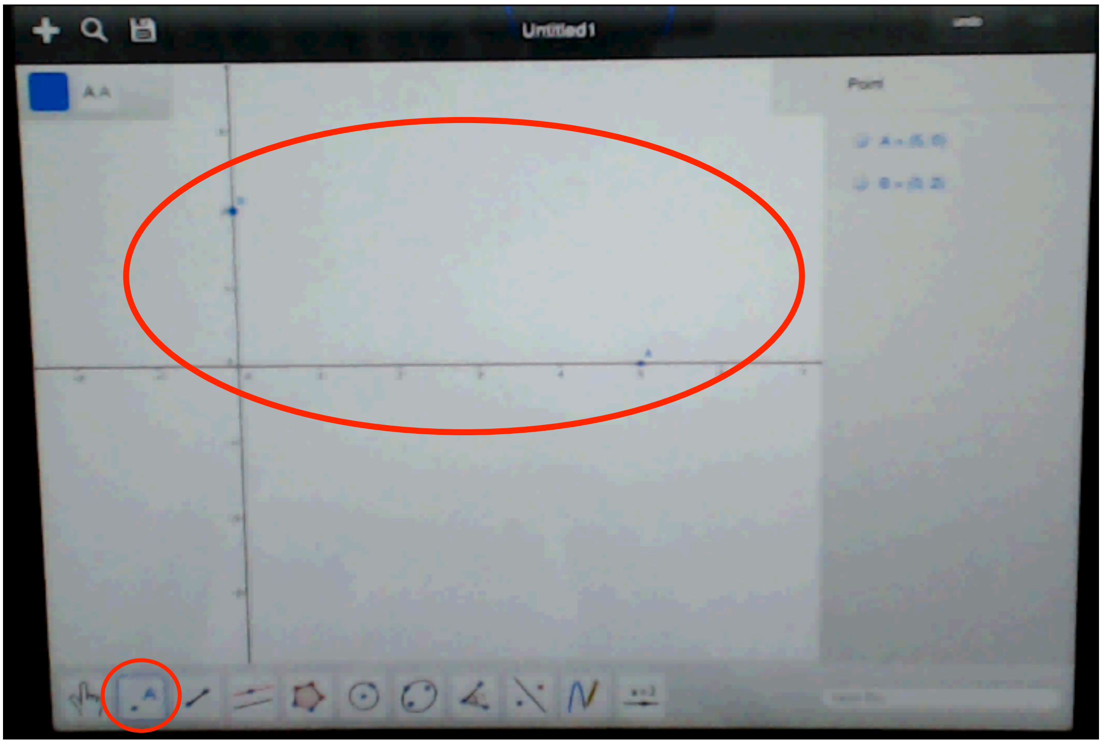


Figure GM 8: Using the point tool and put two points

2. Step: Using the line tool and connect the two points.

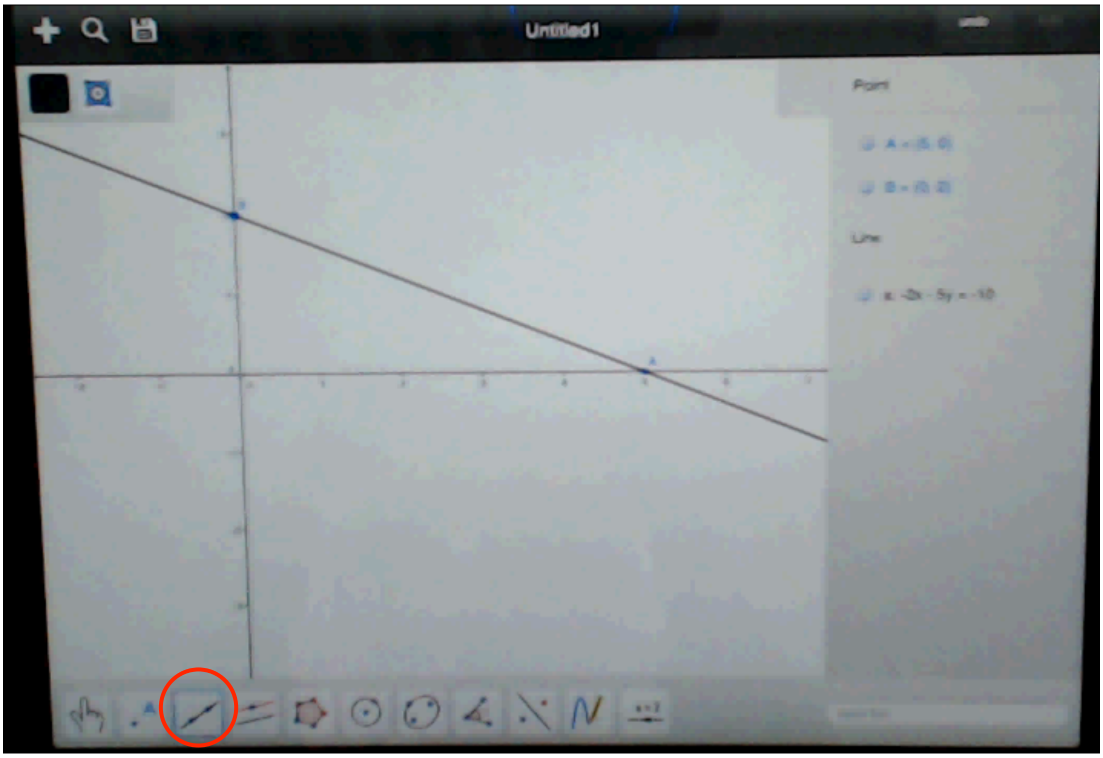


Figure GM 9: Using the line tool and connect the two points.

Main Usability problems and suggestions:

In this task, many participants experienced the same problem. Whether he used the line tool or point tool, he had problems with clicking the wanted coordinates while using either tool. Some participants overcame this problem by using the grid. Some, however, zoomed in the coordinate plane, thus forming the point having the wanted coordinates. It could be said that putting a point where it is desirable has continued to be a problem in the mobile version of GeoGebra software.

Intersecting the axis and put a point on the axis was very sensitive and hard for the users. To overcome this problem, the system should enlarge the area clicked by the user with the help of a lens and make his job easier. In addition, there should be a message on the slider, which cannot be determined by the users. This button caused two participants to waste their time.

The problem faced by one participant with the act of carrying led us to make the following inference: If the user clicks on the object for long and tries to carry it, a pop up menu should appear on the object. One of the alternatives of this menu should be 'Move', while another may be 'Delete'. Thus, he will get rid of having to click the tools continually and also will realize the desired action though unaware of the functions of the tools.

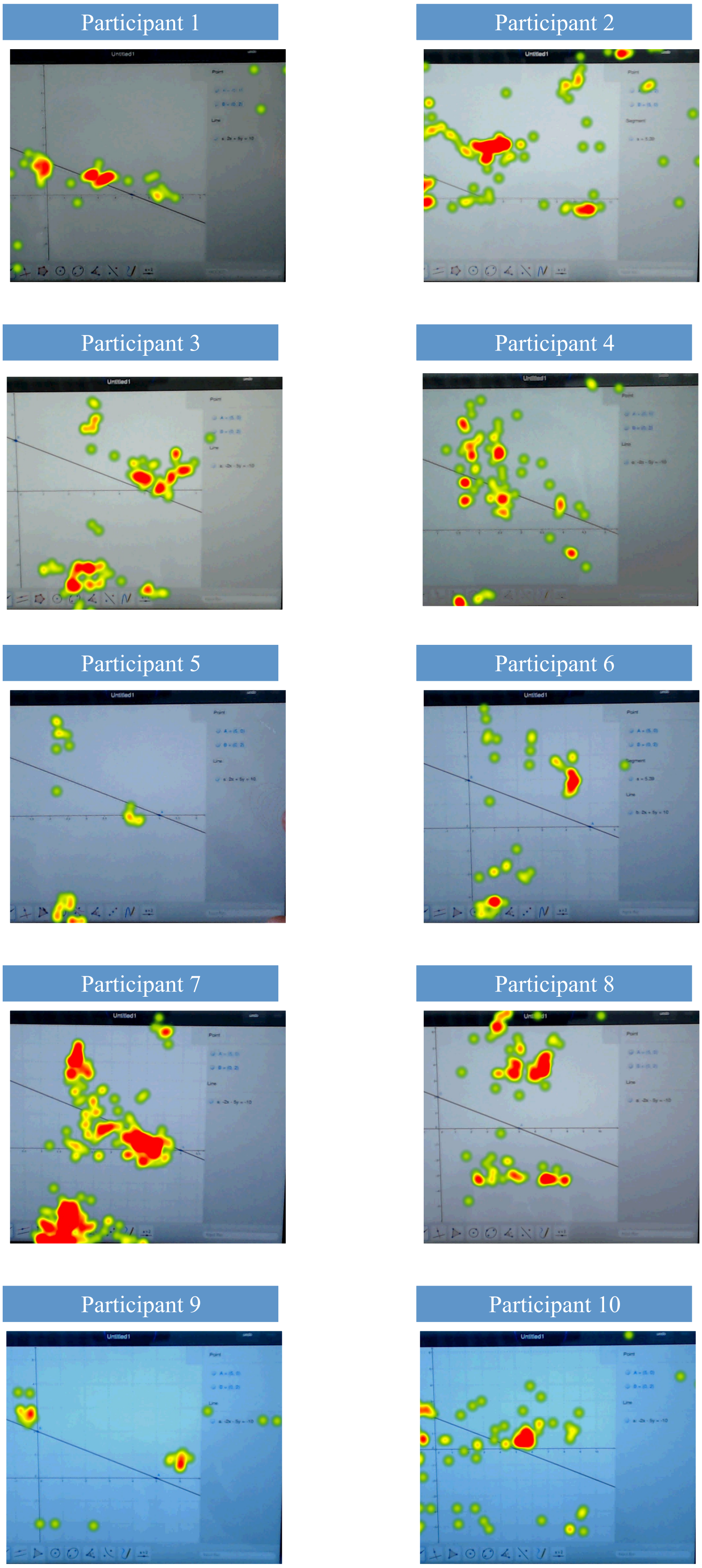


Figure 41: Task 2 Heatmaps

4.3.3.3 Task 3

The Task: Without using polygon tool form a square. Prove that drawn shape is a square

Table 24: Task 3 Eye-Tracker Results of the Third Study

Participants	Spent Time on Task (milliseconds)	Steps Count to Complete the Task	Total Fixation Count
Participant1	163020	14	447
Participant2	742333	107	1874
Participant3	72625	16	132
Participant4	86263	8	210
Participant5	130990	14	221
Participant6	54949	8	65
Participant7	111000	18	278
Participant8	393434	58	480
Participant9	178182	18	382
Participant10	124281	9	313

Only Participant 5 did not complete the task that the others completed. Participant 5' steps counts were not too much it was only 14 steps. For example, participant 2 made 107 steps and completed the task. In this task, participants mostly used point, segment line, and line and angle buttons. Two of them used the input bar and three of them used Redefine window to change the coordinates of the point. Two of them used the move tool and moved the point and segment line. 7 of them used the angle button to prove the square. One of them used slider, symmetry and three-point tools. And one of them used the triangle button to show the angles.

In this task, Participant 2 had more difficulties than the others so we examined her experiences during throughout in detail. Participant 2 mostly used the point and segment line tools to complete the task. He had a lot of difficulty completing this task. She especially attempted a lot to put a point where he liked to. Only in his ninth attempt could he put the point where he first wanted. He also had lots of difficulty putting the other 3 points following the first. He was able to draw a square only in the 105th step. To prove it a square, he used the angle tool. Another difficulty faced by the user was to click the Redefine window open. This window was opened by double clicking the point expected to be changed, but the user did not know this. He even thought that his fingers had something to do with the act of clicking. It took him a lot of attempts to open the Redefine window. However, his ability to open the window did not mean that he could use it duly. He had some trouble this time because the button of Return did not mean Okay (OK). He wrote the coordinates of the point in this window and clicked the scene to approve of it, but there occurred no changes. After a long attempt, he enabled the button of Return to realize its function. Another problem was about constructing an angle with the dimensions given, a function that was present in Desktop version but was not supported in the Mobile version. The user tried to do it by using the angle tool but could not do it.

There are probably three ways to complete the task.

First way

1. Put four points

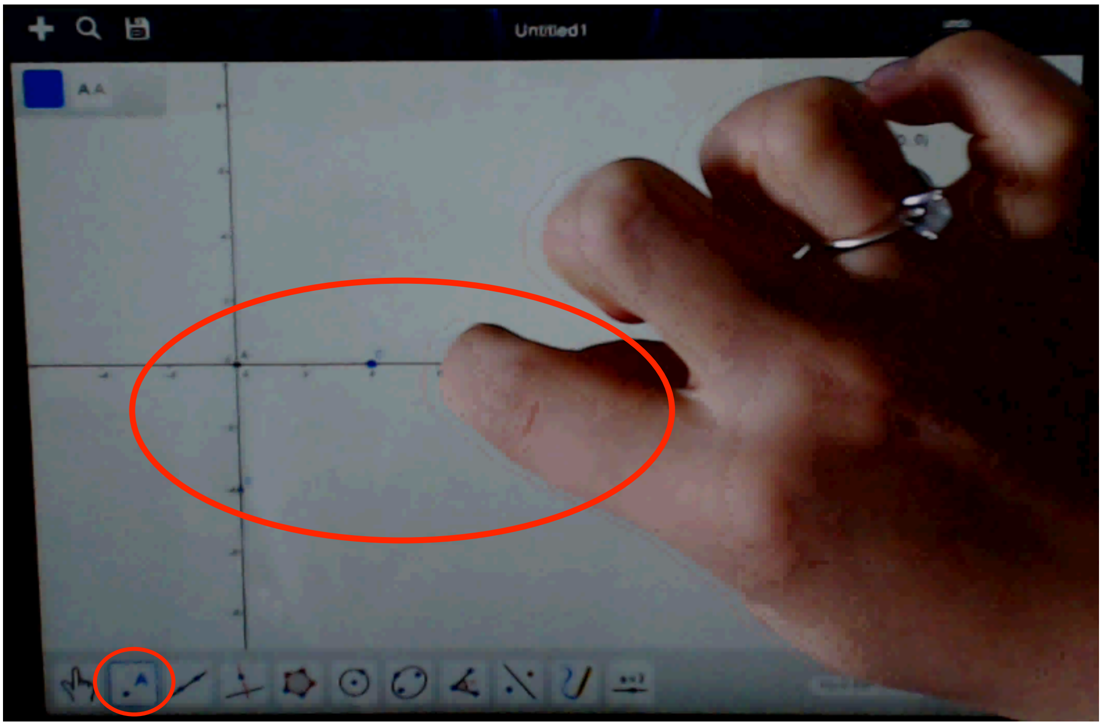


Figure GM 10: Put four points

2. Draw four segments, connecting the points.

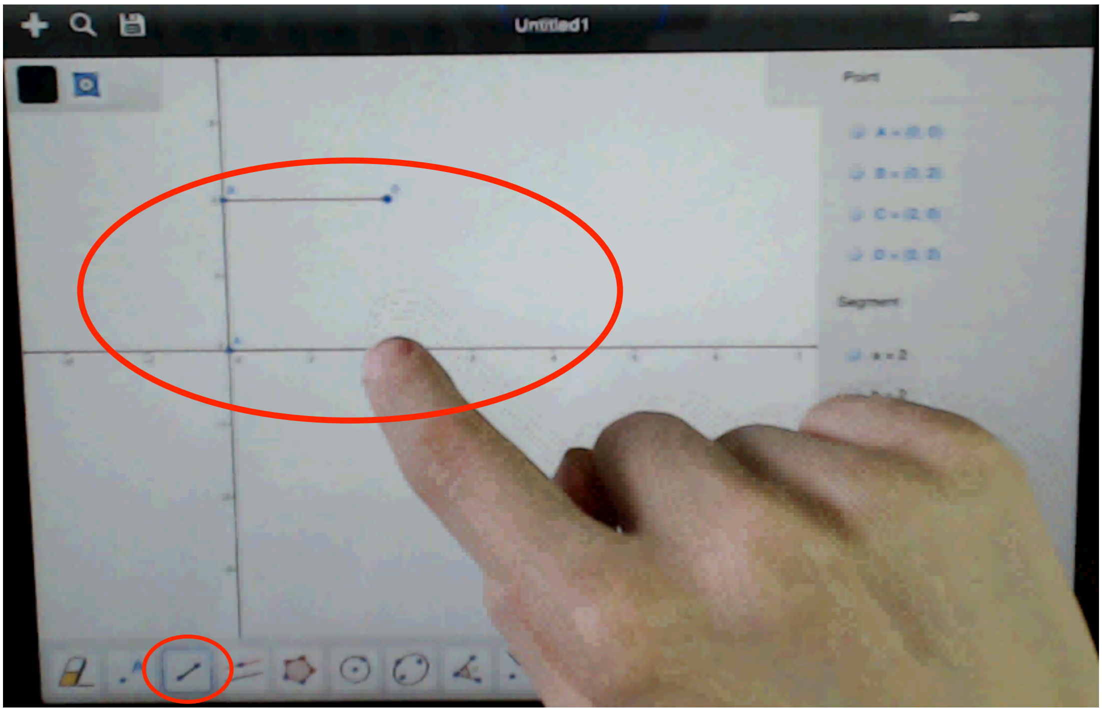


Figure GM 11: Draw four segments, connecting the points.

3. Prove it, using angle tool

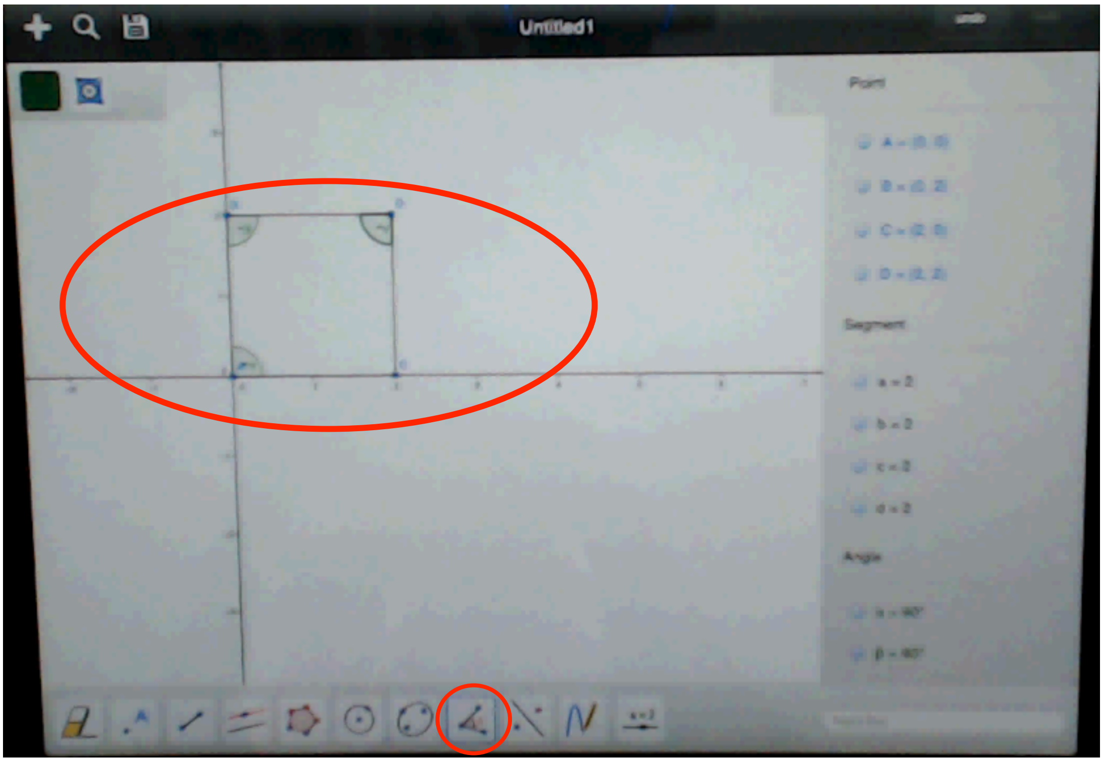


Figure GM 12: Prove it, using the angle tool

Second way

1. Draw four segments.

Figure GM 13: Draw four segments.

2. Prove it, using the angle tool

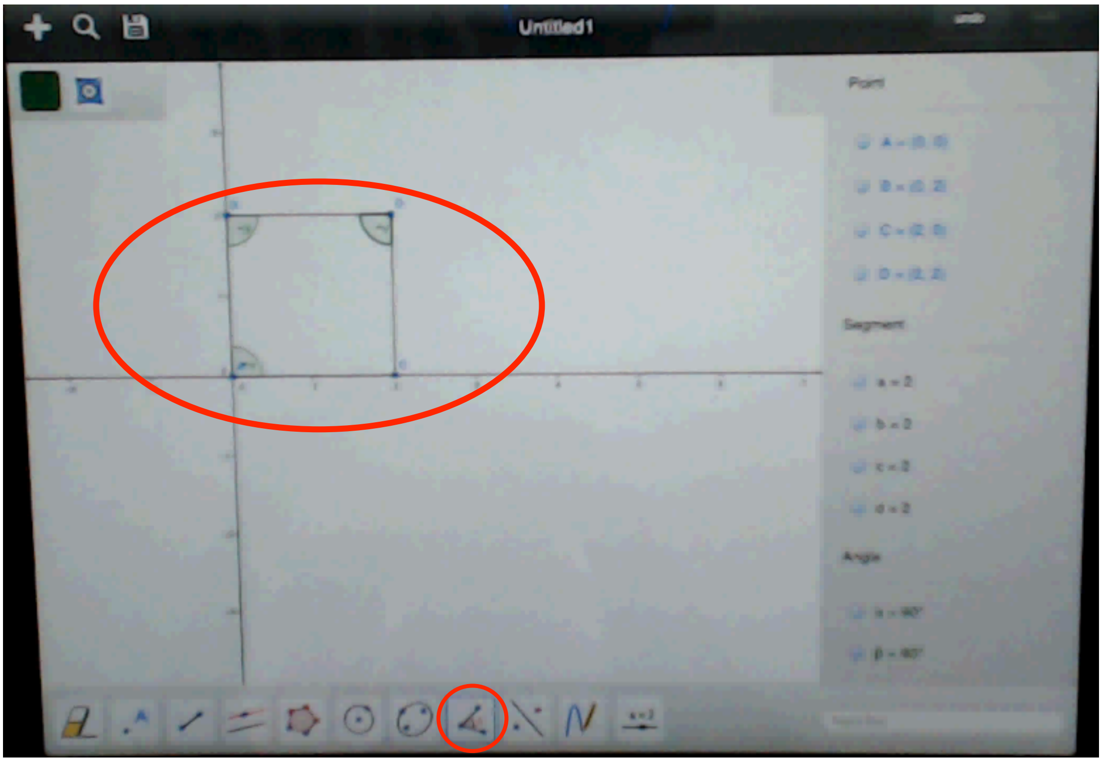


Figure GM 14: Prove it, using the angle tool

Third way

1. Using the input bar and type the points' coordinates or lines' equation.

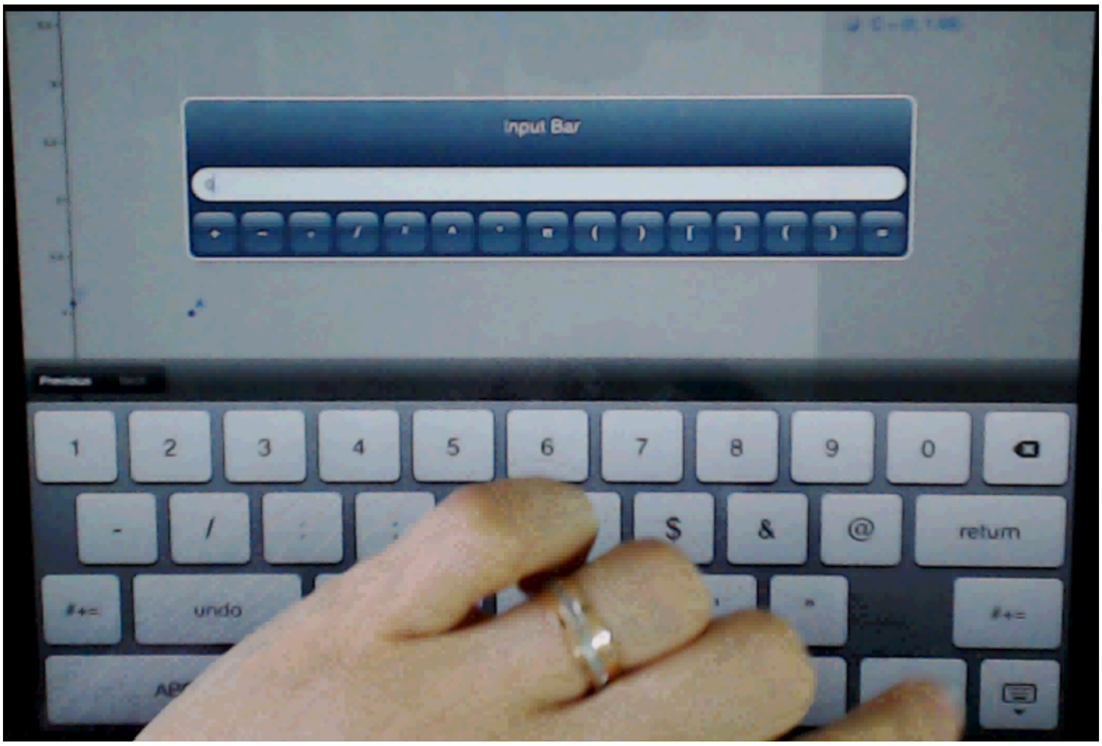


Figure GM 15: Using the input bar and type the points' coordinates or lines' equation.

2. Prove it, using the angle tool.

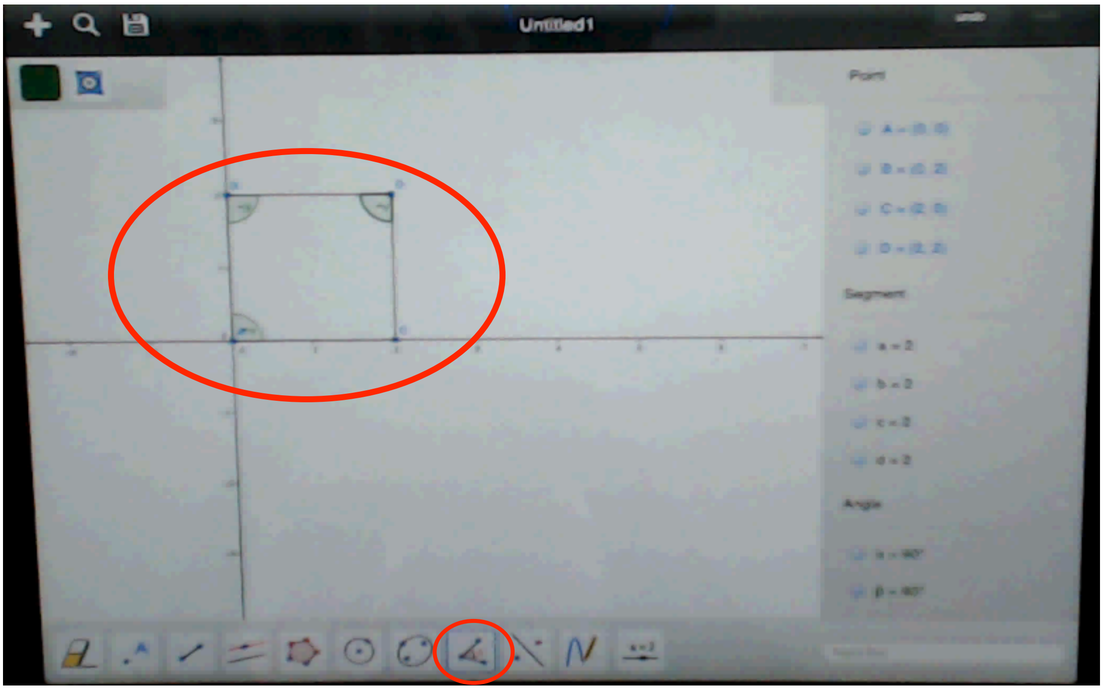


Figure GM 16: Prove it, using the angle tool.

Main problems and suggestions:

The problem faced by many participants in his task was the same. Whether they used the line tool or point tool, they had a problem with not clicking the wanted coordinates while using either tool. Some of the participants could overcome this difficulty by using either Redefine Window or Input bar. Those who failed to overcome the problem lost a lot of time due to this problem. It could be said that putting a point where it is wanted continued to be a problem with the mobile version of Geogebra software. Intersecting the axis and put a point on the axis was very sensitive and hard for the users. The reason of this was the size of point to be smaller than the size of fingertip. To overcome this problem, the system should zoom in the area clicked by the user by means of a lens and make his work easier.

The problems faced while using the angle tool have continued in this task, as well. Even though the participants who used this tool in task 1 for the first time used the same tool in this task again, they went on showing the external angle firstly. The user who tried to carry the point without clicking the move tool in Task 2 repeated the same action in this task, too.

Another difficulty faced by the user was his attempt to click the Redefine window open. This window was opened by double clicking the point expected to be changed but the user did not know this. The participant who could finally open the Redefine window could not carry out the changes he did, because he was confused by the fact that arrow key was return button. The fact that Geogebra does not have its own standard keyboard in such areas as Redefine window and Input bar to enter data and uses the keyboard of the computer in which it is installed makes it difficult for the users to enter data and to cause difficulty in okaying the data.

Another problem was about constructing an angle with the dimensions given, a function, which was, present in Desktop version but was not supported in the Mobile version. One user tried to do it by using the angle tool but could not do it.

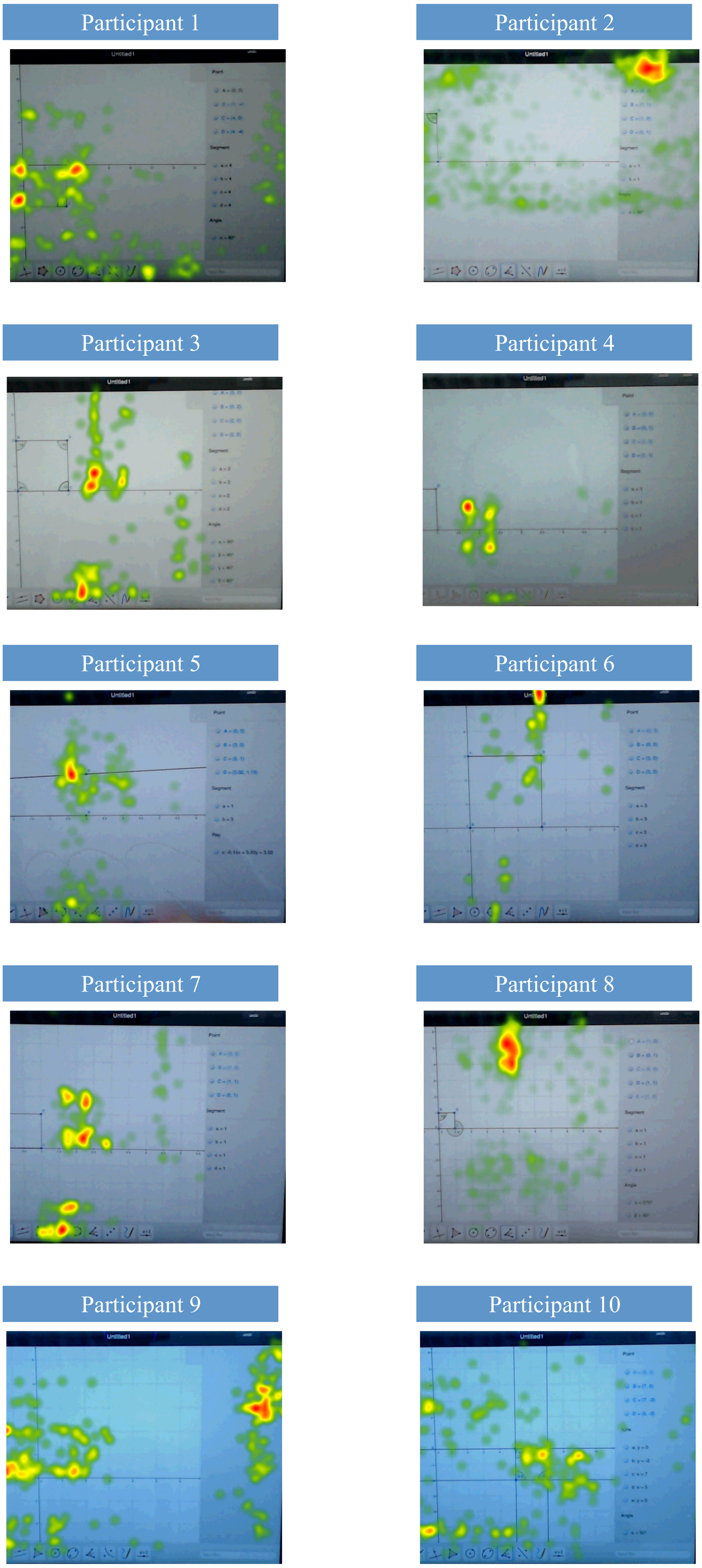


Figure 42: Task 3 Heatmaps

4.3.3.4 Task 4

The task: Draw a graph of the equation $y = 3x^2 +5$.

Table 25: Task 4 Eye-Tracker Results for the Third Study

Participants	Spent Time on Task *milliseconds *	Time to first fixation for input bar.*milliseconds*	Number of fixations before the first fixation on target	Total Fixation
Participant 1	212878	154764	430	641
Participant 2	214818	-	-	525
Participant 3	180000	43435	80	229
Participant 4	72188	6453	39	123
Participant 5	187292	56653	78	283
Participant 6	169219	103768	149	270
Participant 7	381270	175956	834	992
Participant 8	355208	10283	91	307
Participant 9	133300	64161	256	384
Participant 10	220083	-	-	608

All participants completed this task. In this task, we tried to understand users' notability of Input bar. Two participants could not notice the input bar. On average, participants made 432 fixations in total in this task. Before noticing the input bar, they made approximately 245 fixations. Time to first fixation for input bar average was 76, 93 seconds. Before noticing the input bar, they spent their time using the Slider, Pen and Line tools. No one could use the Slider Tool properly. However, they could use the Pen tool. 60 % of participants used Pen tool and drew any object. One of the participants used the Z tool to draw a graph, and then she clicked on this graph and changed the equation to draw the correct graph. Similarly, one of the participants drew a line first, and then clicked on the line's function in the algebra pane, opened the Redefine window and typed the equation for the given function to plot its graph.

In this task, Participant 8 had more difficulties than the others so we examined her experiences during throughout in detail. She always thought that she could draw a graph using Parallel Line Tool. She spent more time using this tool. She looked and used this tool again. Using this tool, she drew a line but she deleted this line and put a point using this point with Parallel Line tool; she drew a line. Then she used the line tool and drew a vector. She deleted all the objects. She looked again at Parallel Line tool. She used this tool and drew a line. While she was trying to change this line's function, she recognized the input bar at 02:31. She gave up using input bar at fixation. Then she tried to change the line's function. She erased the line. The researcher asked her: "Why did you give up using input bar?" She said that because she could not find an area for the input. Then she drew a line and deleted the line. She looked at the Slider tool; she used this tool and she gave up using it. At 04:13 she again looked at the input bar. She typed the function and saw the graph at 05:02. This graph was not the true one because she wrote the function wrong. She, however, noticed that it was wrong. Then she clicked the input bar and drew the graph.

In accordance with the purpose of this task, there appeared problems with finding the input bar to be used. The participant lost much time because he insistently tried to use the parallel line tool and could not use this tool effectively. Even though he found the Input bar and clicked it, he gave up doing so as he had no idea about what it was for, and so he went on clicking other tools. The participant who used the input bar later again did wrong while entering data through the keyboard on the Input bar screen, and he had to repeat this process.

There are two ways for drawing this graph. First way has 3 main steps.

1. Step: Finding the input bar

Figure GM 17: Finding the input bar

2. Step: Typed the equation

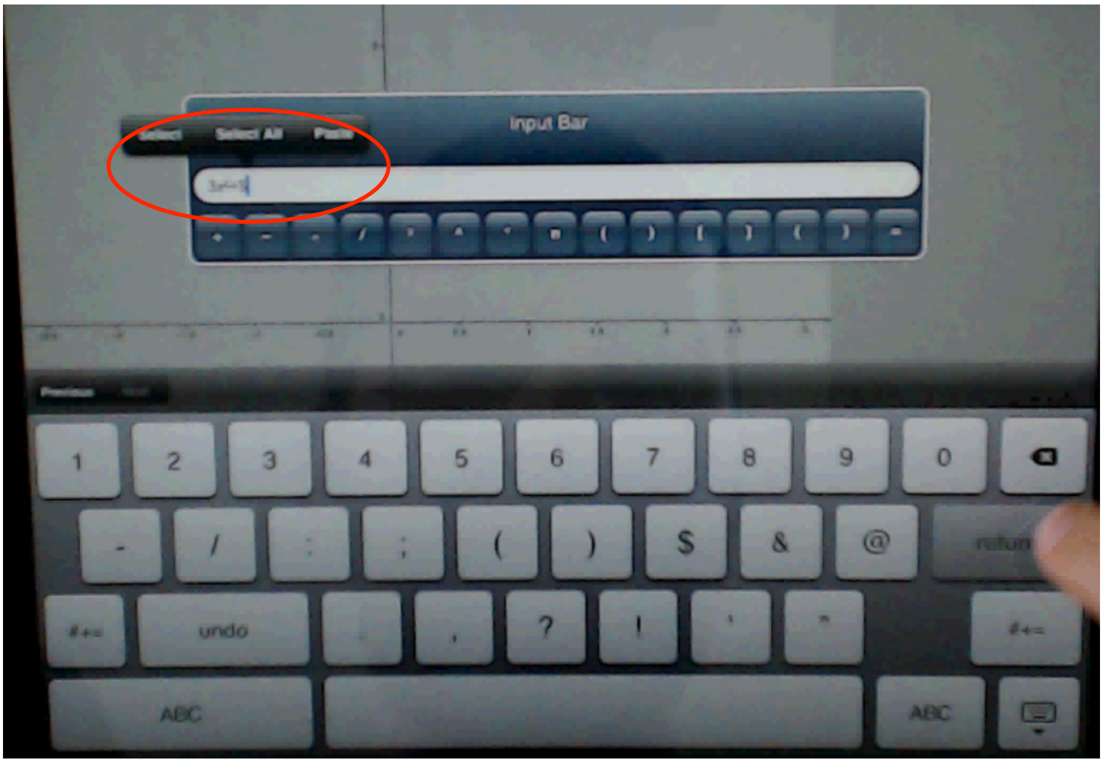


Figure GM 18: Typed the equation

3. Step: Draw the graph.

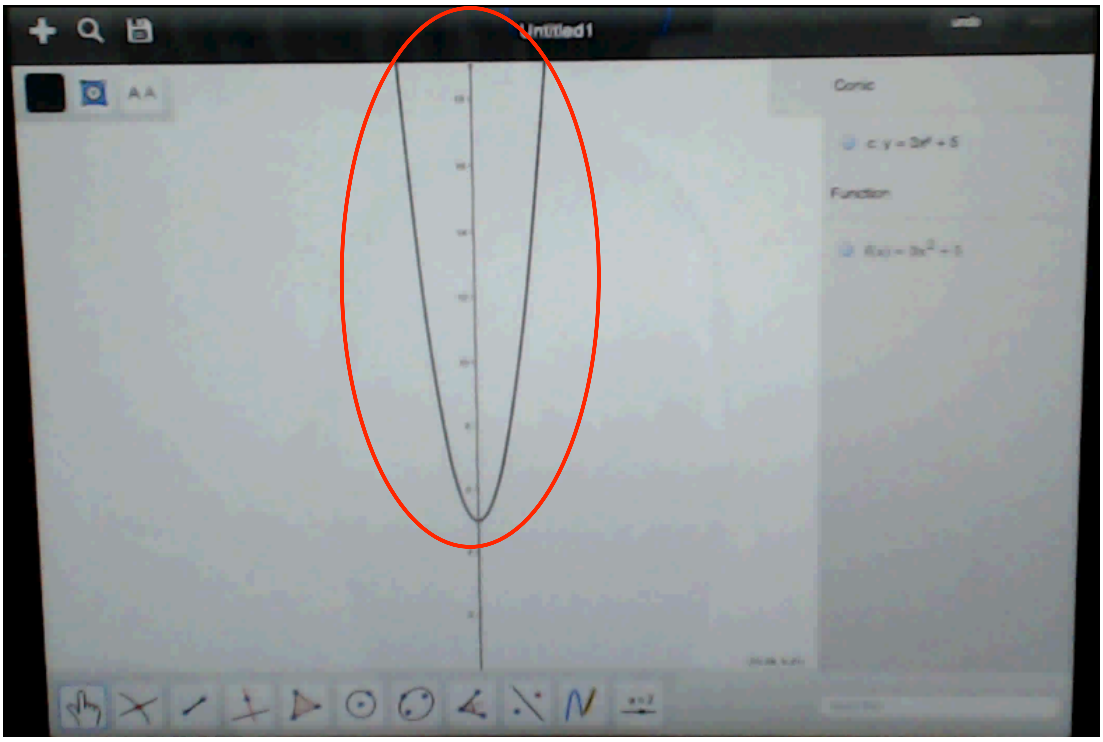


Figure GM 19: Draw the graph

Second way has three main steps too.

1. **Step:** Press on the Z button and draw any graph.

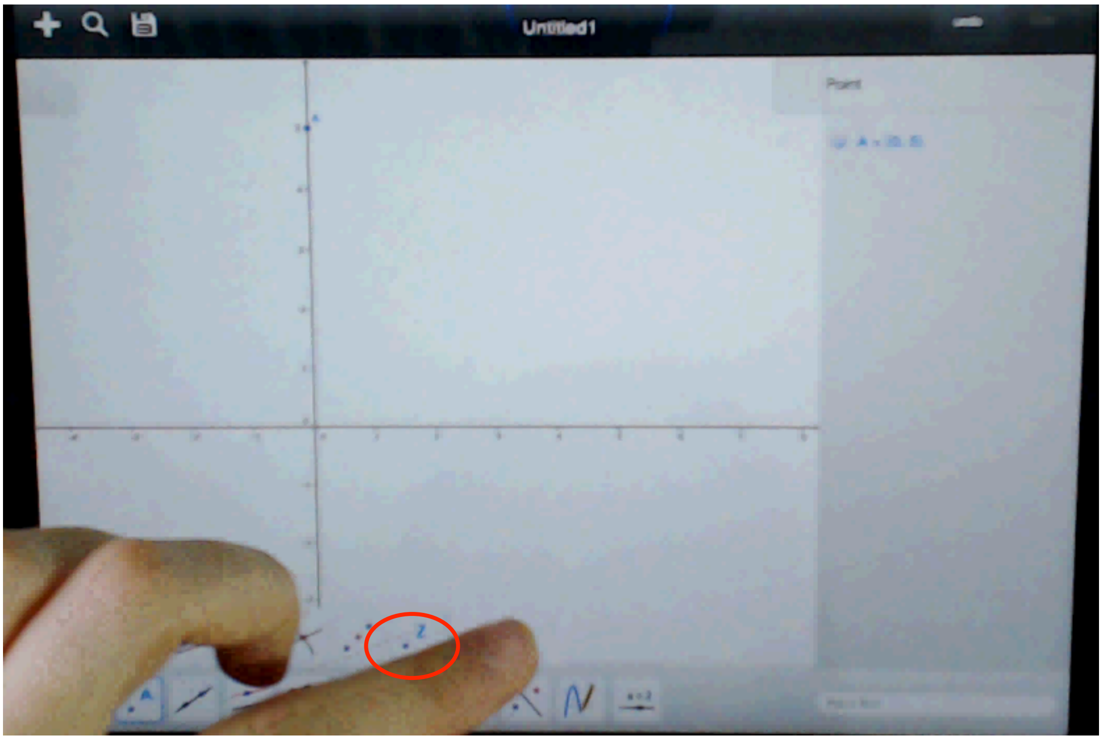


Figure GM 20: Pressing on the Z button

2. **Step:** Open Redefine window and changed the equation

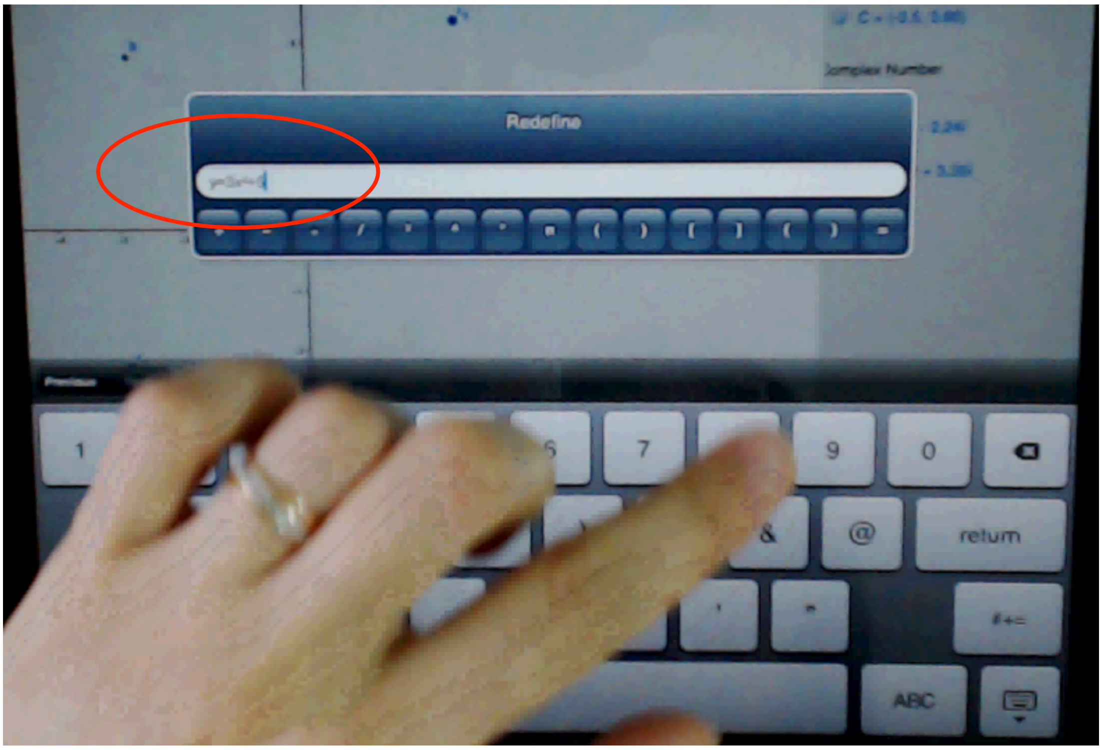


Figure GM 21: Open Redefine window and changed the equation.

3. **Step:** Draw a graph.

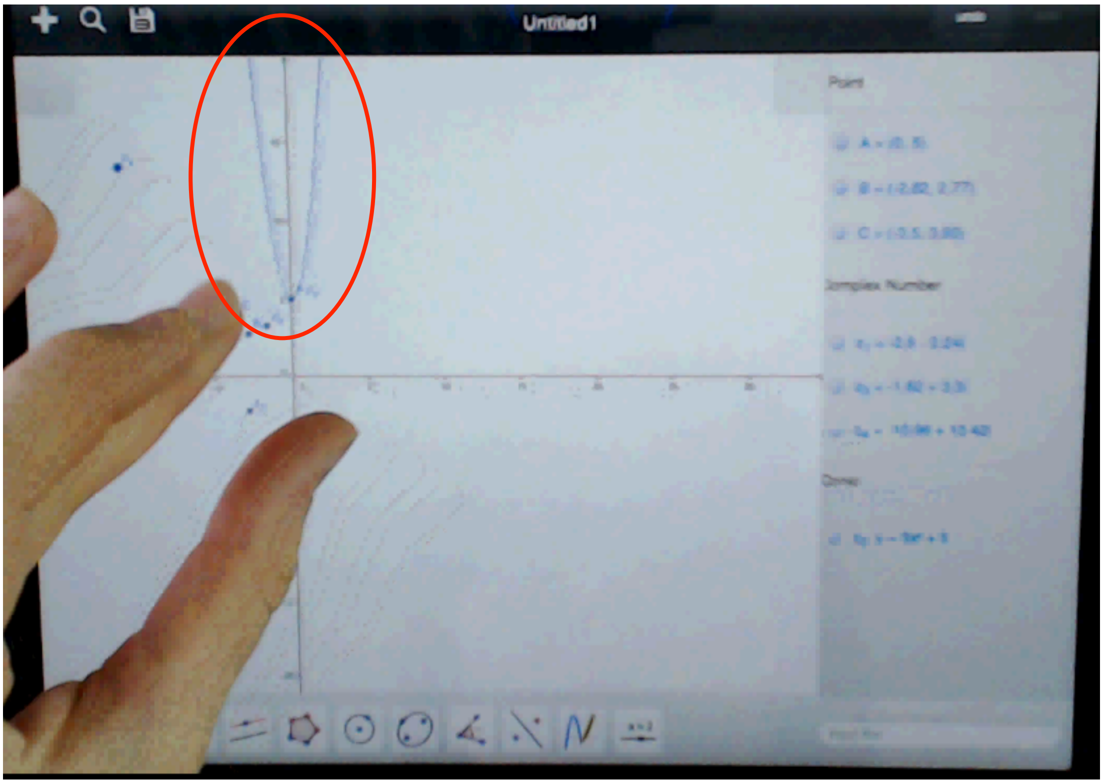


Figure GM 22: Draw a graph.

Main usability problems and suggestions

What we expected of the users in this task was to draw the graph of the equation given by using the input bar. Two of the participants did not use the input bar and instead, one of them used the Z button and drew the graph by changing the equation given by the system through the Redefine window, while the other drew a line by using the Line button and drew the graph by changing the equation of the line using the Redefine window.

In general, the problem faced by all the users in this task was that Input bar could not be found by the users. The participants could find the input bar in their 13th attempt on average. They also spent about 1 minute and 22 seconds for this on average. The reason was that input bar could not be determined on the page. The placement of input bar near the other tools and its giving a warning when approached may be a solution to this problem. 6 of 10 participants clicked the slider button instead of the input bar because the icon of this button had an appearance that would confuse them. The changing of this icon may be another offer for solution.

Another problem was that a keyboard of the device is used when Input bar or Redefine window is opened and a keyboard with a more mathematical characteristic instead is not opened instead. It was observed as big deficiency for Geogebra. Due to this deficiency, the participants spent 25% of their on average trying to enter data on this keyboard.

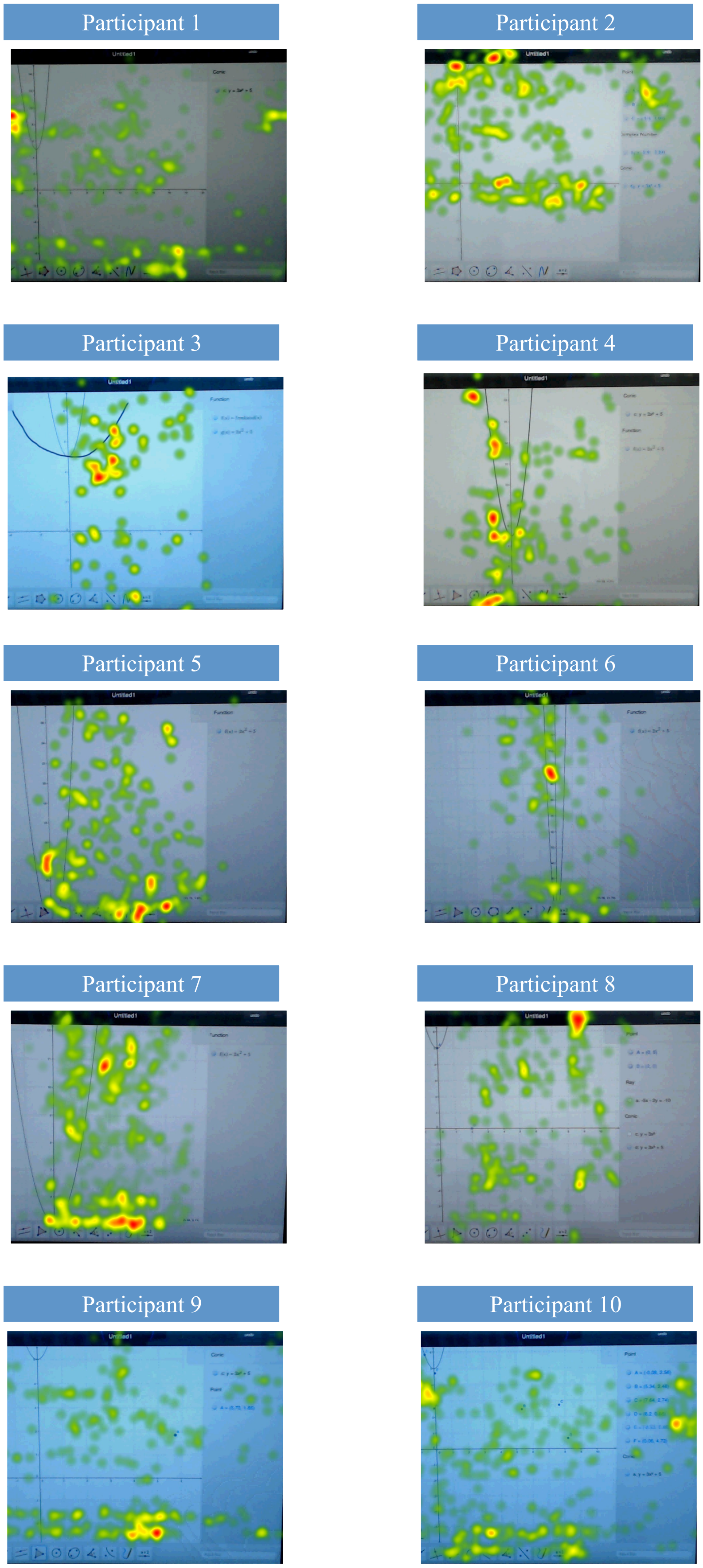


Figure 43: Task 4 Heatmaps

4.3.3.5 Task 5

The task: Draw three parallels and forms an equilateral triangle, which should touch the parallels at its corners.

Table 26: Task 5 Eye-Tracker Results for the Third Study

Participants	Spent Time on Task (milliseconds)	Steps Count to Complete the Task	Total Fixation Count
Participant1	554878	77	1433
Participant2	306081	54	819
Participant3	182812	17	378
Participant4	218438	18	386
Participant5	219583	26	378
Participant6	651938	44	910
Participant7	279240	19	591
Participant8	314844	27	316
Participant9	328600	34	893
Participant10	479260	36	1078

Six participants could complete the task. This was the task in which the number of participants who failed was the highest. Participants mostly used the parallel line, line, polygon, undo, move, erase, angle, and regular polygon tools. Three of them used algebra plane; two of them used the Redefine window; one of them used perpendicular bisector and perpendicular line tool; one of them used angle bisector; one of them used circle through 3 points and input bar; one of them used perpendicular and half line tool, and one of them used point tool.

In this task, Participant 3 had more difficulties than the others so we examined her experiences during throughout in detail. The participant had the utmost difficulty drawing the parallel line while solving this task. To draw 3 lines parallel to each other, the user clicked the parallel line button six times and could draw it in his sixth attempt. To complete the task, he was required to draw an equilateral triangle with corners on these parallel lines. He constructed any triangle using the triangle button. He did not want to replace it with the equilateral. After spending long time using the parallel line button, he gave up doing the other requirements of the task, as well. He gave up complete the task.

In this task we limited the user to drawing a parallel line using parallel line tool and they were free to use all tools to construct an equilateral triangle. However, all participants who completed the task used regular polygon tool to construct and equilateral triangle.

First way:

1. Construct an equilateral triangle using the regular polygon tool.

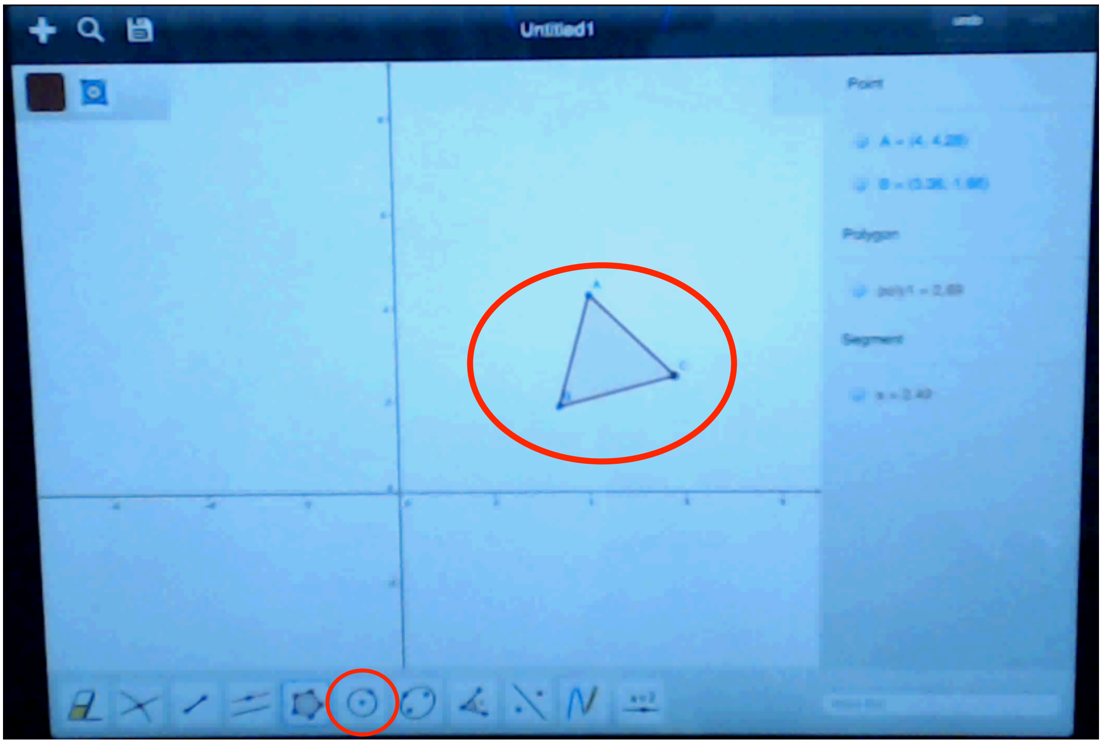


Figure GM 23: Construct an equilateral triangle using the regular polygon tool.

2. Draw three parallel lines using the parallel line button.

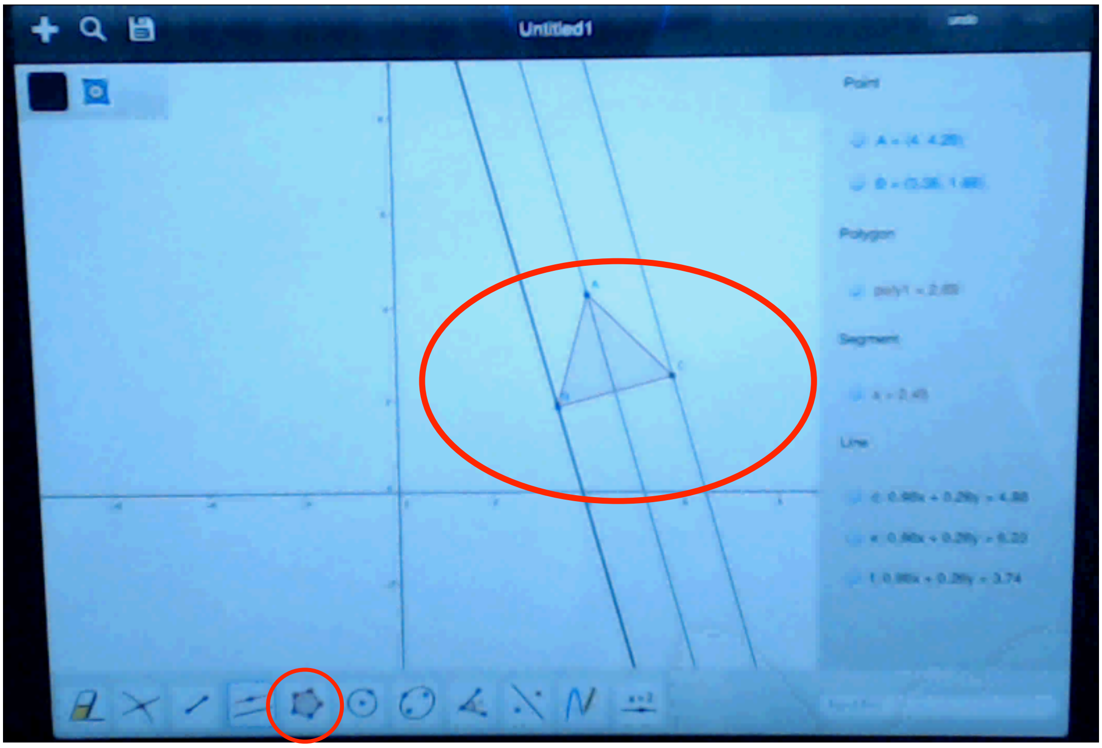


Figure GM 24: Draw three parallel lines using the parallel line button.

or

1. Draw three parallel lines using the parallel line button.

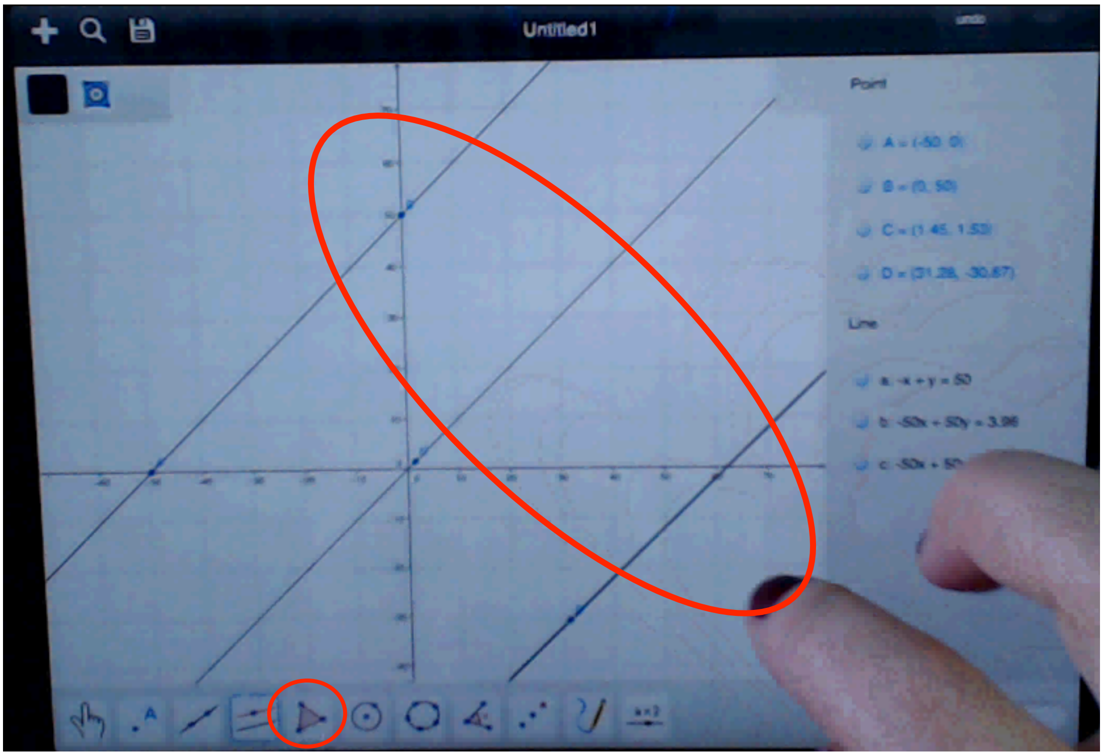


Figure GM 25: Draw three parallel lines using the parallel line button.

2. Construct an equilateral triangle using the regular polygon tool.

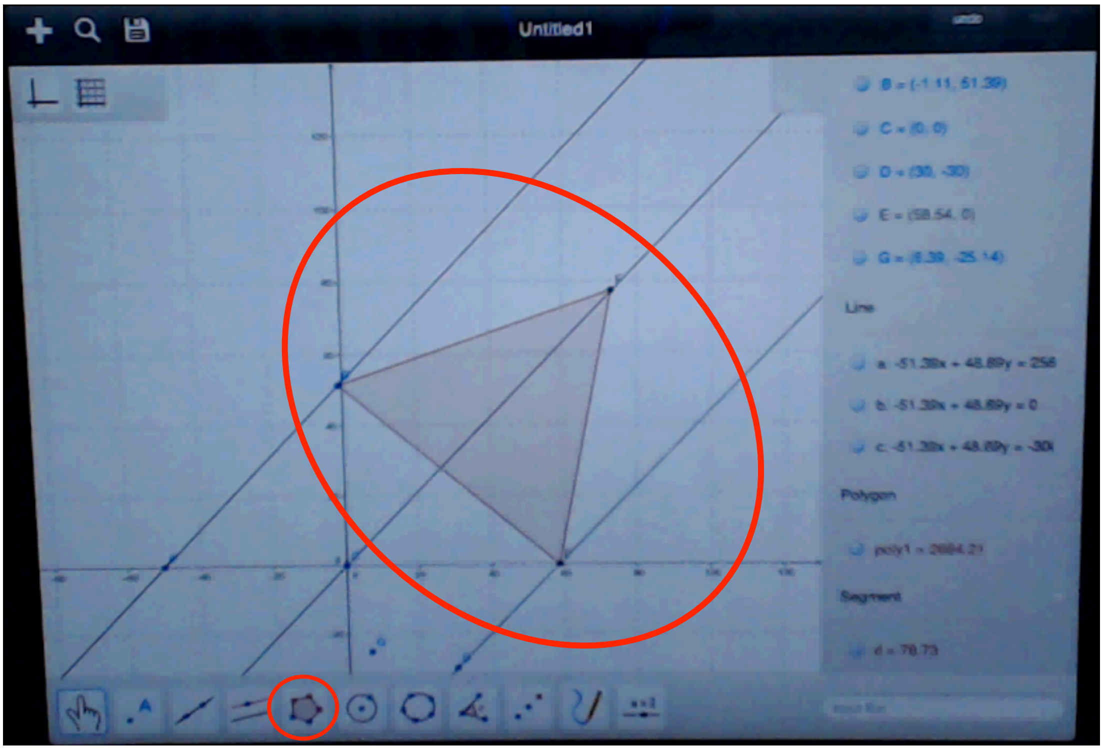


Figure GM 26: Construct an equilateral triangle using the regular polygon tool.

Second way

In this way the difference is contrusting the equilateral triangle with circle and segment tool.

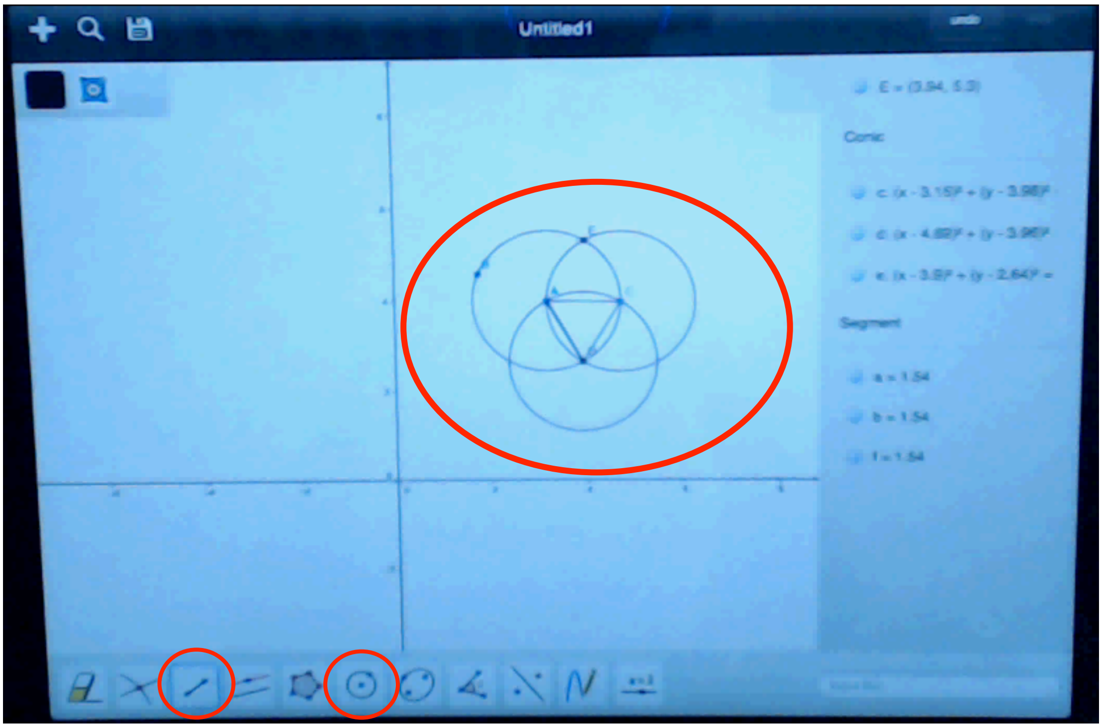


Figure GM 27: Constructing the equilateral triangle with circle and segment tool.

Main usability problems and suggestions

There were two important issues in this task. The first was to draw 3 parallel lines by using the parallel line tool. The other was to construct an equilateral triangle. The problem mostly faced by the participants who used the parallel tool was for them to put points instead of drawing a line. To use the parallel line tool in Geogebra, it was necessary to choose another line firstly and then to draw another line parallel to it. In other words, after clicking the parallel line tool, firstly the line targeted would be clicked and then the screen would be clicked to draw the desired parallel line. The participants who did not know at first that they needed another line faced this problem, and then formed a line to solve this problem, but this time they went on putting points as they did not know the order of clicking. A participant thought why he did not consider the line I, and thereupon he clicked first the parallel line tool and then select button. He, thus, thought he had chosen the line I, and clicked the screen but could do no more than putting points. There is a need for a solution to this problem existing in the desktop version of Geogebra. To solve this problem, the users should be given a hit message when they are on the parallel line tool. Then the steps that they should follow should be determined. For example, when a point is put, it should say “select a line” or the messages such as “first click a line, and then click the screen” will solve the problem.

Although the drawing of an equilateral triangle, which is another element of the task, was easy for some participants, it proved difficult for others. Unable to know that an equilateral triangle could be drawn by using the regular polygon tool, the participants lost time using the other polygon tools. Two participants tried to construct an equilateral triangle by intersecting the circles, but they could not do it. Being one of the basic elements of Task 6, this case will be described in detail there. One of these two participants had first started to construct an equilateral triangle and then he gave up completing the task upon failing to do so. Another problem was that not all the corners of the equilateral triangle were on the parallel line. While some carried the move tool and carried the triangle or lines, others did not think of doing so and erased them and constructed new lines or triangles. For this problem to be solved, Geogebra, as a solution, may allow the user using the regular polygon tool to mark the points he likes to.

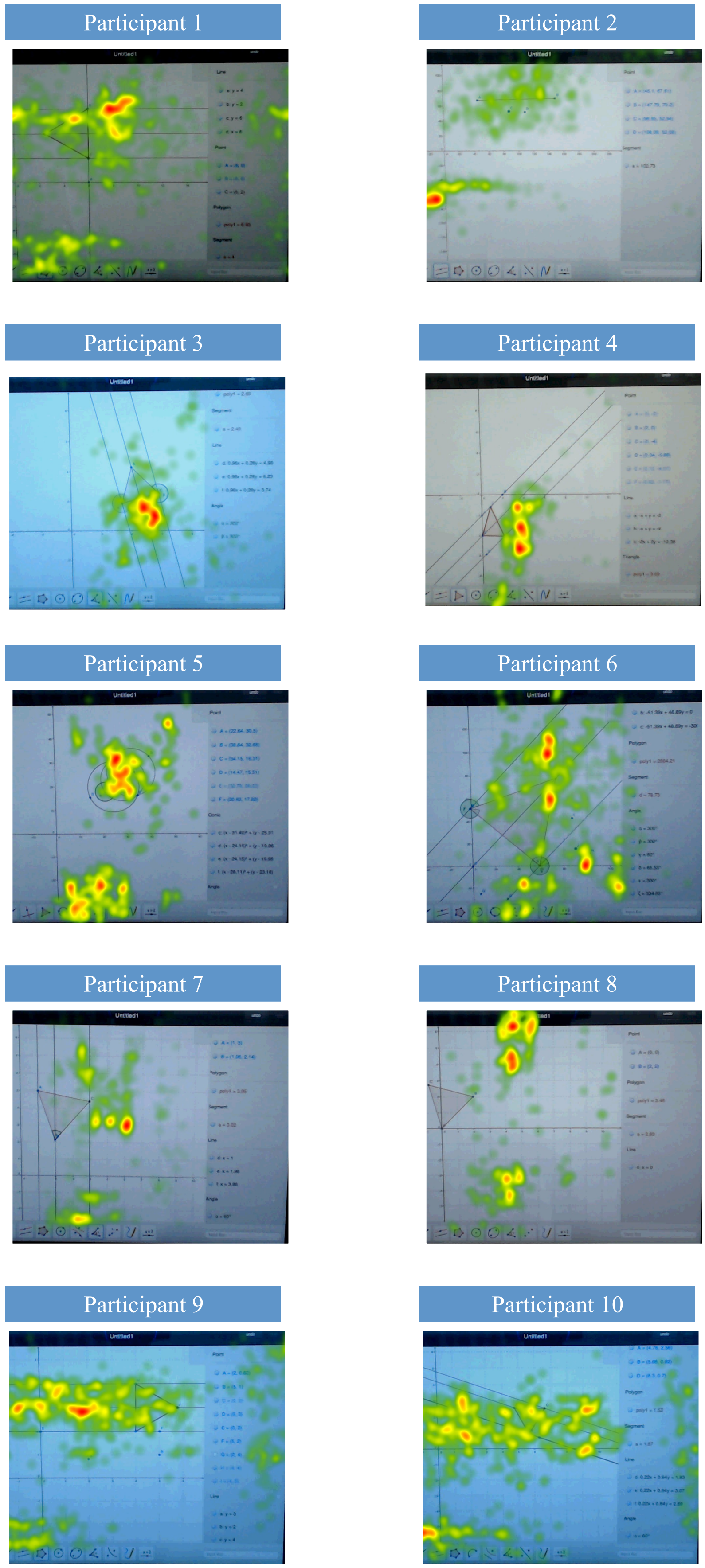


Figure 44: Task 5 Heatmaps

4.3.3.6 Task 6

The task: Using only circles and segments draw and prove a hexagon.

Table 27: Task 6 Eye-Tracker Results for the Third Study

Participants	Spent Time on Task (milliseconds)	Steps Count to Complete the Task	Total Fixation Count
Participant1	448439	39	1068
Participant2	435253	69	1035
Participant3	235312	40	492
Participant4	347812	33	708
Participant5	697500	47	1348
Participant6	407906	38	647
Participant7	585330	49	1424
Participant8	458542	28	553
Participant9	613800	32	1495
Participant10	288135	23	612

In this task, three of the participants could not complete the task while seven of them completed it. We limited the participants to using regular polygon tool. They only used circles and segments to draw a hexagon. However, one of them clicked regular polygon tool and she remembered and gave up using it. All of them used circle and segments tool. They also mostly used undo, erase and redo tools. Seven of them used intersect button to intersect the circles. Two of them used circle sector button. Four of them used move tool to move circles. Four of them used algebra pane and one of them used redefine window to redefine the equation of circle. Three of them used point tool to intersect the circles. One of them used polygon button to connect the points and draw a hexagon; he first constructed the triangles and then completed it to a hexagon. One of them used very different tools, for example circle through 3 points and ellipse tool, to construct the circle and used parallel line tool and line tool. This tool could not help him complete the task.

In this task, Participant 5 had more difficulties than the others so we examined his experiences during throughout in detail. The user mostly used the circle, segment tools while doing this task. One of the parts in which he had a lot of difficulty was while drawing intersecting circles with the same radius. In the 31st step, he could form two circles as he liked to. To be able to go on the question from then on, he needed another point on which these two circles intersected. He looked for the intersection tool but could not find it for long. Instead, he used the circular sector tool and constructed the point that he needed. He drew a third circle and constructed a triangle where these two circles intersected and proved it to be equilateral by using the angle tool. Unable to decide and see what to do next, the participant looked at the screen for long. Using the parallel line button, he used parallel lines. Absorbed by the thought that he could not complete the task, he gave up completing it.

The ways to follow while solving this question:

1. Construct a circle using the circle tool.

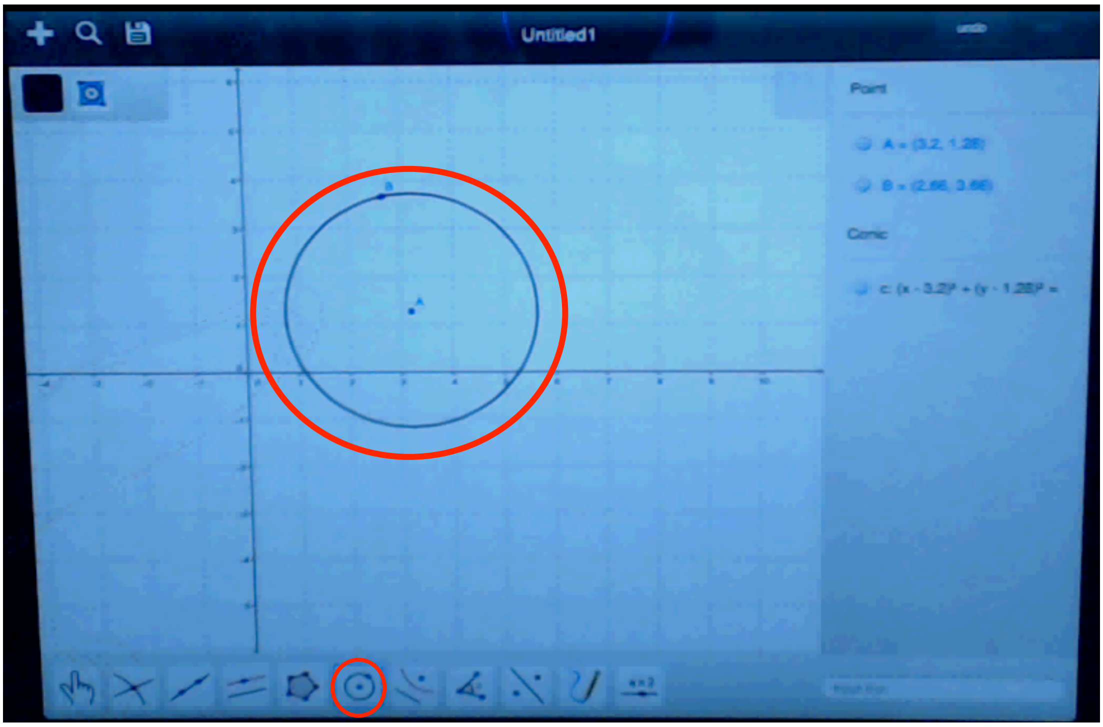


Figure GM 28: Construct a circle using the circle tool

2. Construct the second circle.

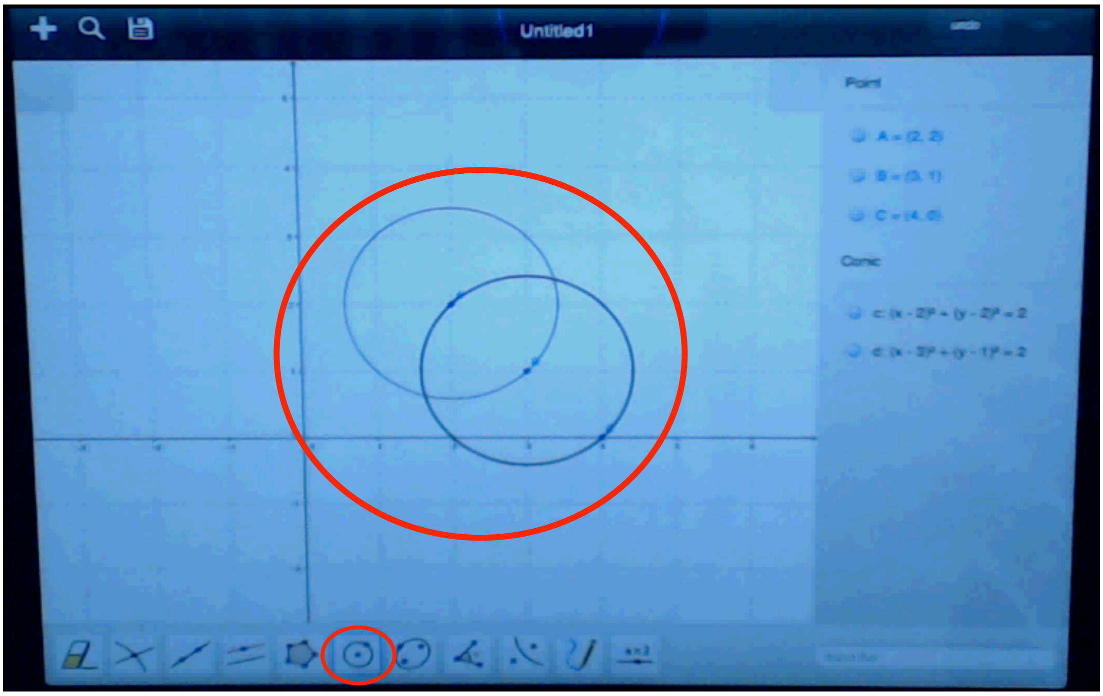


Figure GM 29: Construct the second circle.

3. Intersect the circles
   a) Using the intersection tool.

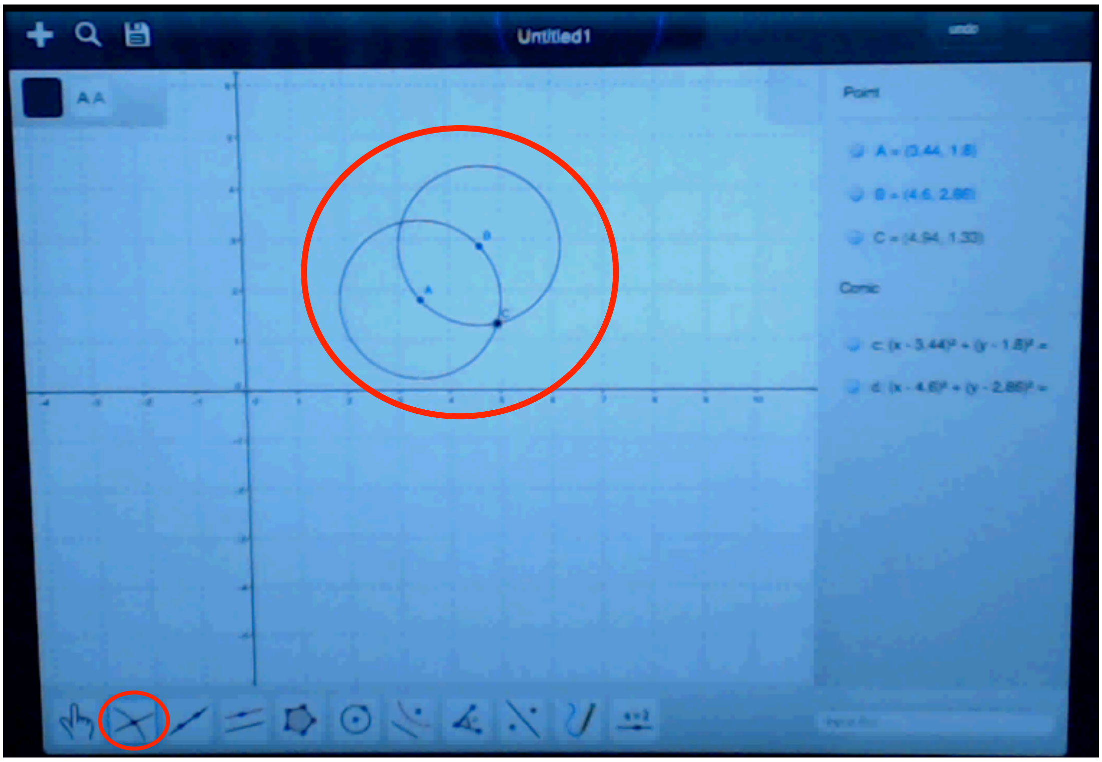


Figure GM 30: Intersect the circles using the intersect tool

b) Using the circle sector button.

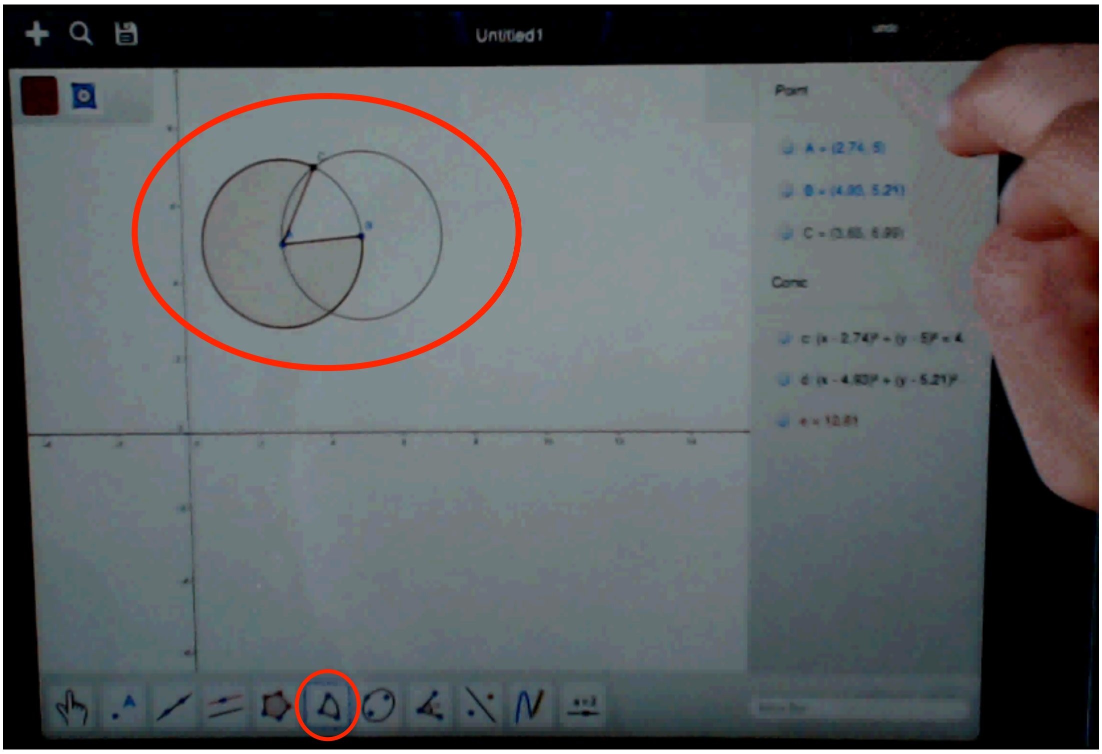


Figure GM 31: Using the circle sector button to intersect the circles

4. Draw the third circle using the circle tool.

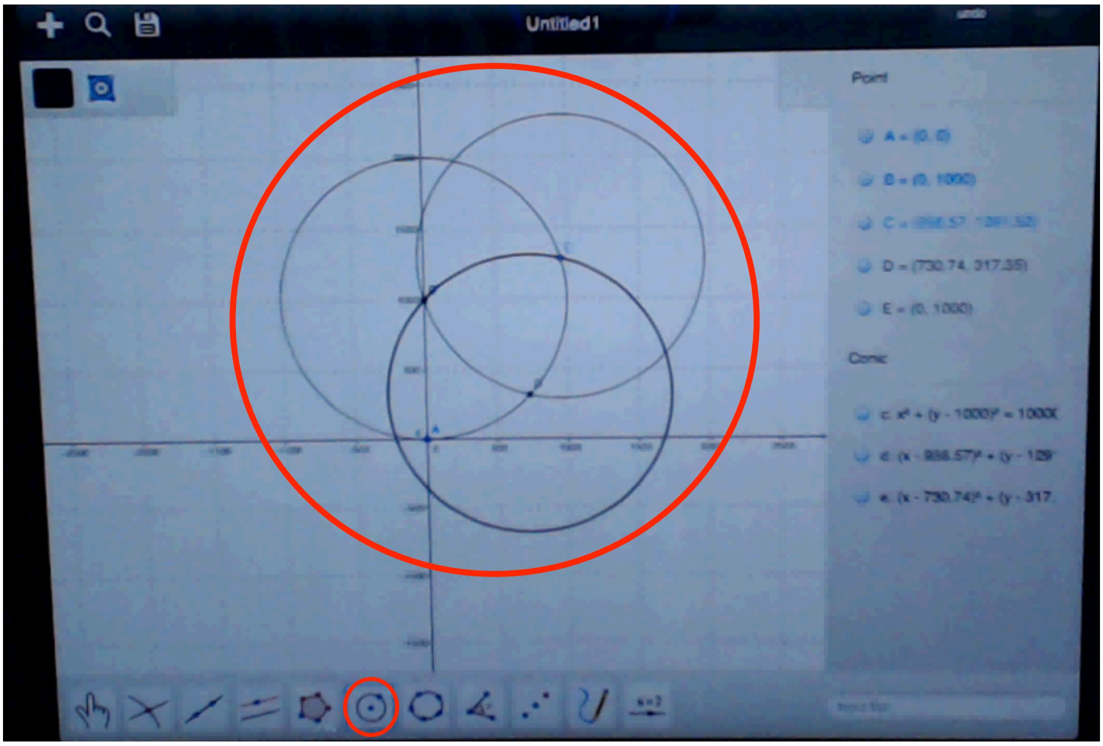


Figure GM 32: Draw the third circle using the circle tool.

5. Draw the other circles and use segment tool and draw segments.

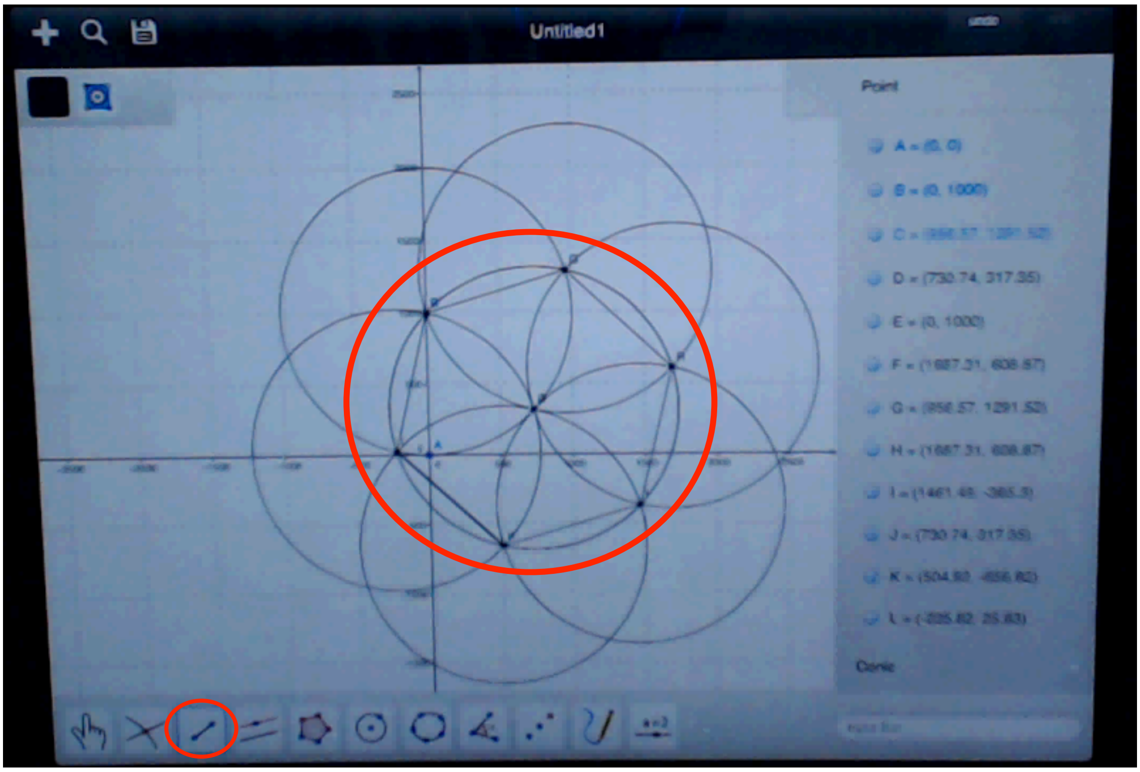


Figure GM 33: Draw the other circles and use segment tool and draw segments.

6. Using the angle tool and show the angles.

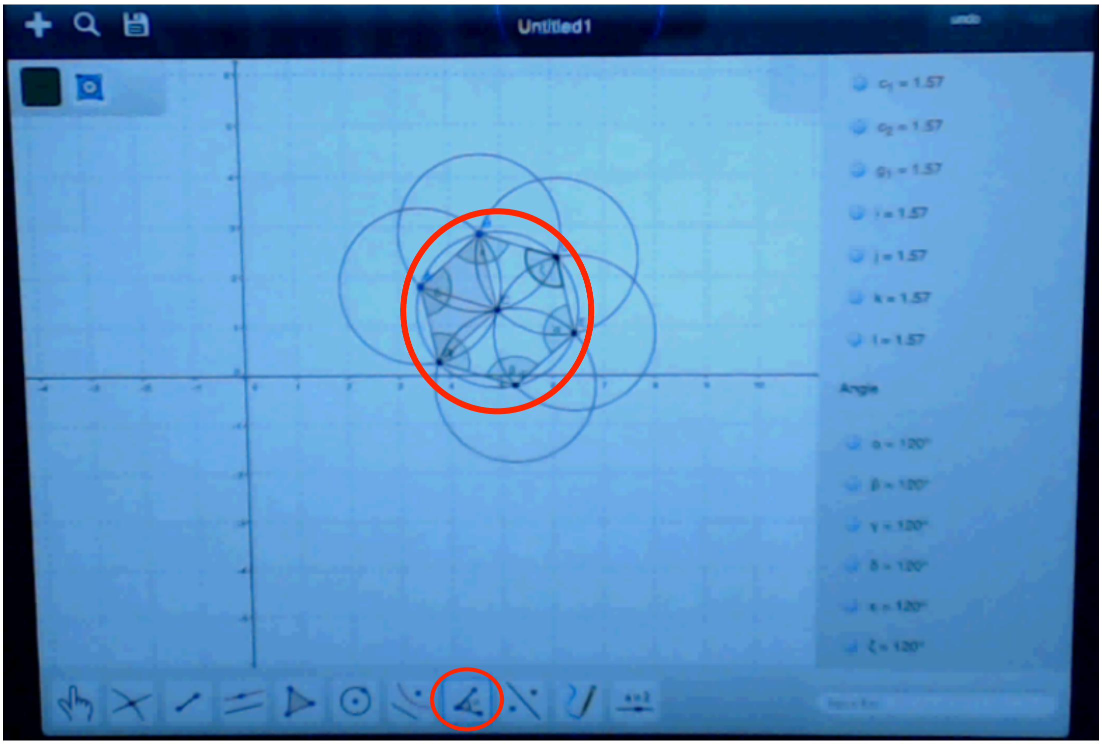


Figure GM 34: Using the angle tool and show the angles.

Main usability problems and suggestions

To complete this task, the participants were required first to use the circle tool to draw circle with A center through B den point and circle with B center through A point. Then they were required to determine the intersecting points of these two circles by using either intersect or circle or circular sector tool. It was necessary to obtain 6 intersecting points by drawing the other circles with these points as their center and passing from A. they would later form a hexagon connecting these points to each other by means of the segment tool. The angle tool was a usable alternative to prove it.

While completing this task, most of the participants had difficulty forming circles with the same radius intersecting with each other. To intersect them accurately, they were required first to draw the circle A center through passing from B and then click the B point as the center and through A point. With no message and guiding about this, the participants drew intersecting circles either with the same radius or with different radius. Though a participant was required to form a circle with B center through A den point and by using the circle with A center through B den point, he formed a circle with C center through A den point. She only put new points and constructed new circles at every turn. Moreover, these circles were not intersected because of the distance between them. Another case in which the participants had difficulty was to form new intersecting points on these intersecting circles. Most of them looked for the intersection tool for a long time. It did not occur to them that the point tools of Tool would be in the subtitle. Considering the duty and usage form of this tool, they ignored the probability that point tools would be in the subtitle, and so they looked for them for long.

They had problems with using the intersect tool, too. It was because it was necessary first to click a circle and then the other circle. Those who tried to put the intersecting point immediately without doing this process failed. Another problem faced by the participants was that everything was being deleted on the screen while they were doing it. The users, therefore, had to redraw the circles, which they had already formed. Similarly, a problem as experienced with the use of delete tool, which led to the deletion of everything on the screen.

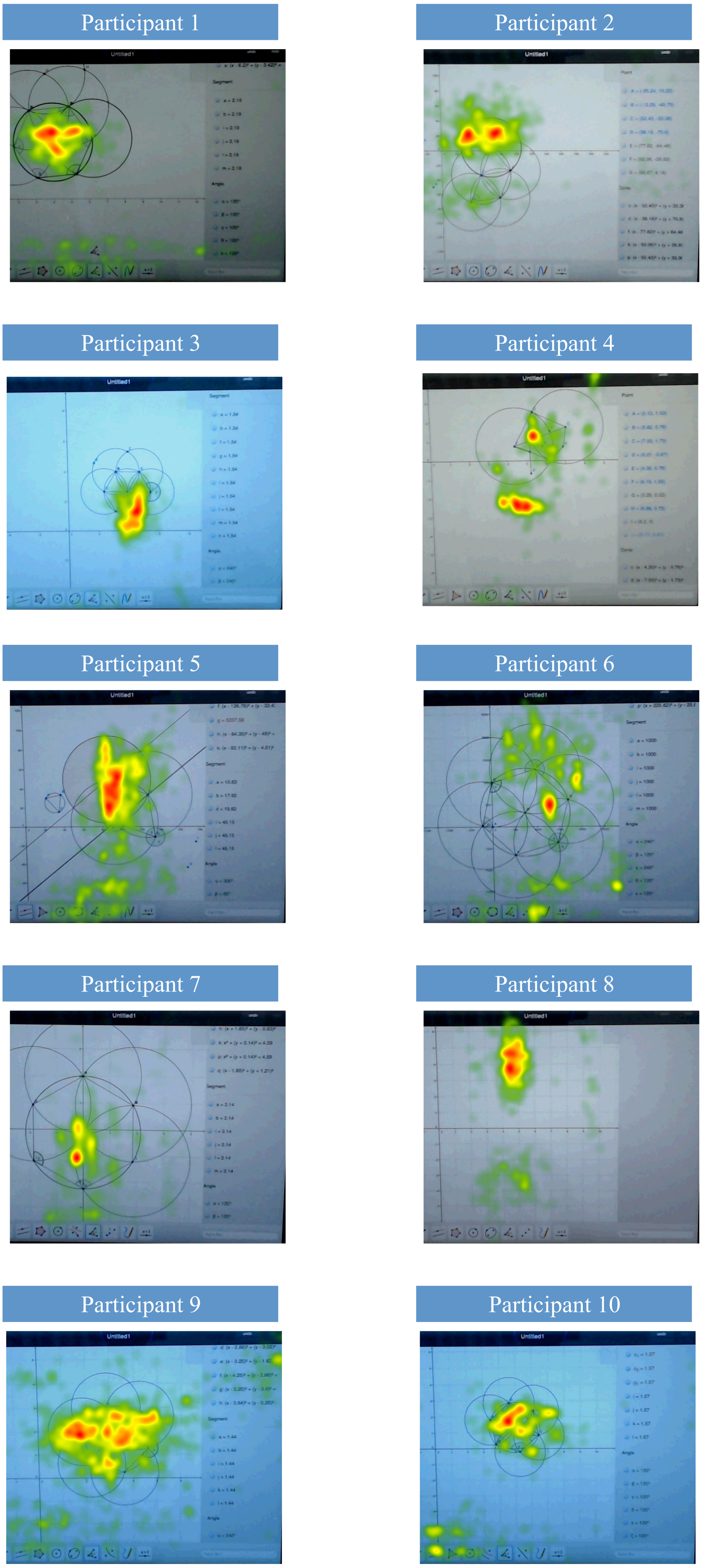


Figure 45: Task 6 Heatmaps

4.3.4 Open-ended questions

The participants were asked their opinion about the Geogebra Mobile Version. Two of them did not indicate their opinions.

4.3.4.1 Participant 2

- Not being able to do what I have done in Geogebra at once makes me get bored.
- It was very hard for me to make any input. I spent a lot of time in order to find "double click to input".
- I could not put the points in the exact place.
- Every time selecting the move tool makes it harder. (it was hard for me to select move tool every time)
- Undo sometimes undoes all to the beginning.

4.3.4.2 Participant 3

- Touchpad screen,
- "undo button" cannot properly take number of modifications
- Typing a function into the input bar makes it harder to select points not in the axes.
- The usage of Erase tool is not clear.

4.3.4.3 Participant 4

- Priority can be given while two different things such as point or line are input.

4.3.4.4 Participant 5

- Menus in which some geometry shapes is together is not user-friendly.
- Moreover, input area where functions are written is hard to be seen.

4.3.4.5 Participant 6

I could not get used to;

- Touch pad since my hands sweat
- The Slider tool (because I could not understand what slider tool real does.)
- Regular Polygon tool (since I could not draw by entering 3.)
- Input bar (since input bar is not user-friendly and it is not easy to understand what can be done in input bar.)

4.3.4.6 Participant 7

- Input bar is not user friendly. I did not expect that when I wrote the function, it drew automatically. Instead, I would do it by using a=2 in Menus.
- Furthermore, it was hard for me to draw 2 intersecting circles.
- I think, it is so difficult to marking a wanted point. For example, I tried so many times to mark the point (5, 0).
- In general, I am not satisfied. Without anybody's help, I would hardly use it.

4.3.4.7 Participant 8

- Pictures (Icons) do not indicate the purpose of the button.
- Any help of the system will make it easier to be used.

4.3.4.8 Participant 9

- While I was drawing a polynomial curve, it takes time to find that the function should be inserted in input area.

CHAPTER 5

DISCUSSION & CONCLUSION

The main goal of this study is to conduct a usability evaluation of desktop and mobile versions of Geogebra, and explore ways in which the system can be improved to better take advantage of the affordances of multi-touch interfaces for constructing dynamic geometry figures. For this purpose, we conducted three different usability studies with different methodologies that are suitable for covering different learning contexts supported by Geogebra. Students, for example, may use Geogebra individually while they are studying on their own or in a class cooperatively. On the other hand, due to the developments in touch-screen technology, users now have additional means to interact with a computer in contrast to mouse-based interfaces. Therefore, we tried to understand the differences between Mouse and Touchpad Pen, in terms of the possibilities they offer for constructing and interacting with dynamic geometry figures in Geogebra. For that purpose, we considered a collaborative scenario, where pairs of users attempted dynamic geometry problems together. The breakdowns they encountered during their collaboration were systematically analyzed to find out whether simply replacing the mouse-based interface with a touch-screen would improve the usability of Geogebra. Finally, we evaluated the recently released iPad version of Geogebra, which is the first dynamic geometry application that allows users to construct and view dynamic figures. Overall, we aimed to identify if Geogebra is effectively taking advantage of touch-based gestures to support the construction of dynamic geometry objects, and to explore in what ways the interface can be explored to make abstract geometry concepts more tangible for students.

Our study is briefly summarized and described above. The aim of this chapter is to make a detailed discussion of the results of our studies.

While conducting the study, we focused on four main research questions concerning the analysis of the usability of Geogebra as listed below:

- (RQ1) How do Geogebra and Geometer's Sketchpad systems compare with each other in terms of their effectiveness and efficiency for building basic geometric constructions?
- (RQ2) What are the usability issues involved with Geogebra in a collaborative problem-solving context that requires more complex geometric constructions?
- (RQ3) Does the touchpad interface provide better support for building more complex geometric objects as compared to the mouse-based standard interface of Geogebra?
- (RQ4) What are the usability issues as regards the tablet version of Geogebra? To what extent do these issues correspond with the ones identified for the desktop/touch pad version of Geogebra?

These questions were examined under three main dimensions of usability. These dimensions were effectiveness, efficiency and satisfaction, respectively.

To evaluate the effectiveness

We considered the percentages of the tasks completed by the participants and analyzed the task in which they had the utmost difficulty. Then we tried to find out the situations that prevented them from completing this task.

To evaluate the efficiency

We calculated how much time the users spent for each task. For eye tracking methodology, we counted average fixation durations, visit durations and mouse click counts. For the breakdown analysis, however, we determined the numbers of breakdowns faced. And in our last study, the number and duratıon of the steps taken to complete each task were analyzed.

To investigate the user satisfaction

For the first study, SUS results were used and the results of the questionnaire were considered. Examples were given from the breakdown situations in our second study and the views of the participants were included. In our last study, the data obtained from the SUS results and open-ended questions were used.

5.1 RQ1. How do Geogebra and Geometer's Sketchpad systems compare with each other in terms of their effectiveness and efficiency for building basic geometric constructions?

This question may be answered with the data obtained from the results of the analysis of Geogebra and Geometer's Sketchpad software in the first study. The results will be discussed under the sub titles of effectiveness, efficiency and satisfaction.

Effectiveness

For the evaluation of the interfaces of Geogebra and Geometer's Sketchpad in terms of their effectiveness, we looked at the percentage of completed tasks. The results are summarized in Table 7 in Chapter 4. When Table 7 is examined, one can see that the first 5 questions were completed by all the participants with both interfaces. However, it could be seen that task 6 was completed by all participants using Geometer's Sketchpad, whereas the same task was completed just by half of the participants in the case of Geogebra.

In Task, 6 we wanted the participants to draw a circle and calculate its circumference, radius and area. Then, we wanted them to create a table of values found by changing the radius of the circle, and expected them to draw a graph using the data in the table. The first level of the Task, which was drawing a circle and showing its area, circumference, and radius was completed by all participants. Geometer's Sketchpad allowed the participants to create the table using these data. For Geogebra, the participants had to manually create the table showing the change of the data by using the Spreadsheet. Those who hadn't used Geogebra ever before or had less experience, had difficulty in drawing a table at the Geogebra Spreadsheet window and eventually were not able to complete this task.

Efficiency

Chapter 4 includes the eye-tracking data concerning the time durations spent by each participant in each task. Should we take a look at the time durations spent by each participant in the tasks, we are required to look at Table 8 for the results of Geogebra and Table 9 for the results of Geometer's Sketchpad. According to our results, it can be seen that participants spent the highest period of time in trying to solve Task 6 by using Geogebra.

A significant difference in total visit duration was observed between the two interfaces for tasks 1, 3 and 6. In tasks 1 and 3, GeoGebra had a significantly shorter total visit duration time. Geometer's Sketchpad had significantly shorter visit duration in task 6. This results shows that Total visit duration in the task for Geometer's Sketchpad was longer than GeoGebra except task 6. The reason why task 6 took longer was due to the problems participants experienced while using the spreadsheets in Geogebra, which ultimately caused some participants fail to complete Task 6.

To estimate the number of mouse clicks of eye-tracking experiment participants, video recordings of participants were examined. A significant difference between GeoGebra and Geometer's Sketchpad in terms of total mouse click counts was observed for tasks 1 and 3 only. In both cases GeoGebra elicited smaller number of clicks as compared to Geometer's Sketchpad. This suggests that users performed smaller number of steps in GeoGebra as compared to GSP for these particular tasks.

Satisfaction

This type of data was obtained from the SUS questionnaire. The average score of the SUS questionnaire is 71,66 for GSP, and 58,75 out of 100 for Geogebra. This shows that Sketchpad's SUS score was higher than Geogebra's SUS score. However, a paired-samples t-test did not reveal a significant difference among both interfaces. In sum, we can say that the participant's attitude was positive for Geogebra and Geometer's Sketchpad.

According to the users' comments, the main problem with Geometer's Sketchpad was about instructions placed on the interface. The participants could not recognize instructions while they were doing the tasks. Instructions are displayed at the bottom of the page and hence not easily recognizable. The other problem with Geometer's Sketchpad was about selecting the objects. They were not comfortable while selecting an object. For this reason they had difficulty calculating and showing the angle. Another problem with Geometer's Sketchpad was the classification of properties and functions in the menu. For example, one of the participants looked at the "Construct" menu for creating a table, but she could not find it under the "Construct" menu; she found it under "Number" menu instead. One participant indicated that there were not enough error messages.

The main problem with GeoGebra was that most subjects could not find and open the "Input Help". The icon of "Input Help" menu was not visible and not easy to click on. Half of the participants opened and used this menu incidentally or they had the experience for clicking and opening it. Another problem for GeoGebra users was the difficulty of identifying the correct icon from menus. The other problem with GeoGebra was transferring data between windows. Two of the participants tried to transfer input data from "Algebra" window to "CAS (Computer Algebra Systems)" window but only of them was successful. The other tried to transfer data from "Graphics" to "Spreadsheets", and after lots of mouse clicks she managed to transfer the data. One of the participants indicated that learning the usage of this software takes a long time and its menu is complex and it is not easy to remember the steps. Moreover, there was another problem with GeoGebra about error messages which only show errors but do not suggest any hints for possible corrections or remedies.

Summary

Overall, the results of the first study suggest that there are only minor differences between Geogebra and Geometer's Sketchpad in terms of the usability of the features they provide for making basic constructions. Since Geogebra is an open-source platform, the remainder of our analysis focused on possible ways to improve its use by using touch interfaces.

5.2 RQ2. What are the usability issues involved with Geogebra in a collaborative problem-solving context that requires more complex geometric constructions?

This question can be answered with the data obtained from the results of breakdown analysis in the situations in which Geogebra software was used by the pairs. We summarized the results under the subtitles of effectiveness, efficiency and satisfaction.

Effectiveness

To answer this question in terms of effectiveness, we used the percentage of the tasks that were successfully completed by the participants. According to our results, there was a single pair who could complete all the tasks. The first 4 questions and task 6 were completed by all the participants. Only pair 2 was not able to complete task 5. Task 8 and task 9 were not completed by Pair 3 and task 10 was not completed by Pair 4 where they were using Mouse. Only half of the participants could complete Task 7.

In task 10, participants had difficulty in using the perpendicular line tool, which was evidenced in the breakdowns observed during communication. In task 7, the participants were asked to construct a regular hexagon by using circles and line segments. The participants who could not complete this task were those who could not intersect the circles properly and could not construct the circles passing from the point they chose. The reasons for this were the inability to control the touchpad pen and to intersect the circles in the desired manner, as well as the fact that they could not know how to do it. Only pair 2 failed to complete Task 5 when they were using the Touchpad Pen. Similarly, Pair 3 was the only group who did not complete tasks 8 and 9 because they got bored with using the Touchpad Pen. In task 8, participants faced difficulty with drawing parallel lines. There was only one task that could not be completed by using the mouse, whereas several task failures were related to issues with using the touchpad pen interface for constructing geometric objects.

Efficiency

The results concerning the time periods spent by each pair in each task are given in Chapter 4. According to the results, the pairs spent the longest time duration while they were trying to solve Task 4. Since none of the pairs could complete task 7 by using the touchpad pen interface, no task completion data is presented for that sub-group.

We used a dialogue-based approach to observe the breakdowns in users' dialogues and map the mismatches between users' actions and software behaviour. Breakdowns were taken as an indicator of social effort pairs had to make to get around the technical challenges involved in producing the desired constructions. The presence of many breakdowns often require more effort to be resolved, which brings problems in efficiency of use. We identified 204 breakdowns in users' dialogues. In addition, we examined the distribution of breakdown situations the participants faced in each task. The highest number of breakdowns was 52 in Task 7, 30 in Task 1, and 25 in Task 4.

The reason of breakdowns in Task 4 was related to the issues with using the Perpendicular Line Tool. In this task participants tried to draw three perpendicular lines. They easily drew two perpendiculars, but in the step, most of the groups experienced a breakdown. In particular, when they tried to draw, the program put points not a line. To overcome this breakdown they deleted all the objects on the screen and drew again. After they tried a few times, they could draw the last perpendicular line. Some participants who had similar breakdowns gave up using this tool. Geogebra can be improved by a slight modification of this feature. For instance, when users click on a point and then click on a line or line segment, the perpendicular tool should draw the perpendicular line through that point.

The highest number of breakdowns happened while participants were using the line drawing feature, which included 47 breakdown cases. 3 of these breakdowns occurred when drawing a line, 8 of them were about tangents and 12 of them were done while using the Perpendicular Line Tool. 6 of them were encountered while using the Parallel Line Tool, and 3 of them were about the Perpendicular Bicestor Tool. 12 of them were about Segment Tool, 2 of them were about Segment with Given Length from Point Tool. All of these cases indicate usability issues regarding the use of lines and line segments, which provide the basic building block of many geometric constructions.

Angle Breakdown was encountered 33 times when participants tried to display the interior angles of a polygon. For example, in task 2 users need to draw a square without using the rectangle tool. In this task users also need to prove that the polygon they had drawn was a square. For that reason participants frequently used the angle tool. When they tried to display the interior angles, many groups ended up displaying the exterior angles instead. This was due to the way the angle tool is designed, which expects users to click on the points that define two intersecting lines or line segments in counter clockwise order, so that the angle appears inside the polygon. When the order was not followed an exterior angle could be drawn instead of an interior angle. No explicit message or hints are provided on the interface, so most participants failed to insert the angles in the desired location.

In addition to this, participants had 16 breakdowns when using the Segment tool. For example, while they were drawing a square, some of the teams tried to draw a straight line through point A and point B. But they could not do it easily. They recognized that the angle was not 90 degrees and the line length was not 10. They wanted to stop at 7 point; however, the line stopped at 7.23 point. When they noticed that they have drawn a line which they did not want, they tried to correct line's length using Algebra View. Moreover, in Study 3, in task 2, participants used the line tool they had problems with clicking the wanted coordinates while using tool. Some participants overcame this problem by using the grid. Some, however, zoomed in the coordinate plane, thus forming the point having the wanted coordinates.

Our analysis indicated issues with the Parallel Line Tool as well. Participants experienced 6 breakdowns while using this tool. For example, when the task was to draw three parallel lines and to create an equilateral triangle using these lines, some of the teams tried to draw a line parallel to the x-axis but they had a breakdown related to drawing a parallel line. They tried to remember how they could do it. They undid everything and drew a line on the x-axis. they tried to draw a parallel line. one of the participants suggested drawing a parallel line, she followed the instructions and drew the parallel lines.

The last major breakdown occurred while participants were using the move tool; which was experienced 20 times. For example, when participants tried to move a point constrained on a line segment, they had difficulty in selecting and dragging the point, which generated some breakdowns in problem solving.

Satisfaction

Data regarding user satisfaction were obtained in reference to the utterances of the participants recorded during the experiment and from the comments they made during the open-ended questions after the experiment. For example, in the first pair's dialogues, they made positive comments about the ease of use of the tool towards the end of the session.

A: "Now, we might be misusing the program" (Şuan varya biz programı yanlış kullanıyor olabiliriz)

B: "Why. (Neden)

A: "It is very easy to use, we can move everything."(Bayağı kolaymış aslında her şeyi taşıyabiliyoruz.)

The second pair mentioned that the program has deficits. They tried to draw a circle but the program created the circle in a different location. As a result of this situation, B2 mentioned that it was a fault of the program. In task 7, A2 reported: "The program is too bad." B2 approved of A2 and said that "the program is not really good". Moreover, A2 complained about the program. He wanted to enter the value into the program but he did not. They also stated they could not use the program and that the program was too complicated.

The fourth pair tried to draw a perpendicular line but they could not. They stated that they did not know how to use the program. After trying for some time, they managed to use the program and stated every time that they could not use the program until now but this time they could use it and move the objects.

The fifth pair stated that "The usage of the program is very hard" in the open-ended section. They also mentioned, "It definitely can't replace human interaction. Solving with this program is definitely not the same as solving on paper. I spend an hour or more on the device to solve what I could have solved on paper in 5 minutes. They continued their conversation, "We have been beating around the bush for 75 minutes just to draw a right angle though it would have been easy to draw it with a compass." B5 stated that the user interface of the program has some problems.

Summary

Overall, participants faced many breakdowns during the experiment. The highest number of breakdowns happened while participants were using the line drawing feature, which included 47 breakdown cases. Drawing line segments, perpendicular segments and parallel lines were also challenging for most groups. These breakdowns were related with line tools, so we can say that drawing line tools in Geogebra cause problems in terms of usability. When we compare the results of our study with the study of Hohenwarter, Hohenwarter, & Lavicza (2010), "The Segment between Two Points" tool and the Move Tool, which they classified as easy to use, were not found to be easy to use in our study. Finally, the angle tool turned out to be problematic since users had hard time communicating to the tool where they want the angle to appear in the diagram. Most of the other breakdowns were related to achieveing some level of desired precision in the construction, such as drawing a segment for a partiuclar length and drawing along a grid line. The use of the touchpad pen seemed to have contributed to the usability issues observed in the second experiment, which is discussed furhter in the next section.

5.3 RQ3. Does the touchpad interface provide better support for building more complex geometric objects as compared to the mouse-based standard interface of Geogebra?

This question can be answered with the data obtained from the results of breakdown analysis in the situations in which Geogebra software was used by the pairs. We indicated the results under the subtitles of effectiveness, efficiency and satisfaction.

Effectiveness

All the participants attempted all the tasks, but only one pair could complete all of the 10 tasks. Half of the teams could not finish task 7, who were all in the A group where they attempted task 7 by using the Touchpad Pen. Only pair 2 failed to complete Task 5, where they were using the Touchpad Pen. Similarly, Pair 3 was the only group that did not complete task 8 and task 9 because they got bored with using the Touchpad Pen. There was only one task that could not be completed by using the mouse. According to the distribution of completed and not completed tasks across both interface conditions, there were significantly more incomplete tasks in the touchpad condition than the mouse condition.

The order in which participants got familiarized with the environment could be another factor on the distribution of task completion times. As a result of the analysis conducted, the task completion time with order and interface type as independent variables did not find a significant order effect, so the order in which each interface type was introduced to the partners did not seem to effect the distribution of response times.

We looked in the distribution of breakdowns detected for each task. Except tasks 2 and 3, the mean number of breakdowns observed during each task was smaller in the case of mouse interface as compared to the touchpad interface. According to statistical analysis, significantly higher number of breakdowns occurred in the touchpad condition. The interaction was not significant, suggesting that the pattern of relationship is similar across tasks, where touchpad brings on average higher number of breakdowns across all tasks.

Tasks also significantly differed from each other in terms of the number of breakdowns observed. In particular, Task 7 stood out among other tasks with the highest number of breakdowns. In this task most of the breakdowns occurred in the touchpad condition. Some of the participants could not click on the location where they wanted to construct circles, which we called as a clicking breakdown. Because the touchpad interface was not as responsive as some of the users expected, they had difficulty in identifying points on the screen which requires a single click. In general, clicking on and selecting any object turned out to be problematic on the touchpad interface.

Efficiency

When we investigated the distribution of task completion times across tasks and interfaces for the successfully completed tasks, we observed that in Tasks 3, 4, and 5 pairs who attempted to solve the problem with the touchpad took less time than the pairs who were using the mouse. Moreover, in tasks 1, 6, 8, 9 and 10, the pairs using the mouse took less time when compared to the touchpad group. According to statistical analysis on task completiton time, there was no a significant difference between interface types. There was a significant effect of task type, which indicates that some of tasks took significant more time to complete.

The order in which participants got familiarized with the environment could be another factor on the distribution of breakdowns. As a result of the analysis, the number of breakdowns with order and interface type as independent variables did not find a significant order effect, so the order in which each interface type was introduced to the partners did not seem to affect the distribution of breakdowns. On average more breakdowns occurred in the touch pad case. Participants faced breakdowns in touchpad case, especially the features clicking and moving actions which were easy with Mouse. In this case, we can say that the features of Desktop versions can not support with touchpad pen conditions. This suggests that providing touch screen features without taking adequate advantage of their unique features may not automatically translate into gains in usability.

Satisfaction

In the second study, we compared using Mouse and Touchpad Mouse. According to breakdown analysis data, participants faced some difficulties while using Touchpad Pen. 64. 22% of the breakdowns occurred because of Touchpad Pen. This is an example from pair 1:

B1: "It doesn't work, the pen run out of the battery." (Gelmediki bu, kalemin pili bitti)

A1: "Click" (tıklasana)

B1: "I click but it doesn't click". (Tıklıyorum ama tıklanmıyor ki).

In this example, because of the use of touchpad Pen, clicking was not easy for B1. B1 thought that the Pen does not work. However, there was no problem with Touchpad Pen. In the same task, B1 mentioned, "If we use Mouse I will do task". We can interpret this sentence as follows: This participant was not satisfied with using Touchpad Pen. According to the breakdown analysis, Pair 1 had 9 breakdowns when using a mouse and 22 breakdowns using a Touchpad Pen.

Moreover, the same pair mentioned in the open question part using Touchpad Pen was harder than the act of using Mouse. Another problem with Touchpad pen was clicking. The first pairs only enjoyed the Touchpad Pen because of it remembers using a paper and pencil.

In the second pair dialogues, they mentioned about using Touchpad pen. A2 stated, "Using a Touchpad Pen is very hard". According to open-ended questions, they found that the Touchpad Pen is very sensitive to control. They mentioned that they definitely preferred using Mouse.

In the third pair dialogues, B3 stated, "Using A Touchpad pen is hard" while they were trying to do task 7. Besides dialogue and conversation, they stated that they need to adapt to it first. It was the first time they had ever used something like this. However, they had hopes to adapt, using the touchpad Pen. But the more you use it, the more you adapt to it. It is like these touch-screen phones; the more you use it, the more you get it.

In the fourth pair's experiences, A4 stated that using the Touchpad Pen stretch, both of them complained about not clicking with the Pen.

In the fifth pair's experiences, B5 could not create an angle with the Touchpad Pen in Task 7. Then A5 stated that using a Mouse is a bad habit. They spent more time to do Task 7. And A5 indicated that drawing without the Mouse was too bad. In the Task 8, they created a triangle and tried to show the angle was 60° but they made an error by 0.01°. They escaped the correct this error (ne diyor anlamadım) and B5 said that they could put the blame on the Touchpad Pen. A5 approved of him. B5 continued and said that "we made it but the Pen did not".

In the sixth pair experiment, A6 had a problem while using the Touchpad Pen. She said, "I click. I am nervous because of this Pen". Then she gave control of the Pen to her partner. Furthermore, she mentioned that using Mouse is definitely easier in the open session part. Her partner added that it is because of her habits. She approved of the habits and continued that the screen should be a bit more tilted and then using Touchpad Pen could be a lot easier.

The other data we gathered from the results of fulfillment of the task. The participants did not complete 11.66% of the tasks. Task 7 could not be completed by the A group who used Touchpad Pen. The participants spent approximately 520 seconds for this question.

To conclude;

- There were significantly more incomplete tasks in the touchpad condition than the mouse condition.
- Interface type was introduced to the partners did not seem to effect the distribution of response times.
- The mean number of breakdowns observed during each task was smaller in the case of mouse interface as compared to the touchpad interface.
- The number of breakdowns revealed that significantly higher number of breakdowns occurred in the touchpad condition
- Tasks also significantly differed from each other in terms of the number of breakdowns observed
- On task completion time where the interface and task are treated as independent variables did not reveal a significant difference between interface types. There was a significant effect of task type, which indicates that some of tasks took significant more time to complete.
- The number of breakdowns with order and interface type as independent variables did not find a significant order effect, so the order in which each interface type was introduced to the partners did not seem to affect the distribution of breakdowns. On average more breakdowns occurred in the touch pad case.
- According to users' remarks, using a touchpad pen is hard and they definitely preferred using the Mouse.

5.4 RQ4. What are the usability issues involved with the tablet version of Geogebra? To what extent these issues parallel the ones identified for the desktop/touch pad version of Geogebra?

This question may be answered with the data obtained from the results of the analysis of Geogebra Mobile in the third study. The results will be discussed under the sub titles of effectiveness, efficiency and satisfaction.

Effectiveness

In order to evaluate the interface of Geogebra mobile, the duration of completed task were analyzed. The data gathered from eye-tracking were analyzed using Tobii software. When the results were examined, it is clear that the first two questions and Task 4 were completed by all participants (100% respectively). However, Task 3, 5 and 6 could not be completed by all the participants. One participant could not complete Task 3, four participants could not complete Task 5, and three participants could not complete Task 6.

There were two important issues in Task 5. The first was to draw 3 parallel lines by using the parallel line tool. The other was to construct an equilateral triangle. The problem mostly faced by the participants who used the parallel line tool was to put points instead of drawing a line. To use the parallel line tool in Geogebra, it was necessary to choose another line first, and then draw another line parallel to it. In other words, after clicking the parallel line tool, first the targeted line, then the screen should be clicked to draw the desired parallel line. The participants who did not know at first that they needed another line faced this problem, and then formed a line to solve this problem, but this time they went on putting points as they did not know the order of clicking.

Efficiency

The distribution of completion times measured in seconds for each successfully completed task were considered for the efficiency analysis. According to our results, subjects took more time to complete tasks 5 and 6. Moreover, a higher level of variability of completion times were observed for tasks 5 and 6 among participants as compared to other tasks.

The transcripts are used for making a more fine-grained analysis of the users' interaction with the tablet version of Geogebra. For each segment categorized as visual search or construction, average fixation duration and number of fixations were considered as indicators of efficiency and cognitive workload. Since undo and erasing actions took on average small amount of time, those segments were not subjected to fixation analysis. According to statistical results, the average time spent on visual search was significantly higher than average time spent on construction actions. There was also a significant interaction effect. This is due to the fact that the time spent on visual search is especially higher than construction in tasks 3 and 6, which indicates that subjects had more difficulty finding related drawing features in these tasks. Moreover, when we investigated the distribution of total fixation counts for each segment type across all tasks. The results showed that the visual search segments have significantly higher number of fixations as compared to construction segments. The difference was particularly high for tasks 3 and 6, which suggest that subjects searched the interface more vigorously in these tasks.

For example, in task 3, the input bar could not be found by many users, possibly due to its appearance as the default search box used in many iOS applications. The placement of the input bar near other tools and giving it a label or inserting some preliminary text such as "enter an equation such as y = x^2 here…" which is erased when user taps on the bar may be a solution to this problem. The other usability problem in this task, the participants had difficulty in finding the intersect tool. Most of them looked for the intersect tool for a long time. It did not occur to them that the points tool of Tool would be in the subtitle. Considering the task and usage form of this tool in this task, they ignored the possibility that points tools would be in the subtitle. Moreover, 6 of 10 participants clicked on the slider button instead of the input bar because the icon of this button had an appearance that would confuse them.

Another problem faced by the participants was that everything was being deleted on the screen when they used the eraser tool. In such cases, users had to start from scratch. A more fine grained erasing feature that helps users isolate the targeted object for deletion seems to be necessary for the tablet version of Geogebra.

Another problem was that the default iPad keyboard is used when the Input bar or Redefine window is opened. A customized keyboard with more mathematical features and symbols would be more useful in this context. Since participants had to spend considerable time for accessing the symbols and numbers, they spent 25% of their on average trying to enter data on this keyboard.

When the number of steps taken by each task is examined, Task 6 took on average the highest number of steps. Task 6 was related with using the circle tool to draw intersecting circles to construct a hexagon. While completing this task, most participants had difficulty forming circles with the same radius intersecting with each other. Without any explicit hints or guidance, the participants ended up drawing intersecting circles either with the same radius or with a different radius. They had problems with using the intersect tool, too. This issue was due to the fact that it was necessary first to click on a circle and then the other circle for the intersection feature to work. Those who tried to put the intersecting point immediately without doing this process failed.

The distribution of average fixation duration values observed in search and construction segments for all tasks suggest that construction segments have higher average fixation values than visual search segments. The interaction effect was not significant, so the pattern of relationship is preserved across different tasks. This suggests that the fixations that guide the construction of dynamic figures tend to elicit higher average duration values than fixations that guide the search process.

Satisfaction

We could look at SUS scale results and answers of open ended questions. Table 21 summarizes the SUS scale ratings of the participants for the Tablet version of Geogebra. The SUS average for the tablet version (47.0) was lower than the SUS score of the Desktop version (58.3) obtained in Study 1, which highlights issues with user satisfaction.

Participant 2 reported that she was bored because of not being able to do what she has done in Geogebra in one time. Noticing the Input bar and finding “double click to open input bar was commented as very hard. Moreover, she stated that she could not put the points in the exact place. The necessity of selecting objects at every time was boring. Undo sometimes undoes all the steps until the beginning. Participant 3 stated typing a function into the input bar makes it harder to select points not in the axes and the usage of Erase tool is not clear. Participant 4 reported priorities could be given while two different things such as point or line are input. Participant 5 stated, Menus in which some geometry shapes are listed together was not user-friendly. Moreover, input area where functions are written was hard to be seen. Participant 6 reported she could not get used to the touch pad since her hands sweat. She could not understand what the slider tool really does. She emphasized she could not draw a triangle by entering 3 in the Regular Polygon tool. Moreover, she stated, since the input bar was not user-friendly, it was not easy to understand what can be done with it. Participant 7 stated Input bar was not user friendly. Furthermore, she reported it was hard for her to draw 2 intersecting circles and it was so difficult to mark a targeted point. Participant 8 stated Pictures (Icons) do not indicate the purpose of the button. She suggested that any help of the system would make it easier to be used. Participant 9 reported that while he was drawing a polynomial curve, it takes time to find that the function should be inserted in the input area.

Summary

We can summarize the usability issues observed in the tablet version as follows:

- The participants had problems with the angle tool. Since almost all participants struggled with having GeoGebra to display the interior angle in the desired place, there is a serious usability issue with the angle tool. The current design expects the user to press on the three points that define the angle in clock-wise order to define where to display the angle.
- The participants had problems with precisely locating the points and lines they wanted to draw. Some participants overcame this problem by using the grid. Some, however, zoomed in the coordinate plane, which made it easier to select the point with desired coordinates. It could be said that putting a point is a problem in the mobile version of GeoGebra software.
- Participants had problem with using the intersect tool. Intersecting the axis and putting a point on the axis was very sensitive and hard for the users. The reason of this was the size of point to be smaller than the size of the user's fingertip. To overcome this problem, the system could zoom in the area clicked by the user by means of a lens similar to the editing magnifier glass used in iOS for text editing.
- Another difficulty faced by the users was related to opening the Redefine window. This window was opened by double clicking on the point expected to be changed, but the user is not hinted or told about this requirement. The participant who could finally open the Redefine window could not carry out the changes he did, because he was confused by the fact that arrow key was the return button.
- The other problem was with the Slider tool. Users could not understand the usage of this tool and the icon of this tool caused confusion.
- The other problem with Geogebra Mobile was finding the input bar. The placement of the input bar caused users to spend more time to complete the task.
- The problem mostly faced by the participants who used the parallel tool was for them to put points instead of drawing a line. To use the parallel line tool in Geogebra, it was necessary to choose a line first and then to draw another line parallel to it. The participants who did not know at first that they needed another line faced this problem.

If we take the studies of Konterkamp and Dorhman (2010) as a reference to our analysis, we see that Geogebra doesn't support the multitouch capabilities most mobile applications employ. For example, Konterkamp (2010) mentioned the user should be able to draw a line using his two fingers at the same time. In other words, if an empty space is touched, it produces only a point, however, when touched with two fingers at the same time this must produce two points and these points should be connected to construct a line. For the multitouch capabilities to be applied the software programmers need to take in consideration some changes. According to our findings, it is necessary to take care of the mapping between the touch gestures and software features in terms of usability. Depending on the usage context addressed by the software, each matching between touch gesture and functionality may not be valid for every case. In terms of usability, however, it seems important to give much thought to the designing of the interface.

5.5 Usability method

In this study we used different usability methods. The first method involved comparing Geogebra to Geometer's Sketchpad with eye tracking technology, and evaluating the tablet version of Geogebra with a mobile eye tracker. In the first methodology we only evaluated basic tools of Geogebra. Eye-tracking experiments provide important statistical information about the experiment such as fixation duration; fixation count, completion time and mouse click amounts. Using eye tracking data we can examine users' activity while they interact with the interface in detail. It provides profound analysis of users' task performances and indicates design issues discovered by users of the system. Eye tracking study needs costly equipment, which is a major disadvantage of using it. Another disadvantage of this study it doesn't support collocated collaborative studies (Öz, 2012). Because of this limitation; we employed a different methodology in the second study.

The second study was conducted using breakdown analysis. Breakdown analysis gives a systematic means of approaching huge quantities of communication. Breakdown analysis focuses on where the user experiences difficulties due to the tool, task or environment and this analysis can motivate some suggestions for addressing the detected usability problems. With this approach huge amounts of data such as video recording can be handled effectively. Thus, breakdown analysis provides systematically discovering problematic aspects in interface design as they are made explicit by the users in their conversation.

Conclusion

In this study, we conducted a usability evaluation of the desktop and mobile versions of Geogebra, and explore ways in which the system can be improved to better take advantage of multi-touch interfaces for constructing dynamic geometry figures. The results of this thesis study shows that users encountered several usability problems with Geogebra. The findings of this thesis informs the developers about existing usability issues and point out ways to address some of these issues through better utilization of the affordances of multi-touch interfaces. Ultimately, such improvements may help students engage with geometric objects in a more effective and naturalistic way. Such improvements may make abstract geometric concepts more tangible and accessible for the students, and thus help them develop a deeper understanding of geometric principles.

As Geogebra is software frequently used at schools, teachers should take over some responsibility to decrease the students' potential problems with usability. Firstly, teachers should prepare a sample task and solve these tasks within the classroom, also introducing the tools that should be used in this task. The introduced sample task should be shared with teachers and some other tasks similar to this one should be delivered to students. In addition, some hints should be provided about the tools that will be used.

This chapter concludes by presenting directions and recommendations for future research as well as the limitations of this study.

5.6 Suggestions for the Geogebra Developers

The following improvements can be suggested to the Geogebra developers:

- Geogebra should provide feedback to the users about what they have done.
- Geogebra should have its own standard keyboard in such areas as Redefine window and Input bar to enter data. The fact that GeoGebra does not have its own standard keyboard with a more mathematical characteristic in such areas as Redefine window and Input bar to enter data and uses the keyboard of the computer in which it is installed makes it difficult for the users to enter data and to cause difficulty in checking the data.
- Geogebra should support handwriting basic equations instead of using keyboard in Input area.
- Geogebra should support the multi-touch features, for example as Konterkamp (2010) mentioned the user should be able to draw a line using his two fingers at the

same time. In other words, if an empty space is touched, it produces only a point, however, when touched with two fingers at the same time this must produce two points and these points should connect and construct a line

- 6 out of 10 participants clicked on the slider button instead of the input bar because the icon of this button had an equation-like appearance that would confuse them. Changing this icon and providing a tool tip message could be considered to avoid this potential confusion.
- There must be informative messages on tools about how to use them, which could be turned off as the user gets accustomed to the basic features. Such a tutorial mode may help users deal with the learning curve involved with Geogebra.
- In the Geogebra Mobile and Desktop Versions, the place of Input bar should be changed and it should be located near other tools.
- The system could allow users to select the location of the angle with a hand gesture similar to how we draw angles on paper by drawing a small arc connecting two existing line segments. In this new feature, after the user selects the angle button, he will draw a short arc touching on both segments between which the angle should appear. Until the user lifts his finger from the screen, the system can display a visual feedback by highlighting the line segments implicated and the anticipated area where the angle will appear. Such a feature would simplify defining angles by eliminating the need to identify 3 points in a specific order, and providing a more naturalistic method the users are familiar with drawing.
- If the user clicks on the object for a long time and tries to carry it, a pop up menu should appear on the object. One of the alternatives of this menu should be 'Move', while another may be 'Delete'. Thus, he will get rid of having to click the tools continually and also will realize the desired action though unaware of the functions of the tools.
- Intersecting the axis and put a point on the axis was very sensitive and hard for the users. To overcome this problem, the system could enlarge the area clicked by the user with the help of a lens and make his job easier.
- There is a need for a solution to Parallel Line Tool problem that exist in the desktop version of Geogebra. To solve this problem, the users can be given a hint message when they are on the parallel line tool. Then the steps that they should follow should be made explicit. For example, when a point is put, it should say "select a line" or the messages such as "first click a line, and then click the screen" will solve the problem.

5.7 Limitations of the Study

While completing this study, we faced some limitations. These are listed below:

- The participants were at the level of university and 22-37 years of age. Other age groups were not examined, so the findings are applicable mainly to university students and adults.
- The experiments lasted nearly an hour and even longer than an hour in some cases, which may have caused some boredom and fatigue towards the end of the experiment.
- The participants were people accustomed with using a mouse who were acquainted with touch-screen devices at a later stage in their lives.
- During the experiment, the participants moved their heads and necks and calibration though not at a significant rate, and thus calibration was partly lost. In some cases, data accuracy was below 70%, especially when the mobile stand was used for the tablet version. Such cases were removed from the analysis.

- Standard AOI analysis was difficult to do in this case since the constructions dynamically change on the drawing area.
- While working with a pair of participants, the participants who did not know each other well remained shy and reserved. Although we tried to find participants who already knew each other, such an event was experienced in one case.
- While Geogebra Mobile was being analyzed, its application in Apple tablet was examined but the devices that use the Android and other mobile operating systems could not be examined.

5.8 Recommendations for Future Research and Practice

The following can be reported as the results of this study:

- The study should be applied to the middle and high-school students.
- The mobile version of Geogebra, should be tested on an android device.
- While using the eye tracker mobile stand, an environment should be formed in which participants will feel comfortable and relaxed and there will be minimal loss of eye tracking records.
- While making the breakdown analysis, we worked on people as pairs who knew each other. In the future studies, those who do not know each other at all should be preferred and, if possible, those of the similar age. Then the effect of this on learning should be measured.
- Experiments should be as short as possible to eliminate fatigue and boredom.

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APPENDICES

APPENDIX A

Dinamik Geometri Yazılımları

Test Sonrası Kullanılabilirlik Anketi

Katılımcı Numarası: _____

Kullanıcı Bilgileri
Cinsiyet:
Yaş:
Eğitim Düzeyi:
Bilgisayar Kullanma Becerisi:

berbat muhteşem
1 2 3 4 5 6 7 8 9 ID

GEOGEBRA
BÖLÜM 1: Sistem Tecrübesi

1. Geogebra programını ne kadar sıklıkla kullanıyorsunuz?
   Hiç kullanmadım__ Haftada bir__ Haftada birkaç kere__

   Günde 1 defa__ Ayda bir __

BÖLÜM 2: Genel Kullanıcı Tepkileri

Geogebra programı kullanımından edindiğiniz izlenimleri yansıtan en uygun sayıyı yuvarlak içine alınız. İlgili Değil = ID

2.1	Geogebra programı hakkındaki genel düşünceler	berbat — muhteşem 1 2 3 4 5 6 7 8 9	ID
2.2	Geogebra programı hakkındaki genel düşünceler	tatmin edici değil — tatmin edici 1 2 3 4 5 6 7 8 9	ID
2.3	Geogebra programı hakkındaki genel düşünceler	sıkıcı — motive edici 1 2 3 4 5 6 7 8 9	ID
2.4	Geogebra programı hakkındaki genel düşünceler	zor — kolay 1 2 3 4 5 6 7 8 9	ID
2.5	Geogebra programı hakkındaki genel düşünceler	uygulama yeterince güçlü değil — uygulama yeterince güçlü 1 2 3 4 5 6 7 8 9	ID
2.6	Geogebra programı hakkındaki genel düşünceler	katı — esnek 1 2 3 4 5 6 7 8 9	ID

BÖLÜM 3: Geogebra programının görünüşü

3.1 Menüdeki araçların keşfi	zor ... kolay	1 2 3 4 5 6 7 8 9	ID
3.1.1 Karakterlerin görüntüsü	bulanık ... net	1 2 3 4 5 6 7 8 9	ID
3.1.2 Yazı tipi (font)	okunaksız ... okunaklı	1 2 3 4 5 6 7 8 9	ID
3.2 Menüdeki bileşenlerinin düzeni çok yardımcıydı	hiç bir zaman ... her zaman	1 2 3 4 5 6 7 8 9	ID
3.2.1 Araçlardaki yönergedeki bilgi miktarı	yetersiz ... yeterli	1 2 3 4 5 6 7 8 9	ID
3.2.2 Yönergelerin arayüzdeki yerleşimi	mantıksız ... mantıklı	1 2 3 4 5 6 7 8 9	ID
3.2.3 Araç çubuğunun arayüzdeki yerleşimi	Uygun değil ... uygun	1 2 3 4 5 6 7 8 9	ID
3.3 Araç çubuğundaki araçların birbiriyle ilişkisi	kafa karıştırıcı ... düzenli	1 2 3 4 5 6 7 8 9	ID
3.3.1 İkona tıkladığımız zaman çıkan şeklin ekran görüntüsü	tahmin edilebilir değil ... tahmin	1 2 3 4 5 6 7 8 9	ID
3.3.2 Programdaki sayfalarda bir önceki sayfaya dönmek	imkansız ... kolay	1 2 3 4 5 6 7 8 9	ID
3.3.3 Görevlerde istenilen bilgiye ulaşmak için izlenen yol	karmaşık ... basit	1 2 3 4 5 6 7 8 9	ID
3.3.3 Seçilen bir aracın başka bir araçla değiştirilmesi	imkansız ... kolay	1 2 3 4 5 6 7 8 9	ID
3.4 Verilen(Girilen) değerlerin programda çalıştırılabilmesi	kötü ... iyi	1 2 3 4 5 6 7 8 9	ID
3.5 Kullanılan renkler	doğal değil ... doğal	1 2 3 4 5 6 7 8 9	ID
3.5.1 Var olan renklerin miktarı	yetersiz ... yeterli	1 2 3 4 5 6 7 8 9	ID

Geogebra programının görünüşü hakkındaki görüşlerinizi lütfen aşağıdaki boş alana yazınız:

____

____

____

BÖLÜM 4: Geogebra Programında kullanılan terimler

4.1 Programda kullanılan terimler	tutarsız	tutarlı	
	1 2 3 4 5 6 7 8 9		ID
4.1.2 Bağlantıların ve ikonların isimleri	belirsiz	açıkça anlaşıla	
	1 2 3 4 5 6 7 8 9		ID
4.1.3 Menü isimleri	tutarsız	tutarlı	
	1 2 3 4 5 6 7 8 9		ID
4.2 Ekranda beliren mesajlar	tutarsız	tutarlı	
	1 2 3 4 5 6 7 8 9		ID
4.2.1 Ekranda beliren talimatların yerleri	tutarsız	tutarlı	
	1 2 3 4 5 6 7 8 9		ID
4.3 Bilgisayar ne yaptığına dair kullanıcıyı bilgilendiriyor	hiçbir zaman	her zaman	
	1 2 3 4 5 6 7 8 9		ID
4.3.1 Bir işlemi gerçekleştirmek tahmin edilebilir bir sonuç doğuruyor	hiçbir zaman	her zaman	
	1 2 3 4 5 6 7 8 9		ID
4.3.2 Şekil çizerken programın tepkisi	uygun	çok uzun	
	1 2 3 4 5 6 7 8 9		ID
4.4 Hata mesajları	yardımcı nitelikte değil	yardımcı nitelikte	
	1 2 3 4 5 6 7 8 9		ID

Geogebra programında kullanılan terimler hakkındaki görüşlerinizi aşağıdaki boş alana yazınız:

BÖLÜM 5: Sistem Kullanımını Öğrenme

5.1 Menüleri arasında gezinmeyi öğrenmek	zor	kolay	
	1 2 3 4 5 6 7 8 9		ID
5.1.1 Başlangıç aşamasındaki öğrenme	zor	kolay	
	1 2 3 4 5 6 7 8 9		ID
5.1.2 Sistemi kullanmayı öğrenme zamanı	kısa	uzun	
	1 2 3 4 5 6 7 8 9		ID
5.2 Deneme yanılma yoluyla programın	zor	kolay	
özelliklerini keşfetmek	1 2 3 4 5 6 7 8 9		ID
5.2.1 Yeni özelliklerin keşfedilmesi	zor	kolay	
	1 2 3 4 5 6 7 8 9		ID
5.3 Kullanılan fonksiyonların kullanım	zor	kolay	
şekillerini hatırlamak	1 2 3 4 5 6 7 8 9		ID
5.4 Verilen görevler doğrudan yerine	asla	her zaman	
getirilebiliyordu (oyalama olmadan)	1 2 3 4 5 6 7 8 9		ID
5.4.1 Yapılacak her iş için kat edilmesi	çok fazla	uygun sayıda	
gereken aşamaların (adım) sayısı	1 2 3 4 5 6 7 8 9		ID
5.4.2 Bir işi bitirmek için takip edilen	asla	her zaman	
adımlar mantıklı bir sırada	1 2 3 4 5 6 7 8 9		ID

Sistemin öğrenimi ile ilgili görüşlerinizi aşağıdaki boş alana yazınız:

GEOMETER'S SKETCHPAD

BÖLÜM 1: Sistem Tecrübesi

1. Sketchpad programını ne kadar sıklıkla kullanıyorsunuz?

Hiç kullanmadım__ Haftada bir__ Haftada birkaç kere__

Günde 1 defa__ Ayda bir kere__

BÖLÜM 2: Genel Kullanıcı Tepkileri

Sketchpad programı kullanımından edindiğiniz izlenimleri yansıtan en uygun sayıyı yuvarlak içine alınız.

İlgili Değil = ID

2.1	Sketchpad programı hakkındaki genel düşünceler	berbat ... muhteşem 1 2 3 4 5 6 7 8 9	ID
2.2	Sketchpad programı hakkındaki genel düşünceler	tatmin edici değil ... tatmin edici 1 2 3 4 5 6 7 8 9	ID
2.3	Sketchpad programı hakkındaki genel düşünceler	sıkıcı ... motive edici 1 2 3 4 5 6 7 8 9	ID
2.4	Sketchpad programı hakkındaki genel düşünceler	zor ... kolay 1 2 3 4 5 6 7 8 9	ID
2.5	Sketchpad programı hakkındak genel düşünceler	uygulama yeterince güçlü değil ... uygulama yeterince güçlü 1 2 3 4 5 6 7 8 9	ID
2.6	Sketchpad programı hakkındaki genel düşünceler	katı ... esnek 1 2 3 4 5 6 7 8 9	ID

BÖLÜM 3: Sketchpad programının görünüşü

3.1 Menüdeki araçların keşfi — zor 1 2 3 4 5 6 7 8 9 kolay — ID

3.1.1 Karakterlerin görüntüsü — bulanık 1 2 3 4 5 6 7 8 9 net — ID

3.1.2 Yazı tipi (font) — okunaksız 1 2 3 4 5 6 7 8 9 okunaklı — ID

3.2 Menüdeki bileşenlerinin düzeni çok yardımcıydı — hiç bir zaman 1 2 3 4 5 6 7 8 9 her zaman — ID

3.2.1 Araçlardaki yönergedeki bilgi miktarı — yetersiz 1 2 3 4 5 6 7 8 9 yeterli — ID

3.2.2 Yönergelerin arayüzdeki yerleşimi — mantıksız 1 2 3 4 5 6 7 8 9 mantıklı — ID

3.2.3 Araç çubuğunun arayüzdeki yerleşimi — Uygun değil 1 2 3 4 5 6 7 8 9 uygun — ID

3.3 Araç çubuğundaki araçların birbiriyle ilişkisi — kafa karıştırıcı 1 2 3 4 5 6 7 8 9 düzenli — ID

3.3.1 İkona tıkladığımız zaman çıkan şeklin ekran görüntüsü — tahmin edilebilir değil 1 2 3 4 5 6 7 8 9 tahmin — ID

3.3.2 Programdaki sayfalarda bir önceki sayfaya dönmek — imkansız 1 2 3 4 5 6 7 8 9 kolay — ID

3.3.3 Görevlerde istenilen bilgiye ulaşmak için izlenen yol — karmaşık 1 2 3 4 5 6 7 8 9 basit — ID

3.3.3 Seçilen bir aracın başka bir araçla değiştirilmesi — imkansız 1 2 3 4 5 6 7 8 9 kolay — ID

3.4 Verilen(Girilen) değerlerin programda çalıştırılabilmesi — kötü 1 2 3 4 5 6 7 8 9 iyi — ID

3.5 Kullanılan renkler — doğal değil 1 2 3 4 5 6 7 8 9 doğal — ID

3.5.1 Var olan renklerin miktarı — yetersiz 1 2 3 4 5 6 7 8 9 yeterli — ID

Sketchpad programının görünüşü hakkındaki görüşlerinizi lütfen aşağıdaki boş alana yazınız:

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BÖLÜM 4: Sketchpad Programında kullanılan terimler

4.1 Programda kullanılan terimler	tutarsız	tutarlı	
	1 2 3 4 5 6 7 8 9		ID
4.1.2 Bağlantıların ve ikonların isimleri	belirsiz	açıkça anlaşıla	
	1 2 3 4 5 6 7 8 9		ID
4.1.3 Menü isimleri	tutarsız	tutarlı	
	1 2 3 4 5 6 7 8 9		ID
4.2 Ekranda beliren mesajlar	tutarsız	tutarlı	
	1 2 3 4 5 6 7 8 9		ID
4.2.1 Ekranda beliren talimatların yerleri	tutarsız	tutarlı	
	1 2 3 4 5 6 7 8 9		ID
4.3 Bilgisayar ne yaptığına dair kullanıcıyı bilgilendiriyor	hiçbir zaman	her zaman	
	1 2 3 4 5 6 7 8 9		ID
4.3.1 Bir işlemi gerçekleştirmek tahmin edilebilir bir sonuç doğuruyor	hiçbir zaman	her zaman	
	1 2 3 4 5 6 7 8 9		ID
4.3.2 Şekil çizerken programın tepkisi	uygun	çok uzun	
	1 2 3 4 5 6 7 8 9		ID
4.4 Hata mesajları	yardımcı nitelikte değil	yardımcı nitelikte	
	1 2 3 4 5 6 7 8 9		ID

Sketchpad programında kullanılan terimler hakkındaki görüşlerinizi aşağıdaki boş alana yazınız:

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BÖLÜM 5: Sistem Kullanımını Öğrenme

5.1 Menüleri arasında gezinmeyi öğrenmek	zor 1 2 3 4 5 6 7 8 9	kolay	ID
5.1.1 Başlangıç aşamasındaki öğrenme	zor 1 2 3 4 5 6 7 8 9	kolay	ID
5.1.2 Sistemi kullanmayı öğrenme zamanı	kısa 1 2 3 4 5 6 7 8 9	uzun	ID
5.2 Deneme yanılma yoluyla programın özelliklerini keşfetmek	zor 1 2 3 4 5 6 7 8 9	kolay	ID
5.2.1 Yeni özelliklerin keşfedilmesi	zor 1 2 3 4 5 6 7 8 9	kolay	ID
5.3 Kullanılan fonksiyonların kullanım şekillerini hatırlamak	zor 1 2 3 4 5 6 7 8 9	kolay	ID
5.4 Verilen görevler doğrudan yerine getirilebiliyordu (oyalama olmadan)	asla 1 2 3 4 5 6 7 8 9	her zaman	ID
5.4.1 Yapılacak her iş için kat edilmesi gereken aşamaların (adım) sayısı	çok fazla 1 2 3 4 5 6 7 8 9	uygun sayıda	ID
5.4.2 Bir işi bitirmek için takip edilen adımlar mantıklı bir sırada	asla 1 2 3 4 5 6 7 8 9	her zaman	ID

Sistemin öğrenimi ile ilgili görüşlerinizi aşağıdaki boş alana yazınız:

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Anketi doldurduğunuz için teşekkür ederiz.

APPENDIX B

Katılımcı Tanıma Anketi

Katılımcı Numarası: _____

BÖLÜM 1 : Katılımcı Bilgileri

Cinsiyet:

Yaş:

Eğitim Düzeyi:

Bölümünüz:

Temel Bilimler(Fizik, Matematik, Kimya, Biyoloji vs.)	
Mühendislik Bilimleri	
Sosyal Bilimler	
Eğitim Bilimleri	
Diğer(Yazınız)	

Bilgisayar Kullanma Becerisi:

berbat muhteşem

1 2 3 4 5 6 7 8 9 ID

GEOGEBRA

BÖLÜM 2 : Sistem Tecrübesi

1. Temel matematik-geometri bilgi düzeyiniz nedir?

berbat muhteşem

1 2 3 4 5 6 7 8 9 ID

2.Geogebra programını hiç kullandınız mı?

Evet__ **Hayır__**

3. Yukarıdaki soruya cevabınız evet ise programı ne kadar sıklıkla kullanıyorsunuz?

Günde 1 defa__ Haftada birkaç kere__ Haftada bir__
Ayda bir kaç defa __ Ayda 1 defa__ Yılda 1 defa__

APPENDIX C

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 Serap YAĞMUR tarafından yüksek lisans tezi kapsamında yürütülmektedir.

Çalışmanın amacı, bilgisayar destekli ortamda işbirlikçi yöntemle problem çözme süreci ve fiziksel bir ortamda yüz yüze işbirlikçi yöntemle problem çözme sürecinin karşılaştırılmalı analizini yapmaktır. Bunun yanında, bu çalışmada kullanılan farklı araçların (touchpad ve personel computer) kullanılabilirliğinin ölçülmesi ve işbirlikçi problem çözme süreçlerine etkisinin gözlemlenmesi hedeflenmektedir.

Bu çalışma süresince hareketleriniz ve konuşmalarınız video/ses kayıt cihazı ile kayıt altına alınacaktır. Uygulama öncesinde yaşınız, bölümünüz, benzer yazılımlarla ilgili geçmiş tecrübeleriniz hakkında genel sorular içeren bir anket doldurmanız istenecektir. Uygulama Enformatik Enstitüsünde hazırlanan Bilişsel Bilimler Laboratuvarı'nda gerçekleştirilecektir. Uygulama yaklaşık 1 saat sürecek olup 20 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 tarafından 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 Serap YAĞMUR (Enformatik Enstitüsü B-104, Tel: 0 312 210 77 21, E-posta: yagmur@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 D

System Usability Scale (SUS)

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.					

APPENDIX E

TASK 1 TRANSCRIPTS

Participant 1					
	Timeline	Event	# of Fix.	Fix.Avg.	Time Duration
1	00:11 – 00:12	Visual search over buttons	2	592	1016
2	00:12 – 00:13	pressed on line button	3	245	583
3	00:13 – 00:27	created line A, line B, line C	39	283	13583
4	00:27 – 00:33	visual search over buttons	18	161	5344
5	00:33 – 00:36	pressed on angle button and showed exterior angle..	6	325	2400
6	00:37	pressed on undo button.	3	139	600
7	00:37 – 0:47	searched over main area.	11	365	4650
8	00:47 – 0:53	showed exterior angle.	19	243	5200
9	00:53	pressed on undo button.	-	-	-
10	00:54– 0:59	showed exterior angle.	8	150	2268
11	01:00	pressed on undo button.	1	802	935
12	01:00– 01:04	showed exterior angle.	10	170	2667
13	01:05– 01:08	selected angle tool.	7	172	3069
14	01:08 – 01:11	showed exterior angle.	12	156	3220
15	01:14– 01:21	pressed on undo button.	19	233	6474
16	01:23 – 01:33	pressed on circle button created two circles.	23	387	10071
17	01:33	pressed on undo.	2	259	533
18	01:34 – 01:38	pressed on circle button and created a circle.	9	352	3837
19	01:38	pressed on undo button.	1	150	234
20	01:38 – 01:45	drew a circle with center point B and pass from A point.	4	213	6084
21	01:45 – 01:55	visual search over buttons.	15	216	10135
22	01:56	pressed on undo button.	2	117	434
23	01:56 – 02:02	visual search over buttons.	19	186	5200
24	02:02 - 02:10	selected segment and created a triangle with using this button.	20	359	8220

25	02:12-02:16	pressed on angle tool and showed exterior angle.	9	464	4405
26	02:20	pressed on undo button.	3	183	767
27	02:20-02:26	showed an internal angle.	16	312	6169
28	02:48	successfully completed the task.			

Participant 2					
	Timeline	Event	# of Fix.	Fix.Avg.	Time Duration
1	00:07 – 00:09	Visual search over buttons	6	475	2617
2	00:11 – 00:26	pressed on circle button drew circles	35	412	16000
3	00:26	pressed on undo button.	2	209	417
4	00:27 – 00:35	visual search over buttons	28	278	7958
5	00:35 – 00:51	pressed on circle button drew circles	48	316	16300
6	00:51	pressed on undo button.	-	-	-
7	00:51 – 00:57	Visual search over buttons	20	285	6151
8	00:57 – 01:08	pressed on line button and created line A.	8	636	3166
9	01:08	pressed on undo button.	22	441	10267
10	01:08–01:16	selected segment and created a triangle with using this button.	25	317	7799
11	01:16–01:20	visual search over buttons.	19	215	3769
12	01:20–01:22	selected angle tool.	6	347	1850
13	01:22 – 01:25	showed an internal angle.	9	306	2617
14	01:43	successfully completed the task.			

Participant 3					
	Timeline	Event	# of Fix.	Fix.Avg	Time Duration
1	00:21 – 00:26	Visual search over buttons	11	291	5115
2	00:26 – 00:34	pressed on polygon tool and drew a triangle.	21	359	8290
3	00:34–00:49	visual search over main area.	48	166	14753
4	00:51 – 00:59	pressed on angle button and showed an external angle.	20	358	8451
5	00:59–01:05	showed an internal angle.	18	268	5701

6	01:05– 01:24	showed an external angle.	51	326	19638
7	01:28 – 01:40	pressed on angle button and showed an external angle.	26	257	14252
8	01:50 – 01:55	pressed on undo	-	-	5250
9	01:55 – 02:00	showed an external angle.	-	-	3937
10	02:01	pressed on undo button.	-	-	-
11	02:01	pressed on redo button.	-	-	-
12	02:07– 02:08	showed an external angle.	-	-	1250
13	02:09	pressed on undo button.	-	-	-
14	02:09– 02:14	showed an internal angle.	5	351	1368
15	02:14– 02:26	showed an internal angle.	32	291	11667
16	02:32	successfully completed the task.			

Participant 4

	Timeline	Event	# of Fix.	Fix. Avg.	Time Duration
1	00:11 – 00:23	Visual search over buttons.	24	161	21726
2	00:23 – 00:43	pressed on line segment button and drew a triangle.	36	901	43556
3	00:43 – 00:49	Visual search over buttons.	18	251	49705
4	00:49– 00:56	selected angle button.	22	193	6856
5	00:56– 01:13	showed all internal angles.	61	181	17750
6	01:25	successfully completed the task.			

Participant 5

	Timelene	Event	# of Fix	Fix.Avg.	Time Duration
1	00:11 – 00:17	Visual search over buttons.	17	172	5586
2	00:17 – 00:21	pressed on point button and put three points.	4	142	4566
3	00:21– 00:29	pressed on segment button and created a triangle by connecting three point.	9	113	9258
4	00:29– 00:47	Visual search over buttons.	12	111	16811
5	00:47– 00:52	pressed on angle button and showed an internal angle.	3	84	5591

6	00:54	completed the task.			

Participant 6

	Timeline	Event	# of Fix.	Fix.Avg.	Time Duration
1	00:10 – 00:14	Visual search over buttons	6	120	5766
2	00:14 – 00:28	pressed on polygon tool and put three points.	25	134	13702
3	00:30– 00:35	pressed on angle button	6	100	3200
4	00:36 – 00:49	pressed on polygon tool and drew a triangle.	15	96	13135
5	00:53– 00:57	pressed on angle button and showed an external angle.	10	119	4318
6	01:04– 01:06	showed an external angle.	6	111	2333
7	01:06	pressed on undo			
8	01:09 – 01:13	pressed on angle button and showed an internal angle.	6	106.5	852
9	01:35	successfully completed the task.			

Participant 7

	Timeline	Event	# of Fix.	Fix.Avg	Time Duration
1	00:07 – 00:14	Visual search over buttons	9	363	6069
2	00:14 – 00:24	pressed on polygon tool and drew a triangle.	24	363	10923
3	00:24– 00:35	Visual search over buttons.	37	220	11192
4	00:35 – 00:41	pressed on angle button and showed an internal angle.	13	395	5652
5	00:49– 00:53	pressed on angle button and showed an internal angle.	12	461	2985
6	01:00	successfully completed the task.			

Participant 8

	Timeline		# of Fix.	Fix.Avg	Time Duration
1	00:08 – 00:13	Visual search over buttons	7	124	4317
2	00:13 – 00:15	selected polygon button.	-	-	2182
3	00:15 –	pressed on polygon tool and drew a	18	136	11044

	00:26	triangle.			
4	00:26 – 00:56	pressed on angle button	17	128	28990
5	00:57 – 01:15	pressed on angle button and showed all internal angles.	3	67	20602
6	01:25	successfully completed the task.			

Participant 9					
	Timeline	Event	# of Fix	Fix.Avg.	Time Duration
1	00:27 – 00:30	Visual search over buttons	8	294	3170
2	00:30 – 00:36	pressed on polygon tool and drew a triangle.	11	404	6046
3	00:36 – 00:46	visual search over algebra pane.	30	237	8433
4	00:46 – 00:52	pressed on angle button and showed an external angle.	13	282	6638
5	00:55 – 00:59	pressed on angle button and showed an external angle.	13	249	4686
6	01:05	successfully completed the task.			

Participant 10					
	Timeline	Event	# of Fix.	Fix.Avg.	Time Duration
1	00:14 – 00:18	Visual search over buttons	7	195	2150
2	00:18 – 00:26	pressed on polygon tool and drew a triangle.	17	287	7199
3	00:26 – 00:38	visual search over algebra pane.	39	184	12356
4	00:39 – 00:43	Visual search over buttons	14	259	4199
5	00:43 – 00:47	pressed on angle button and showed an external angle.	12	197	3400
6	00:47 – 00:49	showed an internal angle.	7	212	1685
7	00:49 – 01:00	Visual search over main area.	29	200	9845
8	01:01 – 01:05	pressed on undo button	9	358	3836
9	01:09	pressed on redo button.	2	168	735
10	01:10 – 01:23	showed all internal angles.	27	416	13990
11	01:30	successfully completed the task.			

TASK 2 TRANSCRIPTS

Participant 1				
	Timeline	Event	# of Fixations	Fixation average
1	(03:01 – 03:06)	Visual search over buttons		
2	(03:06 – 03:14)	pressed on point button and put a point.	20	226
3	(03:14)	pressed on undo button.		
4	(03:19 – 03:24)	pressed on point button.	7	226
5	(03:24–03:27)	pressed on move button and zoomed in the page.	9	215
6	(03:29–03:32)	pressed on point button and put a point.	9	213
7	(03:33 – 03:37)	pressed on line button and created a line connecting A point and B point.	4	596
8	(03:38)	successfully completed the task.		

Participant 2				
	Timeline	Event	# of Fixations	Fixation average
1	(01:56 – 01:59)	Visual search over buttons	12	240
2	(01:59 – 02:03)	selected line button.	14	219
3	(02:03 – 02:16)	pressed on line button and drew two lines.	17	310
4	(02:16)	pressed on undo button.	3	155
5	(02:19 – 02:31)	pressed on move button and moved the line.	48	214
6	(02:31 – 02:35)	pressed on undo button.	20	240
7	(02:39)	pressed on undo button.	3	133
8	(02:41 – 02:49)	pressed on segment drew a segment.	8	310
9	(02:49)	pressed on undo button.	2	376
10	(02:50 – 02:54)	drew two segments.	12	245
11	(02:56 – 02:59)	pressed on undo button.	12	132
12	(02:59 – 03:04)	visual search over buttons.	14	159
13	(03:04–03:16)	pressed on slider button.	30	200
14	(03:16 – 03:20)	visual search over buttons.	20	266

15	(03:20 – 03:24)	pressed on point button and put two points.	8	385
16	(03:26 – 03:28)	pressed on segment button and created a line connecting A point and B point.	5	460
17	(03:38)	successfully completed the task.		

Participant 3				
	Timeline	Event	# of Fixations	Fixation average
1	(02:46 – 02:48)	Visual search over buttons	3	372
2	(02:48 – 02:59)	pressed on line button and drew two lines.	30	226
3	(02:59 – 03:01)	pressed on undo button.	8	190
4	(03:01 – 03:04)	accidently drew a line.	5	203
5	(03:07 – 03:14)	pressed on move button and zoomed in.	13	339
6	(03:16 – 03:18)	pressed on move button and zoomed out.	24	240
7	(03:18)	pressed on undo button.	3	117
8	(03:23 – 03:27)	pressed on line button and drew the line.	8	229
9	(03:30)	successfully completed the task.		

Participant 4				
	Timeline	Event	# of Fixations	Fixation average
1	(01:42 – 02:06)	Visual search over buttons	49	195
2	(02:06 – 02:15)	pressed on point button and put two points.	22	132
3	(02:15 – 02:18)	visual search over buttons.	4	142
4	(02:18 – 02:21)	selected line button.	9	180
5	(02:21 – 02:23)	pressed line button and drew the line.	8	86
6	(02:32)	successfully completed the task.		

Participant 5				
	Timeline	Event	# of Fixations	Fixation average
1	(01:04 – 01:10)	Visual search over buttons	5	143
2	(01:10 – 01:21)	pressed on point button and put two points.	11	113

3	(01:21 – 01:24)	selected line button.	5	90
4	(01:24 – 01:26)	pressed line button and drew the line.	3	111
5	(01:27)	successfully completed the task.		

Participant 6				
	Timeline	Event	# of Fixations	Fixation average
1	(02:00 – 02:03)	Visual search over buttons	3	172
2	(02:03 – 02:12)	pressed on point button and put a point.	6	100
3	(02:12 – 02:14)	pressed on undo button.	5	93
4	(02:14 – 02:16)	pressed on undo button.	2	108
5	(02:16 – 02:24)	pressed on point button and put two points.	8	102
6	(02:24 – 02:29)	visual search over buttons.	3	78
7	(02:29 – 02:33)	pressed on segment button and drew the segment.	4	107
8	(02:36 – 02:41)	pressed on line button and drew the line.	7	144
9	(02:42)	successfully completed the task.		

Participant 7				
	Timeline	Event	# of Fixations	Fixation average
1	(01:13 – 01:47)	Visual search over buttons	64	254
2	(01:47 – 01:51)	pressed on parallel line button and gave up using this tool.	8	313
3	(01:51 – 01:56)	selected line button.	13	303
4	(01:56 – 01:59)	pressed on line button and put a point.	6	414
5	(02:02 – 02:04)	pressed on erase button.	5	364
6	(02:05 – 02:10)	pressed on line button and put a point.	17	368
7	(02:12 – 02:14)	pressed on erase button.	5	384
8	(02:21 – 02:32)	zoomed in the page.	16	260
9	(02:32– 02:36)	pressed on line button and put a point.	7	404
10	(02:40)	pressed on erase button.	3	217

11	(02:42 – 02:46)	pressed on move button and zoomed in the page	16	152
12	(02:48–02:51)	pressed on line button and put a point.	9	408
13	(02:55 – 03:00	pressed on move button and moved the page.	20	228
14	(03:01 – 03:04)	pressed on line button and put a point.	8	413
15	(03:06)	pressed on erase button.	2	118
16	(03:09–03:12)	pressed on line button and put a point.	6	367
17	(03:13)	pressed on erase button.	1	233
18	(03:14 – 03:22)	pressed on line button and put a point.	16	324
19	(03:26 – 03:35)	pressed on move button and zoomed out the page.	26	287
20	(03:35 – 03:46)	pressed on line button and created a line connecting point A and point B.	24	221
21	(03:50)	successfully completed the task.		

Participant 8				
	Timeline	Event	# of Fixations	Fixation average
1	(01:41 – 02:00)	Visual search over buttons	53	160
2	(02:01 – 02:08)	pressed on line button and drew a line.	7	105
3	(02:08–02:18)	visual search over buttons	11	122
4	(02:18 – 02:33)	tried to move the point without clicking move button.	12	128
5	(02:35 – 02:39)	pressed on erase button and deleted the objects.	9	132
6	(02:39 – 02:44)	visual search over buttons.	4	75
7	(02:46 – 02:52)	pressed on segment button and put a point.	7	98
8	(02:52 – 02:54)	pressed on erase button and deleted the objects.	3	89
9	(02:56 – 03:01)	pressed on line button and drew the line.	3	78
10	(03:06)	successfully completed the task.		

Participant 9				
	Timeline	Event	# of Fixations	Fixation average
1	(01:18 –	Visual search over buttons	6	187

	01:22)			
2	(01:22 – 01:26)	pressed line button and drew the line.	7	403
3	(01:32)	successfully completed the task.		

Participant 10				
	Timeline	Event	# of Fixations	Fixation average
1	(01:44 – 01:50)	Visual search over buttons	21	217
2	(01:50 – 01:59)	pressed on slider button.	22	236
3	(01:59 – 02:04)	visual search over buttons	15	193
4	(02:04 – 02:10)	selected line button.	19	242
5	(02:10 – 02:16)	pressed on line button and drew a line.	11	432
6	(02:16 – 02:18)	pressed on undo button.	9	144
7	(02:20 – 02:28)	pressed on line button and drew a line.	19	353
8	(02:35)	successfully completed the task.		

TASK 3 TRANSCRIPTS

Participant 1					
			# of Fix.	Fix.Avg	Total Duration
1.	03:54 – 03:59	Visual search over buttons	10	125	5487
2.	03:59 – 04:05	pressed on point button and put three points.	15	207	6135
3.	04:07 – 04:17	pressed on segment line button and connected the point A and point B, and point A point C.	25	234	8693
4.	04:20 – 04:33	pressed on point button	11	272	7147
5.	04:33 – 05:44	Visual search over buttons	213	213	71701
6.	05:44 – 05:45	pressed on point button and put a point.	2	509	1304
7.	05:45 – 05:51	Visual search over algebra pane.	16	265	5188
8.	05:51 – 06:06	pressed Redefine window and typed the equation.	43	166	14649
9.	06:09 – 06:15	pressed on line segment button and connected the point B and point D and point C and point D.	15	360	7073
10.	06:15 – 06:23	visual searched on algebra pane	33	154	7340
11.	06:26	pressed on undo button.	2	159	217
12.	06:29 – 06:30	pressed on line segment button and connected the point B and point D and point C and point D.	7	194	2170
13.	06:30 – 06:36	pressed on angle button and showed angle button.	14	132	4721
14.	06:37	successfully completed the task.			

Participant 2					
	Timeline	Event	# of Fix.	Fix.Avg.	Duration
1.	03:40 – 03:44	Visual search over buttons	11	222	3516
2.	03:44 – 03:51	pressed on point button and put a point.	12	463	6500
3.	03:51 – 03:53	pressed on undo button.	5	287	2068
4.	03:53 – 03:55	pressed on point button and put a point.	2	642	1102
5.	03:55	pressed on undo button.	-	-	1233
6.	03:55 – 04:00	pressed on point button and put three points.	7	398	3300
7.	04:00	pressed on undo button.	-	-	117
8.	04:00 – 04:03	pressed on point button and put a point.	4	629	3734

9.	04:04	pressed on undo button.	1	200	836
10.	04:04 – 04:05	pressed on point button and put a point.	1	234	850
11.	04:05	pressed on undo button.	1	317	267
12.	04:05 – 04:08	pressed on point button and put a point.	7	298	2602
13.	04:08	pressed on undo button.	1	366	417
14.	04:08 – 04:13	pressed on point button and put a point.	13	219	4434
15.	04:13	pressed on undo button.	1	117	834
16.	04:17 – 04:20	pressed on point button and put a point.	4	566	2735
17.	04:21	pressed on undo button.	4	183	683
18.	04:26 – 04:29	pressed on undo button.	10	247	3251
19.	04:30 – 04:36	pressed on line button and drew a line.	11	448	5766
20.	04:36	pressed on undo button.	3	669	939
21.	04:37 – 04:39	pressed on point button and put a point.	5	376	1350
22.	04:39 – 04:47	pressed on line button and drew a line.	13	350	6884
23.	04:49 – 04:51	pressed on point button and put a point.	3	672	1483
24.	04:51 – 05:00	press on undo button.	15	244	7033
25.	05:00 – 05:11	pressed on point button and put three points.	21	260	9757
26.	05:11	pressed on undo button.	2	241	350
27.	05:12 – 05:19	Visual search over buttons	20	320	7868
28.	05:19 – 05:25	pressed on line button and drew four lines.	10	476	5283
29.	05:25 - 05:28	pressed on angle button and showed an external angle	9	372	4000
30.	05:32 – 05:37	pressed on undo button.	16	250	5389
31.	05:37 – 05:54	Visual search over buttons	49	299	15549
32.	05:54 – 06:00	pressed on three points button	12	233	4168
33.	06:00	pressed on undo button.	1	183	184
34.	06:00 – 06:09	pressed on three points button and put three points.	23	294	9340
35.	06:11	pressed on undo button.	4	108	800
36.	06:13 – 06:17	pressed on line button and drew a line.	10	303	4417
37.	06:17	pressed on undo button.	1	183	467
38.	06:19 – 06:22	pressed on point button and put a point.	6	378	2718

39.	06:23 – 06:30	pressed on line button and drew two lines.	14	463	7200
40.	06:30 – 06:35	Visual search over buttons	16	193	4750
41.	06:35 – 06:40	pressed on angle button showed an internal angle.	8	534	4567
42.	06:41– 06:56	Visual search over buttons	41	241	15183
43.	06:56– 07:01	pressed on undo button.	10	301	4685
44.	07:02 – 07:04	pressed on point button and put a point.	3	805	3068
45.	07:05	pressed on undo button.	3	211	584
46.	07:05 – 07:08	pressed on point button and put a point.	5	180	2668
47.	07:08	pressed on undo button.			267
48.	07:08– 07:14	Visual search over buttons	14	241	5195
49.	07:14 – 07:16	pressed on move button.	5	277	1484
50.	07:17– 07:19	pressed on undo button.	3	178	701
51.	07:19 – 07:23	zoomed in the page.	19	174	4854
52.	07:24 – 07:34	pressed on point button and put two point.	26	234	9979
53.	07:34	pressed on undo button.	3	122	400
54.	07:34 – 07:46	pressed on three points button and put three points.	36	230	11956
55.	07:46	pressed on undo button.	-	-	133
56.	07:46 – 07:51	Visual search over buttons	15	101	4376
57.	07:51 – 07:58	pressed on undo button.	19	155	6757
58.	08:02– 08:05	pressed on point button and put two point.	12	171	2918
59.	08:06– 08:25	visual search over algebra pane and tried to open redefine window.	51	203	19348
60.	08:25 – 08:37	pressed on redefine window and typed the point's coordinates.	25	152	11657
61.	08:37 – 08:49	visual search over algebra pane and tried to open redefine window.	27	168	11460
62.	08:49 – 09:05	pressed on redefine window and typed the point's coordinates.	20	189	15928
63.	09:05 – 09:30	visual search over algebra pane and tried to open redefine window.	70	203	24453
64.	09:30– 09:37	pressed on undo button.	14	318	6217
65.	09:37 – 09:47	visual search over algebra pane and tried to open redefine window.	24	342	9701
66.	09:47 – 09:54	pressed on input bar and typed the point's coordinates.	17	146	6863

67.	09:54 – 10:00	visual search over main area.	17	290	5702
68.	10:00 – 10:02	pressed on erase button.	7	148	2072
69.	10:04 – 10:07	pressed on point button and put a point.	12	169	3109
70.	10:07 – 10:36	visual search over algebra pane and tried to open redefine window.	70	223	29865
71.	10:36 – 10:45	pressed on erase button.	19	200	6707
72.	10:45 – 10:46	pressed on point button and put two point.	4	350	1636
73.	10:47 – 11:41	visual search over algebra pane and tried to open redefine window.	30	166	13263
74.	11:42	pressed on erase button.	2	442	700
75.	11:42 – 11:44	pressed on point button and put two point.	6	130	1588
76.	11:44 – 12:20	visual search over algebra pane and tried to open redefine window.	103	213	35050
77.	12:20	pressed on erase button.	2	300	383
78.	12:22 – 12:24	pressed on point button and put two point.	7	159	2268
79.	12:24 – 12:32	visual search over algebra pane and tried to open redefine window.	19	215	7196
80.	12:32 – 12:34	researcher helped her to open redefine window.	5	116	918
81.	12:34 – 12:44	visual search over algebra pane and tried to open redefine window.	25	211	9058
82.	12:44 – 12:59	pressed on input bar and typed the point's coordinates.	38	159	15417
83.	12:59 – 13:13	visual search over algebra pane and tried to open redefine window.	39	201	12774
84.	13:13 – 13:30	pressed on redefine window and typed the point's coordinates.	32	158	13385
85.	13:30 – 13:35	visual search over main area.	20	194	5552
86.	13:35 – 13:42	pressed on erase button.	17	232	6188
87.	13:42 – 13:44	pressed on point button and put a point.	5	324	1501
88.	13:44 – 13:49	visual search over algebra pane and tried to open redefine window.	16	238	4533
89.	13:49 – 14:06	pressed on redefine window and typed the point's coordinates.	58	158	16566
90.	14:07 – 14:09	visual search over algebra pane and tried to open redefine window.	12	196	3166
91.	14:09 – 14:24	pressed on redefine window and typed the point's coordinates.	50	160	14795
92.	14:28 – 14:29	pressed on point button and put a point.	4	269	1549
93.	14:29 – 14:34	visual search over algebra pane and tried to open redefine window.	412	191	4683

94.	14:34 – 14:46	pressed on redefine window and typed the point’s coordinates.	31	219	11753
95.	14:46 – 14:48	visual search over algebra pane and tried to open redefine window.	5	387	2620
96.	14:48 – 14:56	pressed on redefine window and typed the point’s coordinates.	29	153	7870
97.	14:56 – 14:58	pressed on point button and put two point.	5	180	1617
98.	14:58 – 15:04	visual search over main area.	15	172	6144
99.	15:04 – 15:13	pressed on redefine window and typed the point’s coordinates.	24	199	9446
100. .	15:14 – 15:18	pressed on point button and put a point.	19	201	5602
101.	15:18 – 15:22	visual search over algebra pane and tried to open redefine window.	5	130	852
102.	15:22 – 15:33	pressed on redefine window and typed the point’s coordinates.	36	176	10991
103.	15:36 – 15:41	pressed on line button and drew two lines.	16	190	4934
104.	15:41	pressed on undo button.	1	283	199
105.	15:44 – 15:52	pressed on line segment button and created two lines connecting the points.	22	207	7251
106.	15:54 – 16:01	pressed on angle button and showed an internal angle.	19	238	6634
107.	16:02	successfully completed the task.	-	-	-

Participant 3

	Timeline	Event	# of Fix.	Fix.Avg.	Duration
1.	03:42 – 03:45	Visual search over buttons	5	237	3205
2.	03:45 – 03:50	pressed on line segment button and drew a segment.	8	299	6530
3.	03:50	pressed on undo button.	2	435	801
4.	03:50 – 03:57	visual search over main area .	16	320	6227
5.	03:57– 04:05	drew three segments.	15	335	8001
6.	04:05	pressed on undo button.	1	216	134
7.	04:05 – 04:14	visual search over buttons.	23	270	8552
8.	04:15– 04:18	pressed on line segment button and put a point.	6	264	4177
9.	04:20	pressed on undo button.	-	-	-
10.	04:21 – 04:36	pressed on line segment button and drew two lines.	20	305	12027
11.	04:36 – 04:43	visual search over algebra pane.	16	127	6635

	Timeline	Event	# of Fix.	Fix.Avg.	Duration
12.	04:43 – 04:46	pressed on angle button and showed an external angle.	7	146	2741
13.	04:48	pressed on undo button.	2	218	535
14.	04:48 – 04:51	showed and internal angle.	4	176	1509
15.	04:55	successfully completed the task.			

Participant 4

	Timeline	Event	# of Fix.	Fix.Avg.	Duration
1.	02:44 – 02:51	visual search over buttons	8	136	7539
2.	02:51 – 02:58	pressed on line segment button and put a point.	12	134	5555
3.	02:58 – 03:01	pressed on erase button.	11	203	2918
4.	03:03 – 03:08	visual search over buttons.	14	333	5205
5.	03:08 – 03:39	pressed on line segment button and created a square drawing four segments.	75	166	29656
6.	03:39 – 03:47	visual search over buttons.	25	184	8077
7.	03:47 – 04:08	pressed on angle button and showed all internal angles.	50	161	20684
8.	04:10	successfully completed the task.			

Participant 5

	Timeline	Event	# of Fix.	Fix.Avg.	Duration
1.	01:39 – 01:49	visual search over buttons	17	148	8365
2.	01:49 – 01:58	pressed on point button and put four points.	5	135	13865
3.	01:58 – 02:10	pressed on erase button.	10	148	6970
4.	02:13 – 02:15	pressed on point button and put a point.	5	87	3345
5.	02:18	pressed on erase button.	1	151	151
6.	02:05 – 02:24	pressed on point button and put two points.	7	122	7251
7.	02:25	pressed on erase button.	-	-	934
8.	02:28 – 02:42	pressed on point button put two points.	38	127	13876
9.	02:42 – 02:46	pressed on erase button.	5	184	2296
10.	02:46 – 02:52	pressed on point button and put two points.	15	88	4925
11.	02:52	pressed on erase button.	2	168	587
12.	02:54 – 03:02	pressed on point button put a points.	15	134	7240

13.	03:02 – 03:34	pressed on line button and drew two lines.	71	138	32934
14.	01:51	he gave up complete the task.			

Participant 6

	Timeline	Event	# of Fix.	Fix.Avg.	Duration
1.	02:54 – 02:59	Visual search over buttons	4	158	3849
2.	02:59 – 03:07	pressed on line segment button and drew two segments.	6	106	8118
3.	03:07	pressed on undo button.	-	-	-
4.	03:12– 03:22	pressed on line segment button and drew two segments.	17	106	9034
5.	03:24– 03:26	pressed on move button and moved the point.	7	150	3251
6.	03:27 – 03:37	pressed on line segment button and drew a segment.	16	114	8966
7.	03:37 – 03:45	visual search over algebra pane.	9	93	8922
8.	03:49	successfully completed the task.			

Participant 7

	Timeline	Event	# of Fix.	Fix.Avg.	Duration
1.	04:02 – 04:09	Visual search over buttons	16	321	5567
2.	04:09 – 04:19	pressed on line segment button and put a point.	13	223	10276
3.	04:19 – 04:30	visual search over main area.	16	273	10021
4.	04:31	pressed on undo button.	3	162	703
5.	04:35 – 04:38	pressed on line segment button and put a point.	9	319	3521
6.	04:42	pressed on erase button.	4	171	886
7.	04:45 – 04:50	pressed on line segment button and drew a line.	16	252	5021
8.	04:55 – 04:57	pressed on erase button.	6	328	2485
9.	04:57 – 05:04	pressed on line segment button and drew a segment.	21	257	6630
10.	05:04 – 05:06	pressed on erase button.	6	230	1521
11.	05:06 – 05:11	pressed on line segment button and put a point.	11	267	4020
12.	05:12	pressed on undo button.	-	-	-
13.	05:15 – 05:17	pressed on erase button.	6	300	1850
14.	05:18 – 05:26	pressed on line segment button and drew a segment.	3	262	868

15.	05:27	pressed on erase button.	4	150	633
16.	05:28 – 05:44	pressed on line segment button and created a square drawing four segments.	41	254	15489
17.	05:44 – 05:51	visual search over algebra panel.	25	130	6880
18.	05:54	successfully completed the task.			

Participant 8					
	Timeline	Event	# of Fix.	Fix.Avg.	Duration
1.	03:20 – 03:27	visual search over buttons			
2.	03:27 – 03:38	pressed on line button and put a point.	19	114	8463
3.	03:38	pressed on erase button.	2	75	567
4.	03:40 – 03:50	pressed on line button and put three points.	17	95	10744
5.	03:52– 03:55	pressed on erase button.	8	240	3034
6.	03:57– 04:05	pressed on point button and put two points.	9	204	3034
7.	04:05 – 04:20	visual search over buttons	7	117	7392
8.	04:20 – 04:34	pressed on line button and put a point.	18	123	11840
9.	04:34	pressed on erase button.			
10.	04:34– 04:53	visual search over buttons.	4	156	15747
11.	04:53 – 05:00	pressed on line button.	13	200	5886
12.	05:01 – 05:10	pressed on line segment button and drew two lines.	20	174	8790
13.	05:12 – 05:19	pressed on point button and put a point.	7	167	3057
14.	05:24 – 05:29	pressed on erase button.	10	153	8663
15.	05:32 – 05:38	pressed on point button and put a point.	7	141	5645
16.	05:39 – 05:52	Visual search over buttons	24	110	12764
17.	05:52 – 05:58	pressed on input bar.	11	139	8876
18.	06:04	press on erase button.	2	144	186
19.	06:04 – 06:20	visual search over buttons	21	130	13652
20.	06:20 – 06:42	pressed on slider button	1	118	19832
21.	06:42 – 06:45	Visual search over buttons	5	167	4074
22.	06:45 –	pressed on pencil button and drew a	10	109	8664

	06:52	line.			
23.	06:54 – 06:56	pressed on erase button.	8	96	1900
24.	06:56 – 07:02	visual search over buttons	3	72	2673
25.	07:02 – 07:15	pressed on symmetry button.	20	167	11914
26.	07:15 – 07:19	pressed on point button and put a point.	7	148	3703
27.	07:23 – 07:48	pressed on symmetry button.	30	128	21698
28.	07:48 – 07:50	pressed on point button and put a point.	2	75	833
29.	07:54	pressed on erase button.	1	133	2370
30.	07:54 – 08:10	visual search over buttons	8	84	13416
31.	08:10 – 08:12	pressed on point button and put a point.	3	112	318
32.	08:12 – 08:30	visual search over main area.	15	85	15143
33.	08:30	pressed on erase button.	-	-	951
34.	08:34 – 08:42	pressed on point button and put three points.	13	105	7032
35.	08:44	pressed on erase button.	2	209	317
36.	08:44 – 08:46	pressed on point button and put a point.	5	96	1885
37.	08:46	pressed on erase button.			
38.	08:48 – 08:50	pressed on point button and put a point.	4	121	1785
39.	08:50 – 08:59	visual search over buttons	5	114	6169
40.	08:59 – 09:13	pressed on line segment button and created a square connecting the points.	21	100	14191
41.	09:13 – 09:27	Visual search over main area.	19	116	15280
42.	09:27 – 09:33	pressed on angle button and showed an external angle.	4	121	7079
43.	09:41 – 09:48	pressed on angle button and showed an internal angle.	14	122	8355
44.	09:54	successfully completed the task.			

Participant 9

	Timeline	Event	# of Fix.	Fix.A vg.	Duration
1.	02:00 – 02:09	Visual search over buttons	15	285	5702
2.	02:09 – 02:18	pressed on segment line button and drew a segment.	10	684	6938
3.	02:18 – 02:25	visual search over algebra pane and tried to open redefine window.	25	243	7566

4.	02:25 – 02:46	pressed on redefine window and typed the point's coordinates.	10	275	15815
5.	02:51 – 02:59	pressed on line segment button and drew a segment.	17	474	9268
6.	02:59 – 03:17	visual search over algebra pane and tried to open redefine window.	52	275	18246
7.	03:17 – 03:25	pressed on undo button.	21	284	7450
8.	03:26 – 03:35	pressed on line segment button and drew two segments.	26	336	9848
9.	03:38	pressed on undo button.	2	292	633
10.	03:42 – 03:46	pressed on redo button.	11	282	3683
11.	03:46 – 03:58	pressed on line segment button and drew two lines.	24	426	11170
12.	03:58 – 04:05	Visual search over buttons	30	220	8221
13.	04:05 – 04:13	pressed on triangle button to show the angle.	26	196	6925
14.	04:13 – 04:28	Visual search over buttons.	46	219	14463
15.	04:28 – 04:30	pressed on undo button.	10	214	2652
16.	04:32	pressed on redo button.	3	221	884
17.	04:35 – 04:43	pressed on angle button and showed two internal angles.	17	456	8032
18.	04:46	successfully completed the task.			

Participant 10					
	Timeline	Event	# of Fix.	Fix.Avg.	Duration
1.	02:48 – 03:20	Visual search over buttons	93	182	31167
2.	03:20 – 03:43	pressed on line segment button and put two points..	61	232	22765
3.	03:47 – 03:50	pressed on erase button.	6	258	2317
4.	03:55 – 04:05	pressed on line button and put three points.	23	185	9588
5.	04:05	pressed on erase button.	3	139	417
6.	04:13 – 04:27	pressed on line button and drew four lines.	13	219	14581
7.	04:27 – 04:35	Visual search over main area.	24	232	7142
8.	04:35 – 04:53	pressed on angle button and showed all internal angles.	43	276	15183
9.	04:53	successfully completed the task.			

TASK 4 TRANSCRIPTS

Participant 1					
	Timeline	Event	# of Fix.	Fix.Avg	Time Duration
1.	00:10 – 00:27	Visual search over buttons	52	173	16795
2.	00:27 – 00:57	pressed on slider button	98	200	30054
3.	00:57 – 01:14	visual search over buttons	29	169	16713
4.	01:15 – 01:25	pressed Parallel Line button.	29	215	9401
5.	01:26 – 01:35	visual search over buttons	14	188	9783
6.	01:36 – 0:37	pressed Polygon button	7	210	1317
7.	01:38 – 01:46	visual search over buttons	24	218	8702
8.	01:46 – 01:50	pressed pencil button and put points	9	246	3752
9.	01:50 – 01:51	pressed Erase button and deleted the points.	3	350	966
10.	01:52 – 01:59	visual search over buttons	19	202	6000
11.	01:59 – 02:05	pressed line button.	10	202	7435
12.	02:05 – 02:08	pressed move button and zoomed in the page.	12	171	3234
13.	02:08 – 02:18	pressed line button.	28	153	9497
14.	02:18 – 02:47	visual search over buttons	83	191	26978
15.	02:48	noticed Input bar button and pressed it.	-	-	-
16.	02:48 – 03:29	used Input bar and wrote the function.	135	176	38702
17.	03:30	saw the graph.	4	129	584
18.	03:42	successfully finished the task.			

Participant 2					
	Timeline	Event	# of Fix.	Fix.Avg	Time Duration
1.	00:01 – 00:13	pressed on slider button.	34	222	11448
2.	00:13 – 00:36	visual search over buttons	31	252	23412
3.	00:36 – 00:38	pressed on Erase button	7	153	1993
4.	00:38 – 00:44	pressed on point button and put point A.	19	234	5700
5.	00:44 –	visual search over buttons	37	205	21120

	01:06				
6.	01:06 – 01:20	pressed on pencil button	36	170	13690
7.	01:20 – 01:44	visual search over buttons	68	208	23417
8.	01:44 – 01:53	pressed Z button and put points	26	273	8785
9.	01:53 – 01:55	pressed on the function.	10	182	2302
10.	01:55 – 02:06	opened Redefine window.	36	188	10919
11.	02:06 – 02:24	visual search over buttons	51	267	17352
12.	02:24 – 02:26	pressed on Z button.	7	210	2233
13.	02:26 – 03:27	opened Redefine window and changed the function.	25	199	10037
14.	03:28	saw the graph.	5	153	833
15.	03:33	finished the task.			

Participant 3

	Timeline	Event	# of Fix.	Fix.Avg	Time Duration
1.	00:17 – 00:38	pressed on point button.	37	343	22511
2.	00:38– 00:45	pressed on pencil button.	23	154	6090
3.	00:46– 00:47	pressed on undo button	3	372	1166
4.	00:47– 01:00	visual search over buttons	16	216	12653
5.	01:00	noticed Input bar.	1	85	289
6.	01:00 – 01:53	pressed on Input bar and typed an equation	110	150	50270
7.	01:53– 02:23	visual search over main area	15	151	25793
8.	02:23– 02:48	pressed on Input bar and typed an equation	10	122	24818
9.	02:48 – 03:00	visual search over main area	-	-	-
10.	03:00 – 03:06	pressed on move button and zoomed in the page	1	67	6067
11.	03:06	saw the graph.	-	-	-
12.	03:13	finished the task.			

Participant 4

	Timeline	Event	# of Fix.	Fix.Avg.	Time Duration
1.	00:13 – 00:18	visual search over buttons	10	219	4985

2.	00:18– 00:30	pressed on pencil button and draw a graph	19	165	11280
3.	00:30– 00:35	pressed on move tool.	8	142	6453
4.	00:40	noticed Input bar.	5	103	900
5.	00:40 – 01:01	pressed on Input bar and typed an equation	30	164	20885
6.	01:02	saw the graph.	4	138	683
7.	01:23	finished the task.			

Participant 5

	Timeline	Event	# of Fix.	Fix.A vg	Time Duration
1.	00:08 – 00:11	visual search over buttons.	8	142	3184
2.	00:11– 00:13	pressed on pencil button.	4	154	1433
3.	00:13– 00:30	visual search over buttons	25	124	17906
4.	00:30– 00:48	pressed on slider button.	36	127	17175
5.	00:49	noticed Input bar.	2	175	834
6.	00:49 – 02:36	pressed on Input bar and typed an equation	135	111	106710
7.	02:36– 03:06	visual search over main area	57	116	29854
8.	03:06 – 03:08	pressed on move button and zoomed in the page	6	133	1533
9.	03:08	saw the graph.	1	333	1017
10.	03:15	finished the task.			

Participant 6

	Timeline	Event	# of Fix.	Fix.A vg	Time Duration
1.	00:07 – 00:12	visual search over buttons.	-	-	5750
2.	00:12 – 00:25	pressed on pencil button.	24	172	12599
3.	00:25 – 00:52	visual search over buttons	42	123	26900
4.	00:52 – 01:03	pressed on pencil button.	20	129	11165
5.	01:04 – 01:09	pressed on undo button.	4	1400	4792
6.	01:11 – 01:28	pressed on pencil button	31	126	16437
7.	01:28 – 01:43	visual search over buttons	25	162	14651
8.	01:43	noticed Input bar.	2	159	932
9.	01:43–	pressed on Input bar and typed an	55	124	33866

	02:17	equation			
10.	02:18–02:30	visual search over main area	19	117	12620
11.	02:31	saw the graph.	3	94	349
12.	02:55	finished the task.			

Participant 7					
	Timeline	Event	# of Fix.	Fix.Avg	Time Duration
1.	00:07 – 00:09	visual search over buttons	7	326	2217
2.	00:09 – 00:41	pressed on slider button.	63	218	31922
3.	00:45 – 00:58	pressed on pencil button.	46	233	12063
4.	00:58 – 01:22	pressed on slider button	65	235	24715
5.	01:22 – 01:28	pressed move button	18	199	5150
6.	01:28 – 02:32	pressed on slider button	193	178	63806
7.	02:32 – 02:56	visual search over buttons	65	281	23665
8.	02:56 – 03:35	pressed on slider button.	109	196	33800
9.	03:35 – 03:47	visual search over buttons	34	268	11783
10.	03:47– 04:15	pressed on pencil button.	74	185	27231
11.	04:15 – 04:17	pressed erase button and deleted the graphs	7	226	2225
12.	04:17 – 04:37	visual search over buttons	43	203	20142
13.	04:37– 04:47	pressed on symmetry button	28	176	9168
14.	04:47 – 04:51	pressed erase button	11	241	4086
15.	04:51 – 05:09	visual search over buttons	48	257	17996
16.	05:09 – 05:16	pressed on slider button.	23	157	7104
17.	05:17	noticed input bar.	1	233	1104
18.	05:17– 05:55	pressed on Input bar and typed an equation	109	188	38118
19.	05:55– 06:18	visual search over main area	26	168	22852
20.	06:18	saw the graph	2	92	518
21.	06:26	completed the task.			

Participant 8					
	Timeline	Event			
1.	00:08 – 00:17	visual search over buttons	6	87	9781
2.	00:17 – 00:35	pressed on parallel line button.	7	88	17339
3.	00:36 – 00:41	pressed erase button	4	83	5100
4.	00:41 – 01:00	visual search over buttons	9	228	21830
5.	01:00 – 01:11	pressed on parallel line button.	4	121	22803
6.	01:11 – 01:13	pressed erase button.	1	69	2305
7.	01:13 – 01:34	visual search over buttons	14	86	20825
8.	01:34 – 01:55	pressed on parallel line tool and put a point.	5	117	21060
9.	01:55 – 01:56	selects segment button.	-	-	1630
10.	01:56– 02:09	created a segment connecting A and B	9	97	12410
11.	02:09 – 02:15	pressed erase button and deleted the line	8	125	5143
12.	02:15 – 02:19	selects segment	3	100	4307
13.	02:19– 02:31	created a segment connecting A and B	21	114	10652
14.	02:31	pressed algebra pane and opened Input bar.	-	-	-
15.	02:31 – 02:46	pressed ınput bar and closed ınput bar.	20	107	13124
16.	02:46 – 03:08	visual search over algebra pane.	35	120	23876
17.	03:08 – 03:11	pressed erase button.	1	68	2792
18.	03:11– 03:18	visual search over buttons	7	98	8174
19.	03:19– 03:20	pressed on parallel line button.	1	100	683
20.	03:21 – 03:25	pressed on segment button.	8	113	4891
21.	03:26 – 03:36	visual search over buttons	17	130	10132
22.	03:36– 03:40	pressed on parallel line button.	6	158	3804
23.	03:40– 03:42	pressed erase button.	5	164	2340
24.	03:43 – 03:49	pressed on segment button.	12	113	6395
25.	03:50 – 03:53	pressed erase button.	-	-	3118

26.	03:53–03:58	visual search over buttons	9	123	4767
27.	03:59–04:04	pressed erase button.	6	98	4746
28.	04:04 – 04:08	selected segment button.	10	113	3455
29.	04:08 – 04:13	created a segment connecting A and B	3	122	5335
30.	04:13	noticed Input bar.	-	-	-
31.	04:13 – 05:02	pressed on Input bar and typed an equation.	5	110	47550
32.	05:08 – 05:45	pressed on Input bar and corrected the equation.	24	88	37135
33.	05:51	saw the graph	-	-	-
34.	06:00	completed the task.	-	-	-

Participant 9					
	Timeline	Event	# of Fix.	Fix.Avg.	Time Duration
1.	00:04–00:09	visual search over buttons.	17	219	4386
2.	00:09–00:12	selects pencil tool.	7	519	3373
3.	00:12–00:16	pressed on pencil button.	11	328	4023
4.	00:16–00:26	pressed on slider button.	30	247	10167
5.	00:26–00:33	pressed on pencil button.	14	355	6508
6.	00:33–00:51	visual search over buttons.	58	188	18071
7.	00:51–01:03	pressed on slider button.	36	266	11574
8.	01:03–01:34	visual search over buttons.	86	250	30652
9.	01:34	noticed input bar.	3	112	319
10.	01:34 – 02:10	pressed on Input bar and typed an equation.	109	227	35389
11.	02:12	saw the graph.	4	96	568
12.	02:17	finished the task.			

Participant 10					
	Timeline	Event	# of Fix.	Fix.Avg.	Time Duration
1.	00:10 – 00:23	visual search over buttons	33	212	13329
2.	00:23 – 00:42	pressed on slider button.	53	223	18914
3.	00:42 – 01:10	visual search over buttons	87	187	27507

4.	01.10 – 01:12	pressed line button and drew a line.	7	264	2085
5.	01:12 – 01:23	searched to open Redefine window.	29	274	10261
6.	01:23 – 01:34	pressed on Redefine window	35	190	10607
7.	01:34 – 01:43	visual search over buttons	26	199	8947
8.	01:43 – 01:44	pressed on erase button and deleted the line.	5	187	1607
9.	01:44 – 01:54	visual search over buttons	29	267	9323
10.	01:54 – 02:00	selected hemicycle button.	17	247	6117
11.	02:00 – 02:05	pressed on hemicycle button.	17	213	5321
12.	02:05 – 02:09	pressed erase button and deleted the hemicycle	12	223	2675
13.	02:12– 02:18	pressed on line button and drew a line.	25	214	9252
14.	02:22 – 03:25	opened Redefine window and typed the equation.	9	185	3539
15.	03:26	saw the graph	3	145	870
16.	03:50	completed the task.			

TASK 5 TRANSCRIPTS

Participant 1					
	Timeline	Event	# of Fixations	Fixation average	Time
1	(04:00 – 04:10)	visual search over buttons	37	194	3583
2	(04:10 – 04:22)	Pressed parallel line button and put two points.	31	258	10989
3	(04:22	Pressed on undo button.	5	143	833
4	(04:24 – 04:27)	Pressed erase button.	10	269	3469
5	(04:27 – 04:39)	visual search over buttons	20	189	10735
6	(04:39 – 04:42)	Pressed on point button and put a point.	7	407	1919
7	(04:42 – 04:44)	visual search over algebra pane and tried to open redefine window.	4	388	1583
8	(04:44 – 04:46)	Pressed on Redefine window	5	283	1500
9	(04:46 – 04:55)	visual search over algebra pane and tried to open redefine window.	28	240	8676
10	(04:55 – 04:59)	Pressed on Redefine window	16	180	3885
11	(04:59 – 05:02)	visual search over main area.	9	211	3008
12	(05:02 – 05.05)	pressed on erase button.	5	344	2003
13	(05:05 – 05:41)	pressed on redefine window and typed an equation.	102	182	36006
14	(05:41 – 05:44)	Visual search over algebra pane and tried to open redefine window.	8	269	2484
15	(05:44 – 05:52)	pressed on redefine window and typed an equation.	24	184	81343
16	(05:52 – 05:55)	visual search over algebra pane and tried to open redefine window.	9	280	3167
17	(05:55 – 06:03)	pressed on redefine window and typed an equation.	28	159	7587
18	(06:03 – 06:08)	visual search over buttons	15	157	4304
19	06:08 – 06:15)	pressed on polygon button and put two points.	16	373	6772
20	(06:15 – 06:20)	Visual search over main area.	17	140	4327
21	(06:20 – 06:27)	pressed on redefine window and typed an equation.	24	201	6705
22	(06:28 – 06:38)	Pressed on polygon button and put a point.	38	247	10701
23	(06:39 – 06:41)	pressed on erase button.	8	217	1985
24	(06:41 – 06:50)	Pressed on polygon button and put two points.	25	294	8630

25	(06:50 – 07:01)	Pressed on move button.	21	138	9247
26	(07:01 – 07:05)	visual search over algebra pane and tried to open redefine window.	10	309	3922
27	(07:05 – 07:13)	pressed on redefine window and put a point.	26	252	8042
28	(07:13 – 07:15)	visual search over buttons	7	184	1901
29	(07:15 – 07:19)	Pressed on point button and put a point.	10	218	3669
30	(07:19 – 07:32)	visual search over main area.	37	177	12256
31	(07:32 – 07:36)	Selected polygon button.	12	157	3851
32	(07:36 – 07:39)	visual search over main area.	13	145	3306
33	(07:39 – 07:47)	Pressed on polygon button and created a triangle.	17	298	6874
34	(07:47 – 07:51)	Pressed on angle button and created an internal angle.	7	429	2951
35	(07:51 – 07:56)	visual search over algebra pane and tried to open redefine window.	15	318	5184
36	(07:56 – 08:03)	pressed on redefine window and tried to type 60° angle.	23	177	6572
37	(08:03 – 08:10)	visual search over main area.	20	208	6858
38	(08:10 – 08:13)	Pressed on move button.	9	183	2717
39	(08:13 – 08:15)	Pressed on erase button.	6	186	1333
40	(08:15 – 08:22)	Selected regular polygon tool.	24	178	7189
41	(08:22 – 08:33)	Pressed on regular polygon button and created an equilateral triangle.	31	165	11152
42	(08:36 – 08:40)	Pressed on erase button and accidentally deleted the line.	13	110	4446
43	(08:40 – 08:46)	pressed on angle button and showed two external and two internal angles.	18	148	4644
44	(08:49 – 08:54)	Pressed on erase button.	15	175	4478
45	(08:55 – 09:41)	Pressed on move button and tried to move the triangle.	128	220	46007
46	(09:43 – 09:50)	Pressed on polygon button and draw a triangle.	19	108	7369
47	(09:53 – 09:57)	Pressed on erase button.	11	149	2344
48	(09:57 – 10:00)	Visual search over buttons.	3	73	2542
49	(10:00 – 10:05)	Pressed on erase button.	8	109	3639
50	(10:05 – 10:15)	pressed on polygon button and draw a triangle.	21	222	8721

51	(10:15 – 10:22)	Pressed on regular polygon button and created an equilateral triangle.	18	292	6554
52	(10:22 – 10:29)	Visual search over buttons.	4	130	7020
53	(10:29 – 10:35)	Pressed on erase button.	10	229	4811
54	(10:39 – 10:42)	Pressed on vector polygon button	11	230	3236
55	(10:42)	Pressed on undo.	3	139	467
56	(10:42 – 10:44)	Pressed on vector polygon button	4	192	917
57	(10:44)	Pressed on undo.	2	175	283
58	(10:46 – 10:50)	Pressed on vector polygon button	11	182	3837
59	(10:50 – 10:53)	Pressed on undo.	9	176	2302
60	(10:55 – 11:03)	Pressed on vector polygon button	17	164	7935
61	(11:07)	Pressed on undo.	3	174	1401
62	(11:07 – 11:29)	Visual search over buttons.	63	185	18670
63	(11:29 – 11:40)	Pressed on regular polygon button and created an equilateral triangle.	25	151	7490
64	(11:40 – 11:45)	Visual search over buttons.	7	181	5382
65	(11:45 – 11:55)	Pressed on move button.	9	157	4382
66	(11:55 – 12:00)	Visual search over buttons.	14	128	4711
67	(12:04 – 12:09)	Pressed on regular polygon button and created an equilateral triangle.	16	164	5024
68	(12:09 – 12:17)	Visual search over buttons.	11	141	7559
69	(12:18 – 12:21)	Pressed on regular polygon button and created an equilateral triangle.	12	249	3786
70	(12:21 – 12:26)	Pressed on undo.	17	131	4778
71	(12:27 – 12:32)	Pressed on erase button.	15	188	5220
72	(12:32 – 12:35)	Pressed on line button and drew a line.	8	329	3267
73	(12:35 – 12:45)	Visual search over buttons.	31	157	9048
74	(12:45 – 12:51)	Pressed on regular polygon tool.	14	150	5157
45	(12:51 – 13:01)	Visual search over buttons.	17	101	9184
76	(13:03 – 13:10)	Pressed on regular polygon button and created an equilateral triangle.	15	317	6589
77	(13:15)	Successfully completed the task.			

Participant 2					
	Timeline	Event	# of Fixati ons	Fixation average	Time
1	(03:43 – 03:51)	visual search over buttons	21	327	7533
2	(03:54)	pressed line button.	4	146	567
3	(03:59 – 04:12)	Pressed on perpendicular bicestor button.	37	286	13502
4	(04:12 – 04:16)	Pressed on perpendicular line button.	10	164	3284
5	(04:16 – 04:20)	Pressed on undo button.	12	155	4250
6	(04:26 – 04:29)	Pressed on erase button.	15	209	3616
7	(04:29 – 04:48)	Pressed on perpendicular bicestor button.	55	209	17072
8	(04:48 – 04:52)	Pressed on segment button and draw a segment.	14	235	4833
9	(04:55 – 05:01)	Pressed on perpendicular bicestor button.	20	285	6500
10	(05:01 – 05:07)	Visual search over buttons.	15	256	4938
11	(05:07 – 05:10)	Pressed on segment button and draw a segment.	5	94	2707
12	(05:10 – 05:20)	Visual search over buttons.	30	208	9002
13	(05:20 – 05:31)	pressed on parallel line button and draw a line.	27	236	11086
14	(05:33)	Put a point.	1	717	733
15	(05:33 – 05:35)	pressed on undo button.	4	163	1568
16	(05:37 – 05:43)	Pressed on parallel line button and draw a line.	14	361	6316
17	(05:44)	Pressed on undo button.	4	146	718
18	(05:45)	Pressed on erase button.	3	145	450
19	(05:46)	Pressed on parallel line button.	1	783	867
20	(05:48 – 05:50)	Pressed on undo button.	11	249	2834
21	(05:53 – 05:59)	Pressed on segment button and drew a segment.	15	205	6247
22	(05:59 – 06:07)	Pressed on parallel line button and put two points.	22	221	7702
23	(06:08 – 06:12)	Pressed on undo button.	12	177	4688
24	(06:12 – 06:17)	Pressed on segment button and drew a segment.	11	161	4567
25	(06:17 – 06:22)	Pressed on parallel line button and put two points.	17	205	4724
26	(06:23 – 06:28)	Pressed on undo button.	14	173	4517

27	(06:28 – 06:30)	Pressed on segment button and drew a segment.	4	109	1951
28	(06:30 – 06:32)	Pressed on undo button.	5	167	1399
29	(06:33 – 06:37)	Pressed on move button.	14	182	4516
30	(06:37 – 06:46)	Pressed on segment button and drew a segment.	24	192	8269
31	(06:46 – 06:49)	Pressed on move button.	7	121	3133
32	(06:49 – 06:55)	Pressed on parallel line button and put two points.	11	196	6158
33	(06:55 – 07:05)	Pressed on segment button and drew a segment.	33	163	9106
34	(07:07 – 07:12)	Pressed on parallel line button and put two points.	20	189	5234
35	(07:12 – 07:16)	Pressed on line button.	15	201	4401
36	(07:16 – 07:26)	visual search over buttons	27	207	8639
37	(07:27)	Pressed on undo button.	4	275	1534
38	(07:28 – 07:32)	Pressed on segment button and drew a segment.	10	333	4481
39	(07:32 – 07:37)	Pressed on parallel line button and drew a line.	11	299	4246
40	(07:37 – 07:51)	pressed on parallel line button and put two points.	29	267	13322
41	(07:51 – 07:55)	pressed on move button.	14	240	4166
42	(07:55 – 08:00)	Pressed on parallel line button and put a point.	13	213	4238
43	(08:01)	Pressed on undo button.	5	131	806
44	(08:03 – 08:07)	Pressed on move button.	10	179	3733
45	(08:07 – 08:14)	Pressed on parallel line button and put a point.	19	223	6990
46	(08:14)	Pressed on undo button.	2	159	617
47	(08:14 – 08:20)	Pressed on segment button and drew a segment.	14	199	5723
48	(08:20 – 08:22)	Pressed on move button.	4	184	1334
49	(08:22 – 08:27)	Pressed on parallel line button and put a point.	11	259	4341
50	(08:27)	Pressed on undo button.	2	125	522
51	(08:29 – 08:34)	Pressed on segment button and drew a segment.	13	264	5219
52	(08:34 – 08:42)	Pressed on move button.	19	221	6752
53	(08:42 – 08:46)	Pressed on parallel line button and put two points.	10	164	5163
54	(08:49)	Gave up complete the task.			

Participant 3					
	Timeline	Event	# of Fixations	Fixation average	Time Duration
1	(03:26 – 00:27)	Visual search over buttons	-	-	-
2	(03:27 – 03:32)	selected parallel line button.	8	140	4534
3	(03:32 – 03:39)	pressed on line button and put a point.	11	153	7223
4	(03:39 – 03:57)	pressed parallel line button and put points.	30	233	17213
5	(03:57 – 04:10)	pressed on line button and drew a line.	15	369	24013
6	(04:10 – 04:13)	pressed on undo button.	-	-	-
7	(04:13 – 04:19)	pressed on move button and move the page.	-	-	-
8	(04:19 – 04:25)	pressed on line button and drew a line.	14	219	5638
9	(04:26 – 04:37)	pressed on parallel line button and drew a perpendicular line	21	264	10652
10	(04:37 – 04:40)	pressed on undo button.	8	146	13485
11	(04:40 – 04:52)	pressed on parallel line button and drew two parallel lines and put a points.	30	258	12514
12	(04:52 – 04:54)	pressed on undo button.	5	300	1786
13	(04:54 – 04:58)	pressed on parallel line button and drew three parallel lines	8	442	3417
14	(04:58 – 05:32)	visual search over buttons.	101	253	34473
15	(05:32 – 05:47)	pressed on polygon button and created a triangle	9	342	4959
16	(05:47 – 06:21)	Visual search over buttons.	96	291	33602
17	(06:25)	Gave up complete the task.			

Participant 4					
	Timeline	Event	# of Fixations	Fixation average	Time
1	(01:38 – 01:45)	Visual search over buttons	12	147	7167
2	(01:46 – 01:57)	Pressed parallel line button.	11	160	11472
3	(01:57 – 02:09)	pressed on polygon button and drew two segments.	22	212	10179
4	(02:09 – 02:12)	pressed on undo button.	6	181	4023

5	(02:12 – 02:15)	pressed on erase button.	6	109	968
6	(02:18 – 02:36)	pressed on regular polygon button and created an equilateral triangle.	45	137	16735
7	(02:36 – 02:39)	Visual search over buttons.	3	117	401
8	(02:39 – 03:32)	Pressed parallel line button and drew any line and put points.	98	212	52000
9	(03:33 – 03:36)	Pressed on undo button	4	245	1285
10	(03:36 – 03:42)	pressed parallel line button	12	167	3902
11	(03:42 – 03:45)	pressed on undo button.		127	1235
12	(03:45)	pressed on redo button.	-	-	-
13	(03:45 – 04:24)	pressed on parallel line button.	37	209	39014
14	(04:24 – 04:32)	Pressed on angle bicestor button and drew a line.	15	184	6839
15	(04:32 – 04:45)	pressed on parallel line button and	46	170	12407
16	(04:45 – 05:01)	Visual search over buttons.	35	163	15667
17	(05:01 – 05:11)	Pressed on angle button and showed two external angle.	6	108	2455
18	(05:17)	successully completed the task			

Participant 5

	Timeline	Event	# of Fixations	Fixation average	Time
1	(03:33– 03:55)	Visual search over buttons	27	134	21923
2	(03:55 – 04:00)	Pressed on line button.	12	95	4844
3	(04:00 – 04:05)	pressed on angle button.	13	125	5934
4	(04:05 – 04:13)	pressed on input bar.	9	101	6967
5	(04:13 – 04:31)	Used angle button and created an angle.	31	114	16955
6	(04:31 – 04:40)	pressed on polygon button and drew a segment.	18	67	8927
7	(04:40 – 04:49)	Pressed on erase button.	29	137	9053
8	(04:49 – 04:52)	Pressed on polygon button.	5	108	3289
9	(04:52 – 04:57)	Pressed on input bar.	6	158	4417
10	(04:57 – 05:02)	Visual search main area.	14	128	5523

11	(05:02 – 05:08)	pressed on angle tool.	14	110	6586
12	(05:08 – 05:13)	pressed on erase button.	4	96	4340
13	(05:13 – 05:22)	Visual search main area.	16	99	9656
14	(05:22 – 05:30)	Pressed on angle button.	19	121	8083
15	(05:30 – 05:34)	pressed on erase button.	6	139	3932
16	(05:35 – 05:47)	Visual search over buttons.	24	117	12130
17	(05:47 – 06:01)	Pressed on circle through 3 points button and drew circles.	25	143	13937
18	(06:02)	Pressed on undo button.	-	-	-
19	(06:02 – 06:09)	Pressed on circle through 3 points button and drew circles.	13	142	6953
20	(06:09)	pressed on undo button.	-	-	-
21	(06:09 – 06:34)	Pressed on circle through 3 points button and drew circles.	50	130	25294
22	(06:34)	pressed on undo button.			
23	(06:34 – 06:49)	Pressed on circle through 3 points button and drew circles.	25	125	15430
24	(06:49 – 06:59)	pressed on polygon button and drew two segments.	18	131	9667
25	(06:59 – 06:05)	Pressed on angle button and created an angle.	95	125	53326
26	(07:12)	Gave up to complete the task			

Participant 6

	Timeline	Event	# of Fixations	Fixation average	Time
1	(03:13 – 03:20)	Visual search over buttons	10	107	2049
2	(03:20 – 03:29)	Pressed parallel line button and put points.	22	135	8903
3	(03:29	pressed on undo button.	-	-	-
4	(03:29 – 03:44)	Pressed parallel line button and put points.	15	118	14685
5	(03:44 – 03:50)	Pressed on move button	3	129	6930
6	(03:50 – 03:56)	Visual search over buttons.	4	126	1764
7	(03:56 – 04:32)	Pressed parallel line button and put points.	45	117	36296
8	(04:32 – 05:05)	Visual search over buttons.	57	136	33681
9	(05:05 – 05:09)	Closed the project and opened a new project.	6	106	2416
10	(05:09 –	Visual search over main area.	13	97	5583

	05:15)				
11	(05:15 – 05:24)	pressed on line tool and put two points.	11	91	8736
12	(05:24 – 05.26)	pressed on move button and moved the point.	4	92	1950
13	(05:28 – 05:34)	pressed on line button and drew a line.	10	112	6661
14	(05:34 – 05:56)	Pressed on parallel line button and drew a line.	37	113	21785
15	(05:56 – 06:01)	pressed on undo button.	3	89	4852
16	(06:01 – 06:08)	pressed on line button and drew a line.	9	85	6133
17	(06:08 – 06:15)	Pressed on move button and moved the line.	9	106	7235
18	(06:15 – 06:26)	Pressed on parallel line button and drew a perpendicular line.	11	135	6100
19	(06:26	Pressed on undo button.	-	-	-
20	(06:26 – 06:40)	Used parallel line tool and drew two parallel lines.	20	146	11391
21	(06:40 – 06:51)	Pressed on move button and moved the line.	16	91	9851
22	(06:51 – 07:12)	visual search over main area.	44	110	20800
23	(07:12 – 07.43)	Visual search over polygon tool.	60	127	30071
24	(07:44 – 07:53)	pressed on polygon button and created a triangle.	18	133	8984
25	(07:53 – 07:57)	Pressed on undo button.	2	84	6751
26	(07:57 – 08:02)	visual search over button.	8	111	2868
27	(08:02 – 08:47)	Pressed on move button and moved the line.	50	118	43776
28	(08:47 – 08:57)	Pressed on polygon button and created a triangle.	9	84	6619
29	(08:57 – 09:01)	Pressed on moved button.	3	167	1800
30	(09:01 – 09:26)	pressed on polygon button and created a triangle.	32	98	21441
31	(09:27 – 09:42)	Visual search over main area.	23	107	17279
32	(09:42)	Pressed on undo button.	-	-	-
33	(09:44 – 10:06)	Pressed on rigid polygon button and created a triangle.	30	118	17168
34	(10:06 – 10:10)	Pressed on undo button.	4	87	1767
35	(10:10 – 10:28)	Pressed on vector polygon button.	24	111	17011
36	(10:28 – 10:32)	Pressed on undo button.	2	67	7247
37	(10:33 –	Pressed on regular polygon button	13	92	11575

	10:47)	and drew an equilateral triangle.			
38	(10:47 – 10:55)	Visual search over main area.	19	100	7600
39	(10:55 – 11:43)	Pressed on moved button and tried to move the triangle.	24	112	38557
40	(11:43 – 11:54)	Pressed on undo button.	1	67	18271
41	(11:54 – 13:05)	Pressed on move button and moved the line.	7	212	9836
42	(13:05 – 13:12)	visual search over algebra pane.	129	150	70269
43	(13:12 – 13:54)	pressed on angle button and showed two external and two internal angles.	8	100	5068
44	(14:06)	Successfully completed the task.			

Participant 7					
	Timeline	Event			
1.	07:38 – 07:41	visual search over buttons	7	295	2386
2.	07:41 – 07:56	pressed on parallel line button and put three points.	37	193	15171
3.	07:56 – 08:19	pressed on parallel line button and drew a line.	57	273	22452
4.	08:19– 08:49	pressed on parallel line button and drew two parallel lines.	76	237	19428
5.	08:49 – 08:54	pressed on move button and moved a point.	17	188	4654
6.	08:54 – 09:00	visual search over buttons.	18	285	6336
7.	09:00 – 09:05	pressed on parallel line button and drew a parallel line.	12	285	4505
8.	09:05– 09:20	visual search over buttons.	49	206	14409
9.	09:20 – 09:30	pressed on polygon button and created a triangle.	18	319	9758
10.	09:30 – 09:43	visual search main area.	34	194	12976
11.	09:43 – 09:59	visual search over buttons.	35	158	15100
12.	09:59 – 10:06	pressed on erase button.	14	123	6741
13.	10:06 – 10:30	visual search over buttons.	55	347	23828
14.	10:30 – 10:41	pressed on regular polygon button and created an equilateral triangle.	27	181	10653
15.	10:44 – 10:49	pressed on angle tool and showed external angle.	13	249	5302
16.	10:53 – 10:58	pressed on undo button.	12	195	5613
17.	10:58 – 11:17	pressed on parallel line button and drew three parallel lines.	51	251	17580

18.	11:26 – 11:30	pressed on angle tool and showed internal angle.	11	322	5139
19.	11:34	successfully completed the task.			

Participant 8

	Timeline	Event	# of Fixations	Fixation average	Time
1	(06:14 – 06:35)	visual search over buttons	34	117	19740
2	(06:35 – 07:06)	Pressed on regular polygon button and created an equilateral triangle.	43	111	28381
3	(07:06 – 07:17)	Visual search over main area.	6	125	7148
4	(07:17 – 07:21)	visual search over buttons	2	92	3438
5	(07:21 – 07:30)	Pressed a closed half line button and drew a closed half line.	7	117	4106
6	(07:30)	Pressed on erase button.	1	100	850
7	(07:30 – 07:45)	visual search over buttons	12	85	12097
8	(07:45 – 07:55)	Pressed on parallel line button and put two points.	6	114	8443
9	(07:55 – 07:58)	Pressed on erase button.	2	150	435
10	(08:00 – 08:07)	Pressed on undo button.	2	67	9056
11	(08:11 – 08:35)	Pressed on parallel line button and put a point.	23	108	21260
12	(08:36)	pressed on erase button.	2	92	616
13	(08:38 – 09:02)	pressed on parallel line button and draw a line.	30	120	23436
14	(09:02 – 09:14)	Pressed on perpendicular line button and draw a perpendicular line.	13	118	11489
15	(09:15 – 09:20)	pressed on erase button.	9	128	5139
16	(09:20 – 09:40)	Visual search over main area.	17	115	19919
17	(09:40 – 09:52)	Pressed on parallel line button.	11	91	8489
18	(09:52)	Pressed on erase button.	1	67	167
19	09:52 – 09:57)	visual search over main area.	2	67	5529
20	(09:58)	Pressed on undo button.	-	-	-
21	(10:00 – 10:51)	Pressed on parallel line button and put two points.	69	105	53610
22	(10:51)	Pressed on erase button.	-	-	-
23	(10:54 – 11:06)	Pressed on parallel line button and put a point.	15	115	6567
24	(11:06)	Pressed on erase button.	-	-	-
25	(11:09 –	Pressed on parallel line button and	9	96	4881

	11:16)	drew a line.			
26	(11:19 – 11:23)	Pressed on erase button.	2	100	4859
27	(11:29)	Gave up to complete the task.			

Participant 9

	Timeline	Event	# of Fixations	Fixation average	Time Duration
1	(02:29 –	Visual search over buttons	4	89	1180
	02:32)				
2	(02:32 – 02:50)	Pressed on parallel line button and put two points.	48	251	16912
3	(02:50)	pressed on undo button.	-	-	-
4	(02:50 – 02:56)	Visual search over buttons.	14	182	4459
5	(02:56 – 03:09)	Pressed on line button drew three parallel lines.	39	264	29967
6	(03:09 – 03:22)	Visual search over buttons.	45	223	12438
7	(03:22)	pressed on undo button.	3	211	434
8	(03:25 – 03:29)	Pressed on parallel line button and drew a parallel line.	15	285	4441
9	(03:29 – 03:45)	Visual search over algebra pane and tried to open redefine window.	56	209	10321
10	(03:45– 03:57)	Opened redefine window and changed the point's coordinates.	29	189	11576
11	(03:57 – 04:48)	Visual search over main area and buttons.	156	237	51101
12	(04:48 – 04:54)	pressed on regular polygon tool	22	179	5754
13	(04:54 – 04:57)	Pressed on polygon button.	9	204	2357
14	(04:57 – 05:13)	pressed on regular polygon button and created an equilateral triangle.	22	310	23842
15	(05:13 – 05:30)	Visual search over main area.	31	216	8722
16	(05:32)	Pressed on undo button.	1	1100	1133
17	(05:32 – 05:37)	Visual search over main area.	14	194	4632
18	(05:37 – 05:43)	Pressed on polygon button and draw a triangle.	13	392	5584
19	(05:43 – 06:30)	Visual search over main area.	129	237	46424
20	(06:30 – 06:38)	pressed on regular polygon button.	22	293	7609
21	(06:38)	pressed on undo button.	3	228	618
22	(06:38 – 06:50)	pressed on regular polygon button and created an equilateral triangle.	34	234	10946
23	(06:50 –	Visual search over main area.	11	216	10078

	07:00)				
24	(07:00)	Pressed on undo button.	-	-	-
25	(07:03 – 07:10)	pressed on regular polygon button and created an equilateral triangle.	25	202	6836
26	(07:10 – 07:17)	Visual search over main area.	18	237	6851
27	(07:17)	pressed on undo button.	1	217	467
28	(07:22 – 07:25)	pressed on regular polygon button and put a point.	8	345	3688
29	(07:25)	Pressed on undo button.	-	-	-
30	(07:26 – 07:28)	Used regular polygon tool put a point.	2	1272	2898
31	(07:30 – 07:34)	Used regular polygon tool put a point.	11	245	4119
32	(07:36)	pressed on undo button.	3	168	589
33	(07:41 – 07:50)	pressed on regular polygon button and created an equilateral triangle.	21	230	8993
34	07:57	Successfully completed the task.			

Participant 10					
	Timeline	Event	# of Fixations	Fixation average	Time
1	(04:11 – 04:43)	visual search over buttons	45	171	32238
2	(04:43 – 05:04)	Pressed on polyline button and draw four segments.	50	210	20424
3	(05:07 – 04:12)	pressed on erase button.	12	225	4984
4	(05:12 – 05:17)	visual search over buttons	17	144	4668
5	(05:17 – 05:41)	Pressed on parallel line button and put four points.	67	164	24023
6	(05:41 – 05:44)	Pressed on erase button.	9	198	2550
7	(05:44 – 05:51)	Pressed on line button and draw a line.	22	202	6283
8	(05:53 – 06:44)	Pressed on parallel line button and put two points.	144	205	50859
9	(06:44 – 06:47)	Pressed on erase button.	5	230	2051
10	(06:47 – 06:53)	Visual search over main area.	12	121	5055
11	(06:54 – 07:08)	visual search over buttons.	34	160	13940
12	(07:08 – 07:11)	pressed on line button and drew a line.	5	140	2268
13	(07:11 – 07:29)	pressed on parallel line button and put a point.	42	218	17854
14	(07:29 –	Pressed on erase button.	9	183	3601

	07:33)				
15	(07:34 – 07:36)	pressed on line button and drew a line.	10	135	2554
16	(07:37 – 07:58)	pressed on parallel line button and drew two parallel lines.	54	202	20922
17	(07:58 – 08:10)	Visual search over polygon tool.	30	201	11385
18	(08:10 – 08:24)	Pressed on regular polygon tool and drew an equilateral triangle.	37	156	13054
19	08:24 – 09:05)	visual search over main area.	114	146	40622
20	(09:05 – 09:16)	Pressed on angle tool and showed all internal angle.	18	122	9861
21	(09:16 – 09:30)	visual search over main area.	14	144	13150
22	(09:30 – 09:42)	Pressed on move around point button.	13	164	9382
23	(09:42 – 09:51)	visual search over main area.	8	135	2883
24	(09:51 – 10:01)	Pressed on erase button.	-	-	584
25	(10:01 – 10:12)	Pressed on polygon button and drew a triangle.	13	163	4136
26	(10:12 – 10:15)	Pressed on erase button.	10	155	2384
27	(10:15 – 10:24)	Pressed on regular polygon tool and drew an equilateral triangle.	32	158	8583
28	(10:24 – 10:42)	visual search over buttons	51	219	17841
29	(10:42 – 10:48)	Pressed on line button and drew a line.	16	243	5384
30	(10:49 – 11:03)	Pressed on parallel line button and drew three parallel line.	34	215	14212
31	(11:03 – 11:11)	visual search over main area.	10	202	11851
32	(11:11– 11:49)	Pressed on move button and moved the triangle and lines.	97	186	32326
33	(11:49 – 11:55)	Pressed on angle tool and showed an internal angle	5	193	1517
34	(11:55 – 12:01)	visual search over main area.	11	282	4233
35	(12:01 – 12:08)	Pressed on move button.	14	280	5301
36	(12:08)	Successfully completed the task.			

TASK 6 TRANSCRIPTS

Participant 1

	Timeline	Event	# of Fixations	Fixation average	Time
1.	(13:29 – 13:35)	visual search over buttons	20	193	6823
2.	(13:35 – 13:49)	Pressed circle button and created a circle.	43	215	13708
3.	(13:49 – 13:51)	pressed on undo button.	4	342	1784
4.	(13:51 – 14:12)	Pressed circle button and created a circle.	60	206	20916
5.	(14:12 – 14:20)	Pressed on circular sector button and intersected the circles.	13	99	7521
6.	(14:20 – 14:21)	pressed on undo button.	3	117	937
7.	(14:22)	Pressed on redo button.	4	101	923
8.	(14:24 – 14:32)	Pressed on circular sector button and intersected the circles.	21	129	8100
9.	(14:32)	Pressed on undo button.	1	200	859
10.	(14:33 – 14:40)	Pressed on circular sector button and intersected the circles.	18	189	6255
11.	(14:40 – 14:48)	Pressed on circle button.	20	206	8158
12.	(14:49)	pressed on undo button.	1	784	834
13.	(14:50 – 15:28)	Visual search over buttons.	89	192	37965
14.	(15:28 – 15:33)	pressed on point button and put a point.	10	260	3885
15.	(15:33 – 16:08)	visual search over algebra pane and tried to open redefine window.	69	165	34515
16.	(16:08 – 16:11)	pressed on intersect button and intersected the circles.	10	180	2569
17.	(16:12 – 16:35)	visual search over buttons	42	234	22690
18.	(16:38 – 16:42)	Pressed on circle button and drew a circle.	6	182	4158
19.	(16:42 – 17:03)	Visual search over main area.	48	275	20967
20.	(17:03 – 17:25)	pressed on intersect button and intersected the circles.	63	247	21570
21.	(17:25 – 17:55)	Pressed on circle button.	83	278	29737
22.	(17:55 – 18:05)	pressed on segment button and drew three segments.	24	308	9760
23.	(18:05 – 18:44)	Pressed on circle button and drew a circle.	101	184	38782

24.	(18:44 – 18:46)	Pressed on undo button.	7	164	1667
25.	(18:48 – 19:04)	Pressed on circle button and drew two circles.	48	204	16135
26.	(19:04 – 19:12)	pressed on intersect button and intersected the circles.	21	256	7551
27.	(19:12 – 19:20)	pressed on segment button and drew three segments.	24	236	7810
28.	(19:20 – 19:25)	visual search over main area.	14	300	5420
29.	(19:26 – 19:31)	Pressed on angle button and showed an external angle.	10	247	5564
30.	(19:32 – 19:35)	Pressed on undo button.	8	198	2784
31.	(19:35 – 19:40)	Pressed on angle button and showed an internal angle.	10	109	2950
32.	(19:40 – 19:51)	visual search over algebra pane	10	135	4885
33.	(19:51 – 20:34)	Pressed on angle button and showed four internal and one external angle.	91	151	42768
34.	(20:34)	Pressed on undo button.	2	400	417
35.	(20:36 – 20:41)	Pressed on angle button and showed an external angle.	11	206	4187
36.	(20:43 – 20:46)	Visual search over main area.	8	107	2683
37.	(20:46)	Pressed on undo button.	2	176	285
38.	(20:46 – 20:47)	Pressed on move button and zoomed in the page.	1	500	883
39.	(20:57)	Successfully completed the task.			

Participant 2

	Timeline	Event	# of Fixations	Fixation average	Time
1	(08:58 – 09:00)	visual search over buttons	5	318	1635
2	(09:00 – 09:07)	Pressed circle button and put a point.	15	260	6023
	(09:08)	pressed on undo button.	2	292	583
3	(09:08 – 09:24)	Pressed circle button and created a circle.	34	328	15460
4	(09:24)	Pressed on undo button.	1	83	258
5	(09:25 – 09:38)	Pressed circle button and created a circle.	34	194	12978
6	(09:38 – 09:40)	pressed on undo button.	3	217	1703
6	(09:40 – 09:42)	Drew a circle.	6	189	1266

7	(09:43)	Pressed on undo button.	1	250	516
8	(09:44 – 09:53)	Visual search over main area.	26	215	9210
9	(09:53 – 09:59)	Pressed circle button and drew circles.	17	229	5603
10	(09:59 – 10:11)	Visual search over buttons.	32	174	11584
11	(10:11 – 10:15)	pressed on intersect button and intersected the circles.	8	404	4349
12	(10:17)	Pressed on undo button.	3	123	666
13	(10:19 – 10:30)	pressed on intersect button and intersected the circles.	27	314	10888
14	(10:30)	Pressed on undo button.	1	183	868
15	(10:31 – 10:39)	pressed on point button and put a point.	22	289	7967
16	(10:39 – 10:51)	pressed on intersect button and put a point.	35	203	11480
17	(10:51 – 10:56)	Pressed on circle tool and drew a circle.	21	161	4759
18	(10:56 – 11:05)	visual search over buttons	23	255	8333
19	(11:05 – 11:09)	Pressed on segment button and drew a segment.	10	313	3716
20	(11:09 – 11:14)	Pressed on point button and put a point.	13	272	4835
21	(11:14 – 11:20)	pressed undo button.	10	190	5552
22	(11:20 – 11:33)	visual search over buttons.	36	192	13232
23	(11:33 – 11:47)	pressed on intersect button.	37	254	13302
24	(11:47 – 11:58)	Pressed on undo button and accidentally deleted the circles.	27	216	10755
25	(11:58 – 12:06)	Pressed on circle button and drew a circle.	19	200	8179
26	(12:06)	Pressed on undo button.	1	83	116
27	(12:07)	pressed on redo button.	-	-	-
28	(12:11 – 12:13)	pressed on erase button.	4	192	1438
29	(12:14 – 12:30)	Pressed on circle tool and drew a circle.	50	193	15885
30	(12:32 – 12:37)	Pressed on segment button and drew a segment.	12	229	5000
31	(12:37 – 12:39)	Pressed on point button and put a point.	5	240	1500
32	(12:39 – 12:44)	Pressed on segment button and drew two segments.	12	238	4589
33	(12:45 – 12:48)	Pressed on angle button and showed an external angle.	8	194	2222
34	(12:52)	Pressed on undo button.	2	167	217
35	(12:52 –	Pressed on angle button and showed an	15	232	5945

	12:58)	internal angle.			
36	(12:58 – 13:28)	Visual search over main area.	58	264	29466
37	(13:28 – 13:30)	Pressed on circle button and drew a circle.	5	243	1566
38	(13:31)	Pressed on undo button.	2	184	167
38	(13:33 – 13:36)	Pressed on circle button and put a point.	6	456	2683
39	(13:37)	Pressed on undo button.	1	117	350
40	(13:38 – 13:40)	Pressed on circle button and drew a circle.	5	480	1867
41	(13:41 – 13:51)	Visual search over main area.	24	334	9944
42	(13:51 – 14:00)	Pressed on segment button and drew two segments.	25	280	8733
43	(14:00 – 14:08)	Visual search over main area.	18	298	7802
44	(14:08 – 14:16)	Pressed on circle button and drew a circle.	24	258	7836
45	(14:16)	Pressed on undo button.	-	-	-
46	(14:16 – 14:19)	Pressed on circle button and drew a circle.	6	225	1534
47	(14:19)	Pressed on undo button.	1	700	733
48	(14:20 – 14:29)	Pressed on circle button and drew a circle.	27	228	9083
49	(14:29 – 14:44)	Pressed on segment button and drew two segments.	40	236	14693
50	(14:44 – 14:48)	Pressed on circle button and drew a circle.	6	181	2567
51	(14:48)	Pressed on undo button.	-	-	-
52	(14:48 – 15:00)	Pressed on circle button and drew a circle.	2	67	2050
53	(15:00)	Pressed on undo button.	2	258	634
54	(15:00 – 15:05)	Pressed on circle button and drew a circle.	28	298	10850
55	(15:05)	Pressed on undo button.	1	117	183
56	(15:05 – 15:12)	Pressed on circle button and drew a circle.	23	352	11583
57	(15:12)	Pressed on undo button.	-	-	-
58	(15:12 – 15:17)	Pressed on circle button and drew a circle.	6	503	4686
59	(15:17 – 15:30)	Visual search over main area.	24	195	12621
60	(15:30 – 15:35)	Pressed on circle button and drew a circle.	12	268	4400
61	(15:35 – 15:40)	Pressed on segment button and drew a segment.	14	148	4216
62	(15:40 – 15:49)	Pressed on undo button.	18	232	8817
63	(15:49 – 15:55)	Visual search over buttons.	13	158	5350

64	(15:55 – 16:00)	Pressed on redo.	12	296	6206
65	(16:03 – 16:10)	Pressed on segment button and drew a segment.	16	178	6774
66	(16:10)	Pressed on undo button.	4	275	884
67	(16:11 – 16:13)	Pressed on point button and put a point.	4	276	685
68	(16:15)	Pressed on undo	-	-	-
69	(16:16)	Program failed and closed, could not completed the task.			

Participant 3

	Timeline	Event	# of Fixations	Fixation average	Time
1	(06:40 – 06:45)	visual search over buttons	6	766	4966
2	(06:45 – 06:57)	Pressed circle button and created two circles.	31	180	12051
3	(06:58 – 06:59)	pressed on undo button.	4	221	1083
4	(06:59 – 07:05)	Visual search over main area.	21	195	5602
5	(07:08 – 07:18)	Pressed on circle button and drew a circle.	25	349	10134
6	(07:18)	pressed on undo button.	2	185	319
7	(07:20)	Pressed on redo button.	1	117	752
8	(07:21 – 07:27)	Pressed on circle button and put a point.	17	219	4666
9	(07:27)	Pressed on undo button.	1	67	650
10	(07:29 – 07:30)	Pressed on circle button and put a point.	4	371	1083
11	(07:32)	Pressed on undo button.	3	189	551
12	(07:34)	pressed on redo button.	1	400	633
13	(07:35 – 07:46)	Pressed on circle button and drew a circle.	36	217	10805
14	(07:46 – 07:53)	Visual search over buttons.	14	192	6737
15	(07:54 – 07:55)	pressed on erase button.	5	130	1051
16	(07:57 – 08:01)	Pressed on circle button and put a point.	11	232	4431
17	(08:02 – 08:05)	pressed on undo button.	9	313	2917
18	(08:05 – 08:08)	Pressed on circle button and drew a circle.	8	246	2150
19	(08:08)	Pressed on undo button.	1	67	1168
20	(08:09 – 08:28)	Pressed circle button and created two circles.	31	312	18773
21	(08:28 –	Pressed on undo button.	12	188	3833

	08:32)				
22	(08:33 – 08:44)	Pressed on circle button and drew a circle and put a point.	28	262	10968
23	(08:44)	Pressed on undo button.	1	367	434
24	(08:44 – 08:48)	Zoomed in the page.	11	285	3216
25	(08:49)	Put a point.	4	209	516
26	(08:50)	Pressed undo button.	1	500	566
27	(08:50 – 08:54)	Put a point.	9	165	3189
28	(08:54)	Pressed on undo button.	1	67	2022
29	(08:56 – 08:59)	Drew a circle and put a point.	10	192	3385
30	(09:00)	Pressed on undo button	1	233	267
31	(09:02 – 09:06)	Pressed on circle button and drew two circles.	12	171	4443
32	(09:06 – 09:18)	Pressed on segment button and drew three segments.	22	241	12139
33	(09:18 – 09:24)	Pressed on erase button.	3	112	5071
34	(09:26 – 09:44)	Pressed circle button and drew a circle.	52	204	18179
35	(09:44 – 09:48)	Pressed on segment button and drew a segment.	10	273	3717
37	(09:48 – 09:54)	Pressed on segment button and drew a segment.	18	242	5567
38	(09:55)	Pressed on undo button.	1	200	234
39	(09:55 – 10:20)	Pressed on segment button and drew four segments. Created any polygon.	20	152	26063
40	(10:35)	Gave up to complete the task.			

Participant 4

	Timeline	Event	# of Fixatio ns	Fixation average	Time
1	(05:30 – 05:37)	visual search over buttons	-	-	-
2	(05:37 – 06:03)	Pressed circle button and created two circles.	37	157	26254
3	(06:03 – 06:14)	Pressed on intersect button and intersected the circles.	12	163	11113
4	(06:14 – 06:27)	Pressed circle button and created a circle.	31	181	12387
5	(06:27 – 06:34)	Visual search over buttons.	5	97	6445
6	(06:34 – 06:45)	pressed on segment button and drew three segments.	25	278	11034
7	(06:45 – 07:25)	Visual search over main area.	120	144	40389
8	(07:25)	Accidentally put a point.	-	-	-

9	(07:28 – 07:30)	Pressed on erase button and accidentally deleted the all circles.	5	138	2641
10	(07:31)	Pressed on undo button.	1	117	184
11	(07:31 – 07:38)	Visual search over buttons.	11	185	6288
12	(07:38 – 07:48)	pressed on intersect button and intersected the circles.	15	119	11503
13	(07:48 – 08:00)	pressed on segment button and drew two segments.	15	128	8942
14	(08:02 – 08:06)	pressed on intersect button and intersected the circles.	9	112	3985
15	(08:06 – 08:12)	pressed on segment button and drew two segments.	13	243	5217
16	(08:12 – 08:25)	Visual search over main area.	41	197	12816
17	(08:26 – 08:38)	Pressed on circle button and drew any circle.	19	178	3385
18	(08:38 – 08:40)	Pressed on undo button.	6	220	1771
19	(08:42 – 08:59)	Pressed on circle button and drew any circle.	41	287	15639
20	(08:59 – 09:34)	Visual search over main area.	97	266	34496
21	(09:34 – 09:38)	Pressed on circle button and drew a circle.	8	365	3601
22	(09:42 – 09:50)	pressed on intersect button and intersected the circles.	11	346	11714
23	(09:50 – 10:00)	pressed on segment button and drew a segment.	23	146	9144
24	(10:00 – 10:09)	Pressed on circle button and accidentally put a point.	14	252	9305
25	(10:10)	Pressed on undo button.	2	125	283
26	(10:10 – 10:18)	Pressed on circle button and drew a circle.	18	260	8684
27	(10:18 – 10:24)	pressed on segment button.	3	89	5920
28	(10:24 – 10:29)	pressed on intersect button and intersected the circles.	4	104	1683
29	(10:29 – 10:41)	pressed on segment button and drew two segments.	20	100	9360
30	(10:45 – 10:51)	Pressed on angle button and showed an external angle.	12	202	3568
31	(10:51 – 11:07)	visual search over algebra pane	42	212	15463
32	(11:07 – 11:12)	Pressed on angle button and showed an external angle.	20	197	4809
33	(11:18)	Successfully completed the task.			
	Participant 5				
	Timeline	Event	# of Fixations	Fixation average	Time
1	(07:33 –	visual search over buttons	19	160	7241

	07:42)				
2	(07:42 – 07:45)	Pressed on circle through 3 points button and drew a circle.	10	160	3350
3	(07:46 – 08:01)	Visual search over buttons.	7	99	14592
4	(08:01 – 08:38)	Pressed on line button and drew four lines.	56	123	37327
5	(08:38 – 08:40)	pressed on erase button.	5	113	1500
6	(08:45 – 09:00)	Pressed on line button and drew a line.	20	113	14591
7	(09:00 – 09:10)	Pressed on segment button and drew three segments.	25	162	9578
8	(09:10 – 09:26)	Visual search over main area.	34	166	15853
9	(09:26 – 09:35)	Pressed point button and put points.	20	131	8680
10	(09:35 – 09:59)	Visual search over main area.	48	135	23517
11	(09:59 – 10:06)	Pressed on angle button and showed an internal angle.	21	120	6934
12	(10:06 – 10:25)	Visual search over main area.	43	140	18982
13	(10:25 – 10:32)	Pressed on erase button.	4	101	8342
14	(10:36 – 10:51)	Pressed on circle through 3 points button and drew a circle	16	135	14956
15	(10:53 – 10:58)	Visual search over buttons.	9	89	5906
16	(10:59 – 11:09)	pressed on elips button and drew an elipse.	20	143	9750
17	(11:09 – 11:12)	Pressed on erase button.	7	100	2661
18	(11:13 – 11:19)	Pressed on segment button and drew three segments.	16	108	6489
19	(11:20 – 11:38)	Visual search over main area.	29	124	17826
20	(11:38 – 11:47)	Pressed on circle button and drew a circle.	19	133	8685
21	(11:47 – 11:53)	Visual search over main area.	21	134	5938
22	(11:53 – 11:56)	Pressed on move button and zoomed out the page.	7	157	2670
23	(12:02 – 12:15)	Pressed on circle button and drew a circle.	21	110	13707
24	(12:15 – 12:38)	Visual search over main area.	50	128	22713
25	(12:38)	Pressed on undo button.	-	-	-
26	(12:39 – 12:43)	Drew a circle.	8	140	4339
27	(12:43 – 12:45)	Pressed on move button and zoomed out the page.	6	128	1255

28	(12:50 – 12:55)	pressed on erase button.	11	107	5271
29	(12:55 – 13:19)	Pressed on circle tool and drew a circle.	54	135	23327
30	(13:21 – 13:25)	pressed on erase button.	5	162	3581
31	(13:26 – 13:33)	Pressed on circle tool and drew two circles.	17	109	7444
32	(13:33 – 14:30)	Visual search over buttons to find intersection tool.	122	134	16315
33	(14:30 – 14:36)	Pressed on circular sector button.	7	133	7056
34	(14:38)	Pressed on undo button.	1	100	150
35	(14:38 – 14:46)	Visual search over main area.	9	97	8139
36	(14:46)	Pressed on redo.	1	67	116
37	(14:47 – 15:00)	Visual search over buttons.	20	127	13278
38	(15:00 – 15:09)	Pressed on circle button and drew a circle.	23	135	8646
39	(15:09 – 15:23)	Visual search over buttons.	38	154	14060
40	(15:23 – 15:28)	Pressed on segment button and drew a segment.	2	100	5635
41	(15:29 – 15:42)	Pressed on angle button and showed an external and internal angle.	22	116	14379
42	(15:43 – 15:54)	Visual search over buttons.	19	120	10258
43	(15:54 – 16:04)	Pressed on segment button and drew two segments.	18	118	10213
44	(16:05 – 16:16)	Pressed on angle button and showed an external and internal angle.	22	109	10380
45	(16:16 – 18:39)	Visual search over main area.	344	148	143291
46	(18:40 – 19:06)	Pressed on parallel line button and drew two parallel lines.	34	101	23738
47	(19:12)	Gave up complete the task.			

Participant 6

	Timeline	Event	# of Fixations	Fixation average	Time
1	(14:13 – 14:40)	visual search over buttons	22	107	16122
2	(14:40)	Pressed circle button and put a point.	4	100	766
3	(14:43 – 14:50)	Pressed move button and moved the point.	11	95	6249
4	(14:54 – 15:01)	Pressed circle button and created a circle.	8	82	6937
5	(15:01 – 15:08)	Visual search over main area.	14	132	6085

6	(15:08 – 15:12)	pressed on move button and moved the page.	11	117	3883
7	(15:13 – 15:20)	Visual search over main area.	20	108	7100
8	(15:20 – 15:26)	Pressed circle button and created a circle.	8	100	5683
9	(15:30 – 15:34)	Pressed on undo button and accidentally deleted all circles.	1	66	3766
10	(15:38)	Pressed on redo button.	2	150	150
11	(15:39 – 15:47)	Visual search over main area.	19	107	7901
12	(15:47 – 16:00)	Pressed circle button and created a circle.	27	105	12267
13	(16:00 – 16:50)	Visual search over buttons to find intersection tool	99	126	49609
14	(16:50 – 16:57)	pressed on intersect button and intersected the circles.	16	135	7017
15	(17:01 – 17:12)	Pressed on circle button and put a point.	17	159	10867
16	(17:12)	Pressed on undo button.	-	-	-
17	(17:15 – 17:17)	pressed on intersect button and intersected the circles.	4	125	1316
18	(17:17 – 17:27)	Visual search over main area.	12	114	11200
19	(17:27 – 17:30)	Pressed on circle button and drew a circle.	8	133	2783
20	(17:30 – 17:35)	pressed on intersect button and intersected the circles.	10	105	4320
21	(17:35 – 17:44)	Visual search over main area.	20	128	8116
22	(17:45 – 17:48)	Pressed on circle button and drew a circle.	8	140	3117
23	(17:48 – 18:36)	Visual search over main area.	53	116	47555
24	(18:37 – 18:40)	pressed on intersect button and intersected the circles.	6	106	2828
25	(18:40 – 18:45)	Pressed on circle button and drew a circle.	6	103	3665
26	(18:45 – 18:53)	pressed on intersect button and intersected the circles	-	-	9824
27	(18:54 – 19:04)	Pressed on circle button and drew a circle.	23	141	10688
28	(19:14 – 19:16)	pressed on intersect button and intersected the circles.	3	139	1600
29	(19:16 – 19:22)	Pressed on circle button and drew a circle.	13	135	5667
30	(19:30 – 19:46)	Pressed on segment button drew six segments.	34	129	15952
31	(19:46 – 19:59)	visual search over algebra pane	23	108	12421
32	(19:59 – 20:07)	Pressed on angle button and showed an external angle.	13	95	7000

33	(20:07 – 20:30)	visual search over algebra pane	39	112	24765
34	(20:30 – 20:48)	Pressed on angle button and showed an external angle and two internal angles.	27	118	16200
35	(20:52 – 21:00)	Pressed on angle button and showed an external angle.	6	164	8537
36	(21:00)	Pressed on undo button.	-	-	-
37	(21:05 – 21:10)	Pressed on angle button and showed an internal angle.	6	97	5034
38	(21:13)	Successfully completed the task.			

Participant 7

	Timeline	Event	# of Fixations	Fixation average	Time
1	(11:50 – 12:09)	visual search over buttons	54	270	18717
2	(12:09 – 13:23)	Pressed on circle button and created four circles.	196	270	73857
3	(13:23 – 13:40)	Pressed on regular polygon button.	39	212	17274
4	(13:45 – 14:00)	Pressed on segment button and drew four segments.	44	259	14986
5	(14:00 – 14:04)	Pressed on erase button.	12	199	3152
6	(14:09)	pressed on undo button.	6	139	868
7	(14:13 – 14:14)	Pressed on undo button.	6	272	1017
8	(14:15 – 14:27)	Pressed circle button and created a circle.	29	221	12579
9	(14:27)	Pressed on undo button.	-	-	-
10	(14:27 – 14:46)	Visual search over main area.	57	236	17039
11	(14:46 – 14:48)	Pressed on circle button and created a circle on the other circle.	4	326	1619
12	(14:50)	Pressed on undo button.	-	-	-
13	(14:50 – 15:02)	Visual search over main area.	34	246	10795
14	(15:02 – 15:05)	Pressed on circle button and created a circle on the other circle.	7	365	3251
15	(15:06)	Pressed on undo button.	1	334	367
16	(15:06 – 15:16)	Pressed on circle button and created a circle on the other circle	25	279	8337
17	(15:16)	pressed on undo button.	-	-	-
18	(15:17 – 15:31)	Pressed on circle button and created a circle on the other circle	36	289	14033
19	(15:31)	Pressed on undo button.	1	100	216
20	(15:32 – 15:44)	Pressed on circle button and created a new circle.	33	299	12635
21	(15:44 –	Visual search over main area.	112	307	42140

	16:27)				
22	(16:27 – 16:35)	Pressed on circle button and drew a circle.	21	339	8091
23	(16:35 – 16:42)	Visual search over main area.	18	315	6752
24	(16:42 – 17:00)	Pressed on circle button and accidentally drew a circle.	45	305	16845
25	(17:00 – 17:03)	Pressed on undo button.	7	131	501
26	(17:03 – 17:38)	Visual search over main	99	273	34918
27	(17:38 – 17:45)	Pressed on circle button and accidentally put a point.	19	225	6924
28	(17:45 – 17:49)	Pressed on undo button.	10	194	3571
29	(17:57)	Pressed on redo button.	-	-	-
30	(17:58 – 18:06)	Pressed on circle button and drew a circle.	15	277	8282
31	(18:06)	Pressed on redo button.	-		800
32	(18:10 – 18:17)	Pressed on move button and moved the page.	19	160	6951
33	(18:20 – 18:24)	Pressed on circle button and drew a circle.	10	146	4365
34	(18:25)	Pressed on undo button.	-	-	-
35	(18:26 – 18:31)	Pressed on circle button and drew a circle.	9	203	4565
36	(18:31 – 18:40)	Zoomed in the page.	21	110	8807
37	(18:40 – 18:49)	Visual search over buttons.	22	164	8306
38	(18:49 – 19:27)	pressed on intersect button and intersected the circles.	61	139	38430
39	(19:33 – 19:40)	Pressed on circle button and put a point.	21	128	6396
40	(19:42)	Pressed on undo button.	-	-	-
41	(19:47 – 19:54)	Pressed on circle button and put a point.	23	155	7271
42	(19:54 – 20:12)	Visual search over main area.	34	157	17416
43	(20:12 – 20:17)	Pressed on circle button and drew a circle.	16	205	4831
44	(20:17 – 20:19)	Pressed on erase button to delete the point but accidentally deleted all circles.	5	277	1718
45	(20:20)	Pressed on undo button.	-	-	-
46	(20:26 – 20:29)	pressed on intersect button and intersected the circles.	8	140	2902
47	(20:35 – 21:13)	Pressed on segment button and drew six segments.	98	163	38362
48	(21:16 – 21:31)	Pressed on angle button and showed two internal angles.	44	191	14958
49	(21:34)	Successfully completed the task.			

Participant 8					
	Timeline	Event	# of Fixations	Fixation average	Time
1	(11:40 – 12:24)	visual search over buttons	59	128	38802
2	(12:25 – 12:29)	Pressed on circle button and created a circle.	3	89	4967
3	(12:29 – 12:32)	Pressed on erase button.	2	92	3693
4	(12:36 – 13:00)	Pressed on circle button and created three circles.	34	108	27219
5	(13:00 – 13:13)	visual search over buttons	14	105	12262
6	(13:13 – 13:16)	pressed on erase button.	1	83	3395
7	(13:16 – 13:37)	Visual search over buttons.	24	121	19766
8	(13:37 – 13:40)	Pressed on erase button.	3	100	3614
9	(13:42 – 14:09)	Pressed on circle button and created two circles.	41	106	27033
10	(14:09 – 14:18)	Visual search over buttons.	10	109	8832
11	(14:18 – 14:29)	Pressed on intersect button and intersected the circles.	19	95	2936
12	(14:33 – 14:51)	Pressed on circle button and created a circle.	24	120	18055
13	(14:52 – 15:05)	Pressed on intersect button	29	105	13723
14	(15:07 – 15:23)	Pressed on circle button and created a circle.	20	105	14161
15	(15:25 – 15:27)	Pressed on erase button.	1	67	2072
16	(15:27 – 15:38)	Visual search over buttons.	14	158	8617
17	(15:38 – 16:00)	Pressed on intersect button	25	102	22748
18	(16:00 – 16:30)	Pressed on circle button.	45	112	28152
19	(16:31 – 16:38)	Pressed on intersect button and intersected the circles.	10	117	6292
20	(16:38 – 17:02)	Visual search over main area.	21	112	22864
21	(17:02 – 17:17)	Pressed on circle button and drew two circles.	13	86	15936
22	(17:17 – 17:27)	Pressed on intersect button and intersected the circles.	7	117	7553
23	(17:27 – 17:51)	Pressed on circle button and drew a circle.	26	111	33489
24	(17:51 – 18:34)	Visual search over main	53	128	43019

25	(18:34 – 18:45)	Pressed on segment button and drew six segments.	21	100	10752
26	(18:45 – 19:01)	Visual search over main	14	116	14973
27	(19:01 – 19:15)	Pressed on angle button and showed an external and an internal angle.	11	119	12295
28	(19:19)	Successfully completed the task.			

Participant 9

	Timeline	Event	# of Fixations	Fixation average	Time Duration
1	(08:14 – 08:31)	visual search over buttons	45	369	17062
2	(08:32 – 08:47)	Pressed on circle button and created a circle.	36	421	15106
3	(08:47 – 08:49)	Visual search over algebra panel.	8	305	2187
4	(08:49 – 09:10)	Pressed on redefine window and changed the point coordinates.	36	547	20420
5	(09:10 – 09:48)	Pressed on circle tool and put points and drew a circle	109	344	37545
6	(09:48)	pressed on undo button.	-	-	-
7	(09:49 – 10:19)	Pressed on circle button and created three circles.	81	360	30405
8	(10:19)	Pressed on undo button.	1	183	183
9	(10:19 – 10:50)	Pressed on circle button and created two circles.	64	372	30119
10	(10:50 – 12:30)	Visual search over main area.	238	367	99693
11	(12:30 – 12:40)	Pressed on circle button	20	515	10075
12	(12:40)	Pressed on undo button	2	233	900
13	(12:44 – 12:50)	Pressed on circle buttton and put two points.	13	491	6118
14	(12:50 – 13:47)	Visual search over main area.	145	385	56478
15	(13:50 – 14:03)	Pressed on circle button and drew a circle.	33	391	12850
16	(14:03 – 14:56)	Visual search over main area.	151	330	53385
17	(14:57)	Closed the project and opened a new project.	5	240	1200
18	(15:01 – 15:38)	Pressed on circle button and created a circle and put a point.	103	349	37114
19	(15:38 – 15:41)	Pressed on undo button.	12	250	2900
20	(15:42 – 15:56)	Pressed on circle button and drew a circle.	40	360	13901
21	(15:56)	Pressed on undo button.	-	-	-
22	(15:57 –	Pressed on circle button and drew two	13	478	5936

	16:02)	circles.			
23	(16:03)	Pressed on undo button.	4	238	952
24	(16:04 – 16:40)	Pressed on circle button and drew a circle.	88	401	35857
25	(16:41)	Pressed on undo button.	3	545	1633
26	(16:42 – 17:06)	Pressed on circle button and drew four circles and accidentally put a point.	48	412	23196
27	(17:06 – 17:17)	Pressed on undo button and accidentally deleted the circles.	38	282	10942
28	(17:21 – 17:49)	Pressed on circle button and created six circles.	66	420	27522
29	(17:49 – 17:57)	Visual search over buttons.	9	143	9244
30	(17:58 – 18:13)	Pressed on segment button and drew six segments.	10	164	15389
31	(18:14 – 18:23)	Pressed on angle button and showed an external angle.	26	219	9816
32	(18:28)	Successfully completed the task.			

Participant 10

	Timeline	Event	# of Fixations	Fixation average	Time
1	(12:21 – 12:39)	visual search over buttons	39	156	16949
2	(12:39 – 13:12)	Pressed on circle button and created a circle.	20	160	33241
3	(13:13)	Pressed on erase button.	3	122	600
4	(13:16 – 13:51)	Pressed on circle button and created three circles.	84	236	34798
5	(13:52)	Pressed on undo button.	3	84	1052
6	(13:52 – 14:00)	Visual search over main area.	18	298	8287
7	(14:02 – 14:11)	Pressed on intersect button and intersected the circles.	28	194	9139
8	(14:11 – 14:14)	Pressed on circle button and created a circle.	8	219	2501
9	(14:14 – 14:37)	Visual search over main area.	56	256	22844
10	(14:37 – 14:43)	Pressed on polygon button and created a triangle on circles.	12	199	5285
11	(14:48 – 15:03)	Pressed on circle button.	16	163	16918
12	(15:03 – 15:14)	Pressed on intersect button and intersected the circles.	24	131	10457
13	(15:14 – 15:25)	Pressed on circle button and created a circle.	28	175	11224
14	(15:25 – 15:28)	Pressed on intersect button and intersected the circles.	10	167	2768

15	(15:29 – 15:36)	Pressed on circle button and created a circle.	16	237	7019
16	(15:36 – 15:40)	Pressed on intersect button and intersected the circles.	11	259	4152
17	(15:40 – 15:44)	Pressed on circle button and created a circle.	11	205	3318
18	(15:47 – 16:08)	Pressed on polygon button and created a triangle on circles.	64	182	20344
19	(16:08 – 16:13)	Pressed on intersect button and intersected the circles.	14	266	4985
20	(16:14 – 16:34)	Pressed on polygon button	52	216	19935
21	(16:34 – 16:43)	Pressed on segment button and drew four segments.	24	231	8904
22	(16:47 – 17:07)	Pressed on angle button and showed all internal angles.	22	183	20562
23	(17:09)	Successfully completed the task.			

TEZ FOTOKOPİSİ İZİN FORMU

ENSTİTÜ

Fen Bilimleri Enstitüsü ☐

Sosyal Bilimler Enstitüsü ☐

Uygulamalı Matematik Enstitüsü ☐

Enformatik Enstitüsü ☐

Deniz Bilimleri Enstitüsü ☐

YAZARIN

Soyadı : YAĞMUR
Adı : Serap
Bölümü : Bilişim Sistemleri

TEZİN ADI (İngilizce) : USABILITY EVALUATION OF DYNAMIC GEOMETRY SOFTWARE THROUGH EYE TRACKING AND COMMUNICATION BREAKDOWN ANALYSIS

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 : ……………………