GESTANNOT: A PAPER ANNOTATION TOOL FOR TABLET

by

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Submitted in partial fulfilment of the requirements
for the degree of Master of Computer Science

at

Dalhousie University
Halifax, Nova Scotia
December 2013

DEDICATION PAGE

To my family and friends, for their love and support.

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ABSTRACT

Active Reading is an important part of a knowledge worker's activities; it involves highlighting, writing notes, marking with symbols, etc., on a document. Many Active Reading applications have been designed in seeking to replicate the affordances of paper through digital-ink-based annotation tools. However, these applications require users to perform numerous steps to use various types of annotation tools, which impose an unnecessary cognitive load, distracting them from their reading tasks. In this thesis, we introduce GestAnnot, an Active Reading application for tablet computers that takes a fundamentally different approach of incorporating multi-touch gesture techniques for creating and manipulating annotations on an e-document, thus offering a flexible and easy-to-use annotation solution. Based on the literature review, we designed and developed GestAnnot and then performed lab and field evaluations of the software. In lab evaluation, GestAnnot performed better than one of the best existing annotation application in many aspects, including number of steps. The design was then refined based on the feedback received. The field evaluation of the improved design helped us to understand the performance of the application in the real world. We proposed a set of design guidelines through the feedback received from both evaluations, which any future Active Reading application could benefit from.

ACKNOWLEDGMENTS

Foremost, I would like to express my sincere gratitude to my thesis supervisors Dr. Jamie Blustein and Dr. Kirstie Hawkey for their encouragement, motivation and for providing continuous support in my research work. Their guidance during every stage of the thesis helped me to develop a deep understanding of the project.

I am thankful to rest of the committee members: Dr. Denis Riordan and Dr. Derek Reilly for their insightful comments and suggestions. I acknowledge my gratitude towards the faculty and staff members of Computer Science for their direct and indirect help throughout the duration of my program.

I would like to thank PDFTron Systems Inc. for providing me with the PDF SDK for the implementation of the project. I give my sincere thanks to all the participants who participated in the research studies and helped me in evaluating the software through their valuable feedback.

I am grateful to Mick Bottom and Allison Fulford for their encouragement and support whenever I was in need. I am thankful to my friends and colleagues, Megha Jyoti, Anmol Zakhmi, Namrata Bector, Maha ALJohani, Michael Hackett, Harpreet Singh, Vishal Kumar Toora, Sahil Kochher, Gaurav Arya and all my lovely friends for their selfless support, encouragement and for the time with laughter.

I wish to thank my entire extended family for providing a loving environment for me. My sister, Gurleen Kaur was particularly supportive. Lastly, and most importantly, I wish to thank my parents, Satwant Singh and Jaswinder Kaur. They bore me, raised me, supported me, taught me and loved me. To them I dedicate my thesis.

CHAPTER 1 INTRODUCTION

The combination of reading and critical thinking known as Active Reading [1] is a fundamental part of education and knowledge work. Reading occurs more frequently in conjunction with writing including highlighting, underlining, and scribbling comments either on the original text or on separate notebook, than it does in isolation [2]. Research has indicated that readers use annotations to dialogue with texts (academic conversation with the text) [3] and it improves recall of emphasized items and influence the perception of specific arguments in the source materials [4].

Many people annotate directly on the original document with a wide variety of markings and for different purposes [5, 6]. The annotations can be categorized as telegraphic or explicit. *Telegraphic* annotations are non-textual based and *explicit* annotations are textual notes [7]. First, annotations such as highlighting, underlining and other telegraphic marginal symbols (e.g., asterisk, brackets, angle brackets, arrows, etc.) give procedural clues for further attention i.e. what part is important (or unimportant), what material requires more attention in successive readings. Second, annotation can be place-marks; a reader marks the words, quotes, chemical reactions, etc. to note or record important passages for later use. Third, annotations can be used to help with problem solving; readers work on a problem near where it is presented in the text. Such annotations include symbolic structures and equations. Fourth, annotations in the form of short and long notes written in the margins or near figures constitute interpretive annotations. Other types of annotations include highlighting of passages and incidental marks such as doodles that are completely out of context and signify a lack of engagement with the text [5, 7].

Students, professionals and academic readers use paper for annotating and active readings tasks; but the introduction of various devices such as tablets and e-book readers have provided them the opportunity to perform annotation activities on e-documents as well. Although the use of paper in offices and firms has been reduced due to the digitalization of information, paper continues to be preferred for reading purposes [8]. In addition to the basic positive features of paper such as the ability to be tangibly manipulated and the compact physical attributes of individual sheets of paper [9], the ability to annotate on paper in a fast and fluid way makes it more suitable for active reading tasks such as article review, assignment marking, etc. There are, however, some limitations of paper that are driving the shift towards electronic reading technology. These limitations include fundamental limitations associated with its physical characteristics, such as the requirement of a large space to store papers and the difficulty of accessing and finding information from them [10]. There are other issues related to paper more specific to annotations such as the limited amount of space in the margins. Also, the editing, organizing, and searching of the information within annotations are difficult on paper. These limitations might become significant barrier in the way of information management for researchers, students, and working professionals, thus making it necessary to adapt e-reading. For the above reasons, researchers and commercial firms have been working to bridge the gap between paper and e-documents. Many commercial and academic applications have been developed for the computers that allow a reader to read and annotate on e-document with digital ink. "XLibris" [1] is an example of such application; it was developed about 15 years ago and allows the reader to mark on the scanned image of document with free-form digital ink annotations. Similar reading applications have been developed in the past decade (discussed in Section 2.2 and 2.3) but one common factor that held back these systems to be used in the real world was the limitations with the computing hardware technology e.g. screen resolution, touch sensitivity, processing power, etc.

Recent advances in hardware technology have enabled the development of portable handheld devices such as tablets and e-book readers that have more computing power than before, long battery lives, high-resolution displays, and touch-screens. These devices found most of their success in leisure reading activities, but they do not support academic reading as completely as on paper [10]. Recent studies have shown that one of the major causes for this is the usability problems related with the basic functionalities for marking and annotating documents on these devices [11, 12]. The annotation facility provided by these devices tends to be tedious to use [11, 12] because it involves switching between many annotation tools. This is in contrast to annotations on paper in which case this activity is seamlessly integrated with reading while doing it on paper as the user can annotate with single pen or highlighter [5].

There are some existing academic and commercial annotation applications for touch-screen tablets that provide various annotation tools including highlighting, underlining, commenting, attaching sticky notes, freehand drawing, for annotating e-documents. While using these applications on a tablet, if users want to annotate a document, they can select the particular tool from the tool menu and create the annotation. This process seems very easy to learn and perform, but it might distract the user from the reading process, as it requires four steps to create single annotation: navigating to toolbar menu, finding and selecting the tool from menu, navigating back to the location where the user wished to create annotation and creating the annotation.

The annotation interacts with two key cognitive aspects of reading: the role of working memory and textual/spatial encoding in reader comprehension building [13]. Research suggests that reading involves an expectancy effect that depends upon working memory to retain the words just read in order to allow the next words to be linked together in a meaningful way [13, 14]. Prior studies suggest that annotating often operate concurrently with reading activity [5] and can enhance reading comprehension and facilitate critical thinking by supporting working memory [1, 15]. Hsieh et al. [15] look beyond the working memory and argue how annotating play an important role in the textual encoding process. Textual encoding is the basic perceptual process of converting a sensory input into subjectively meaningful experience [13]. Textual encoding process is facilitated through readers' paraphrasing or elaborating on the textual content in the form of annotations. Furthermore, research [16] argues that there is an evidence to support that memory is used to process information about spatial attributes of texts during reading. Moreover, studies have revealed that the annotations support spatial encoding and help in recalling the information [13]. O'Hara and Sellen [17] argue that making annotations on paper is relatively an effortless procedure than on screen, which contributes to the comprehension-building process as it is more seamlessly integrated with the reading. On the other hand, the user is required to perform numerous steps to create annotation on tablet, which make greater cognitive demand on working memory resources [18, 19] and research suggests that comprehension-building levels decreases when cognitive load increases [14].

This thesis addresses the usability problems of the annotation features present in current reading applications for tablets through the development of an annotation application with enhanced user interface (UI) Designs and Interaction Techniques. The main insight upon which the design is based is that the existing reading applications for devices use the menu-based interaction approach, in which a reader must choose the annotation tool from the toolbar menu and perform the annotations. Instead, we propose that multi-touch gesture techniques for performing the annotation on a tablet could improve the usability as they allow the reader to annotate the e-document by using simple gestures such as single tap, double tap, two finger slide, etc. Additionally, it gives users the ability to switch between various annotation tools by using multi-touch gestures. Results from research indicate that some gestures offer faster performance than the soft button interaction and demands less of the user's attention [20]. Moreover, some direct touch gestures have the potential to be performed with less visual monitoring [20] thus making them suitable for annotation purposes as a reader can concentrate on reading without worrying about the position of the various annotation tools present in the toolbar menu. Furthermore, gestures can be committed to muscle memory [20, 21] thus making fewer demands on working memory. *Muscle memory* involves consolidation of a specific motor task through repetition. When a particular motor activity is repeated several times, it develops a muscle memory, which allows it to be performed in future without conscious effort and with no or minimal attention. For example, riding a bicycle and typing on keyboard are examples of activities that are performed through muscle memory. In addition, gestures do not require any dedicated screen space, which is limited on tablets. As mentioned above, gestures have many positive aspects, but they might demand more learning efforts when beginning to use annotations. In the previous studies (see Section 2.4), human computer interaction (HCI) researchers have introduced many gestures set and then conducted user studies to verify if the gestures are easy to use and natural. However, these multi-touch gestures techniques have not been deployed for annotating purposes in Active Reading application, which have the potential to make the annotation task very natural and easy on tablet devices. This thesis attempts to fill this gap through an Active Reading application that employs a set of gestures for using a variety of annotations on an e-document using a tablet. The evaluation studies conducted for our research helped us to understand that how our application performs better than the existing applications, thus providing a set of guidelines that might be useful to provide an effective and efficient Active Reading application for tablets.

1.1 Thesis Contributions

This thesis contributes in the following areas:

1. Requirement gathering for annotation tools through literature survey of the existing Active Reading applications.
2. Iterative design and implementation of an Active Reading Application that uses gesture-based interactions through a specific set of gestures.
3. In-lab and *in situ* evaluations to assess the functionality and user experience of this application.

1.2 Solution Overview

This section outlines how this thesis addresses the above-mentioned contributions.

1.2.1 Requirement Gathering

We examined prior research in the field of Active Reading to understand why, what and how users annotate on a paper or an e-document. We surveyed various Active Reading application developed in the past for commercial and non-commercial purposes and extracted the necessary design requirements for annotation tools. We also explored previous studies related to multi-touch gestures, which helped in choosing the appropriate gesture set for GestAnnot's user interface. These requirements formed the basis for the initial design of GestAnnot.

1.2.2 Design and Implementation of an Active Reading Application

From the careful analysis of the literature, existing reading devices, and applications, it is evident that paper offers the flexibility of annotations as reader can use single highlighter and/or pen to highlight, underline the text, add comment, draw shapes and symbols, etc. Likewise, a freehand drawing tool can do similar work for creating these annotations on e-documents, but a freehand drawing tool does not fully realize the power of e-reading. This is because software treats all type of freehand annotations as mere drawings with digital ink and thus, it cannot differentiate between underline, comments, symbols, etc., thus making it difficult to extract text from comments and other annotations. Moreover, touch screens are less sensitive, thus the movement of the finger is not precisely tracked resulting in some irregular annotations. In addition, freehand drawing performs better with a stylus as compared to fingers. There are other major issues related to freehand annotation, which are discussed in Chapter 3. To address these issues, reading applications offer various annotation tools such as highlighter, underline, strikeout, etc. from which the user can select the tool to highlight the text, type comments, create sticky notes etc. These tools offer flexibility in choosing colors, size, and other attributes of the annotations and enable users to search and extract information from them. Despite these qualities, the availability of multiple tools poses the challenge that the users need to select the appropriate tool each time they want to create a particular annotation, thus negatively affecting Active Reading experience. To cope with this usability problem, an annotation application is developed in the thesis that involves a different interaction model, which is intended to provide better reading environment.

The application developed for this thesis, named *GestAnnot,* offers similar annotation tools but it allows the user to use these tools through different multi-touch gestures such as single tap for highlighting, double tap for creating a comment, two-finger tap for creating an arrow, etc. Additionally, it offers some gestures to switch between tools such as three-finger swipe for switching between highlight, underline, strike-through and squiggly. The major design challenge was to develop the different gestures for various tools in a way so that these gestures do not conflict with each other when user uses them and should not be too complex so that users can easily learn and recall them while reading. The major objective behind the application was to provide all the necessary annotation features in fewer steps than menu-based applications, thus saving the user's effort and providing better Active Reading environment. The details about the various design features are given in Chapter 3.

GestAnnot is developed for Android platform using PDFTron Mobile PDF SDK [22]. This application can be installed on any android device running Android operating system (version 3.0 or higher).

1.2.3 Evaluation of Active Reading Application

To better understand the implications of gesture based annotation application, we evaluated the system in two phases. In first phase, we conducted a lab study in which we compared GestAnnot with one of the best existing annotation application that offers similar annotation tools with menu-based interactions. The results from this study suggest that GestAnnot significantly reduces the number of steps in creating and editing annotations on tablet and provides better user experience to reader. The study results have enabled us to formulate some guidelines, which should be considered while developing any future Active Reading application. Considering the participants' feedback, some improvements were made in GestAnnot's design, which was then evaluated in the field study.

Annotation activities differ between readers. For example, some readers annotate with special symbols and shapes and some use the basic shapes (e.g., circle or rectangle) only. In addition, the frequency and purpose of annotations varies among individuals. Therefore, the lab study cannot effectively simulate the broader contexts for which reading activities are performed. To evaluate its usability in the real world, a field study was conducted in which this application was given to students on their tablet to use over a period of 2-5 days. This field trial gave us the opportunity to understand whether the features provided in the system would be useful in the real world and what new features could be added to the application to enhance its usability. From the results of this study, we concluded that the annotation tools provided in GestAnnot were sufficient to support a variety of annotations and the gesture set deployed for user interactions was natural and easy to use. Moreover, participant feedback identified features that can be added to the system to make it more effective and efficient annotation application.

1.3 Thesis Roadmap

The introduction part of this thesis covers the background and motivation behind this research. It gives the overview to the design and the evaluation of GestAnnot application. Chapter 2 covers the related work to the active reading applications. We begin by detailing the various application and devices that have been developed for annotating documents. Chapter 3 covers the Design and Implementation of the GestAnnot. It begins with the design requirement and then describes the design elements of GestAnnot including its features and user interface. This is followed by a discussion of implementation challenges. Chapter 4 describes the lab evaluation of GestAnnot in which we compared the GestAnnot with one of the best existing annotation applications. In this chapter, we describe the experimental design, results, and then the implications of the results. At the end of this Chapter, we describe the guidelines formulated from the results, which can be considered during the development of any Active Reading application. Based upon the participants' feedback collected in the lab study, we improved the design. This improved design is described in Chapter 5. Chapter 6 presents the field study, starting from its methodology to the results and then the discussion of the user experience. We discuss the features that were used by the participants, and then describe their preferences and the shortcomings of the application. Chapter 7 discusses the findings from the previous chapters and ties them to the research objectives. It then concludes the thesis with its contributions and the future scope of the research in providing better reading environment.

CHAPTER 2 RELATED WORK

Our research included elements of Active Reading, interaction design and multi-touch gestures. As such, it draws from and builds upon prior research in those three areas. In this chapter, we first survey the research that is related to Active Reading then we examine the previous systems developed for Active Reading and extract out the common requirements. Finally we describe the previous research which has been done to explore multi-touch gestures. We elaborate the design requirements gathered from the literature survey in next chapter and also discuss how GestAnnot's design addresses these requirements.

2.1 Active Reading

Prior work has sought to understand the processes that are involved in Active Reading and to identify the ways in which the electronic devices can support them. Research suggests that Active Reading involves four core processes: content extraction, navigation, layout, and annotation [23, 24]. *Content extraction* involves the copying of original content to a secondary surface when the reader performs outlining or note-taking [24]. *Outlining* allows the reader to produce the alternative representation of the meaning of the original text, which is generally achieved by identifying the subdivisions of text and assigning the facts extracted from the text to these subdivisions after reading it carefully. O'Hara et al. [23, 25] suggest that users must easily be able to review, organize, and trace their extracted content back to its source. *Navigation* involves moving both within and between documents, flipping between different portions of text to compare them, turning a page, or as when searching for text. Past work has revealed the navigational aspect of Active Reading including: non-linear navigation [9], cross-document navigation, and ability to create short-term bookmarks [26, 27]. Other studies have considered the importance of skimming [28] in reading and how readers use the notes created on an external surface other than the original document [29, 30]. *Layout* is the process of visually and spatially arranging the documents for the purpose of cross-referencing or for gaining the overview of a document [24]. Past studies suggest that a reading environment requires support for viewing different pieces of content in parallel, while maintaining the document's original linear, sequential structure [23, 31].

Another set of studies have identified how computers fall short of supporting Active Reading process and what improvements can be made in computers to better support Active Reading. Sellen and Harper [32] conducted an ethnographic study to gain knowledge about how knowledge workers interact with their documents and what are the roles of paper in participants' socio-technical environments. Through this study, they gained the understanding of how computers were inadequate in supporting participants' paper-oriented behaviors and suggested guidelines for making the computer more suitable to support paper-based practice. Considering a broader sample population, Adler et al. [2] conducted a diary study to understand how, where, what and why people read at work and suggested design ideas for helping computers to better emulate the affordances of paper. Towards similar goals, O'Hara and Sellen [17] used lab study to compare the reading experience on paper vs. on computer screen. From the observations of this study, they derived design implications for digital system to better support a reading task, in particular the need to provide adequate annotation tools, control over spatial layout of content and quick navigation. Ten years later, Morris et al. [31] conducted a similar study, in which they described the progresses made by computers and reported that tablets were able to perform on par with paper in their Active Reading tasks. Moreover, they identified few numbers of areas where computers provide support but paper lacks e.g. copy/paste, spell check, query-based search. In a recent study, Tashman and Edwards [33] emphasized the impression of computers' growing dominance over paper for Active Reading. They observed that due to pervasive use of digital tools, people's habits have changed therefore the Active Reading tasks are now more readily performed on digital devices rather than on paper.

There have also been a number of systems developed to support Active Reading. We have described few prominent systems in Section 2.2 and 2.3.

2.2 Freeform Digital Ink Based Annotation System

XLibris [1] was developed to offer active reading experience to users on a paper-like interface. It allows the users to mark the scanned image of a document with the freeform digital ink annotations using a pen tablet display. The whole screen can be used to annotate and user can write in the margins as well as on the text. This system uses static documents only, but it has been extended [34] to support reflowing and reshaping of annotations if the underlying layout of the document changes. In the extended version, whenever the document layout changes, the annotations adjust themselves through zooming and changing its size and shape. In order to select a particular tool such as highlighter, pen, eraser, etc., the user is required to press the pen down and hold it stationary, which brings up a pie menu of available tools. The initialization of the pie menu toolbar and the selection of tools from toolbar in this way can be problematic because holding a pen on one spot causes *bleeding* [1] which is excessive flow of ink at one spot. XLibris only allows drawing handwritten notes, which might make for a paper-like experience but limits the reusability of annotations. For example, one cannot extract textual information from the handwritten notes or edit previously created annotations. The annotations created by this system cannot be switched between visible and invisible, thus it has many of the same limitations as paper. Moreover, the movement of the pen may results in irregular and sloppier annotation since touch screens are slippery and less sensitive than paper [35].

Baldonado et al. [36] developed an annotation system called Notable, which separates the annotation platform from the reading platform. This system integrates the notes taken on a Palm OS based handheld device with the original document. The reader reads the document on paper and writes down the notes on the Palm Pilot [36] using a specific input alphabet, Graffiti, instead of normal handwriting. The major limitation of this system was that it does not allow the user to annotate directly on the e-document, instead the user has to read the annotations independently from the original document. Also, it requires the user to write the notes in the Graffiti alphabet, which requires learning.

Agrawala et al. [35] developed a digital ink annotation system, DIZI, which enlarges the region of the underlying document for drawing freeform annotation through zoom-in. The design of the DIZI is based upon the insight that digital ink is larger and more illegible than real ink annotations on paper; this can make it difficult to mark individual characters and words, make comments in the limited white space, write between the lines, and write long comments. The resulting annotations overlap the text and clutter the screen space because of their higher density than the real ink annotations. Also, the screen size of the tablet is smaller than a standard sheet of paper; therefore, it shrinks the text to fit the screen, which further impairs the legibility problem of digital ink annotations. DIZI addresses these issues by magnifying the portion of the document where the user intends to create an annotation. It generates a rectangular zoom region when the pen touches the screen while the user holds the pen button. The user can write within the zoom region and after completing the annotation, the zoomed region shrinks back to normal size along with the annotation when user taps the document while holding the pen button. Furthermore, DIZI allows the user to see the overall context of the underlying document because the zoomed region only covers a small portion of the screen. Although DIZI addresses many issues related to digital ink annotations, there are some limitations that can be attributed to its design. First, the zoomed rectangle covers some portion of the underlying document, which hides that portion of original text thus making reading more difficult. Second, it requires the user to initiate and close the zoom rectangle, which might also affect the reading experience as it adds extra steps in the process.

As discussed earlier, freeform annotation tools enable the user to annotate an e-document using pen and tablet in a similar fashion to using paper. But there are certain issues that are related to digital ink annotations. First, freeform digital annotations suffer from the *grouping problem*, that is, how to group individual ink strokes in a single annotation [37]. For an instance, if the user writes two words with freeform digital ink, then the system may consider the words as a single annotation or two separate annotations. The correct grouping of annotations is crucial for the purpose of reuse and editing. For example, consider a scenario in which a user has written a comment in the marginal space consisting of two handwritten lines. Later on, when the user wants to edit his comment, if system treats both lines as two separate annotations, then the user will need to edit both annotations separately. This may not be how the user would expect it. Research suggests that the annotations can be grouped based upon their temporal order, spatial arrangement, or a combination of both [37]. The temporal order based approach is easy, but it may result in irregular annotations when the stroke are made out of order (e.g., putting a dot on the letter 'i' after completing the word) [37].

Another issue related to freeform annotation is the misclassification of ink annotations. For example, classification of a horizontal arrow into an underline might confuse the user [37]. As discussed, freeform annotations are sloppier than real ink annotations on paper because of their large size. To overcome this issue, Arvo [38] and Zanibi [39] provided methods to automatically clean the user's ink strokes. Bargeron et al. [37] deployed a similar approach of cleaning the freeform annotation [37]. A user evaluation with 18 participants revealed that participants were not satisfied with the "cleaned annotations" because their ink strokes were not cleaned as expected.

One of the most important challenges for ink annotations is handwriting recognition, which is a crucial requirement for a query based search feature (i.e., if the user wants to search the information among the handwritten notes). Therefore, it is essential to extract the text from the handwritten notes. Landay et al. [40] have conducted extensive research on sketching user interfaces. Although various handwriting recognition techniques can identify text from the handwritten notes, they might not be accurate for some cases. Consequently, the misinterpretation of a user's annotation might disturb the reading experience and annoy them. This situation is further impaired if the system misclassifies the underline or any other shape to handwritten notes resulting in incorrect annotations.

From the above discussion, it is evident that freeform annotations have certain limitations. To overcome these limitations, another genre of annotation applications has evolved that provides various annotation tools as opposed to single freeform digital ink pen. These tools include highlighter, underline, sticky notes, text comments, shapes, symbols, etc. from which user can select any tool to create corresponding type of annotation. In next section, we describe some of the applications that offer these annotation tools.

2.3 Tool-Based Annotation Systems

Many desktop and online applications have been developed in past decade to support text annotations. Adobe Reader is a widely used PDF reader for desktop computers, which allows highlighting text and adding sticky notes to PDF document. PDF X-Viewer [41] is similar software but it provides more annotation tools than Adobe Reader such as underline, strike through, comment box, arrow, square, polygon, and freehand drawing. Although it facilitates a wide variety of annotation tools, it has many issues that might impede the reading experience. First, when the reader selects a particular tool (e.g., comment tool), it changes the current tool to comment tool and whenever user clicks on the document it creates a text box at that position. After creating comment, if user wishes to highlight the text, he has to switch to highlight tool and then highlight the text. The switching of tools might exert more cognitive load, which is absent in case of free form annotations tools. Second, the comment annotations appear in the form of a text box, which require manual resizing when it overlaps the underlying text. Third, it is difficult to draw freehand annotations using mouse.

With the growing population of users who consider the Internet as their primary source of information, researchers have been focusing on providing a variety of online annotation tools [42, 43]. WebNotes [44] is a commercial annotation tool that was designed to support online research. It allows users to highlight and to make notes on websites and PDF files. Additionally, it enables users to organize their notes, bookmarks, and documents, and to share annotations via e-mail, permalink and Twitter. Diigo [45] is a powerful web-based annotation tool that supports the development of critical reading skills by allowing users to highlight and add sticky notes to webpages. It facilitates collaborative learning by allowing users to interact with and comment on annotations of peers. Such tools that allow the annotation of text, facilitate sharing of annotations, and attend discussion are called Social Annotation Tools [46]. Earlier studies have concluded that annotations influence the way in which the subsequent readers perceive the original text [4]. Therefore, social annotation tools foster new level of knowledge through the aggregation of information from multiple users [46].

Tashman and Edward introduced LiquidText [24, 47], an active reading system for multi-touch displays and tablets. One of its features that differentiate its design from the other systems discussed above is the layout of the screen. It divides the screen area into two panes [24]; the left displays the original text, while the right is the workspace area that provides free space to user for creating and manipulating comments and document excerpts. Using unimanual and bimanual fingertip gestures [48], the user can select various excerpts from the text and drag them into work area while the excerpt also remains in the original text. *Unimanual* gestures involve the use of only one hand whereas *bimanual* gestures require both hands. These excerpts can be moved across the screen and linked together while remaining associated with original text. In order to highlight the text, the user is required to perform a bimanual selection technique: press and hold the selection button in the menu bar using a fingertip of one hand while a fingertip of the other hand simultaneously selects the text. Once the selection is done, the menu button is released and a flick up gesture is performed on the selected text to highlight it [24]. Other features allow users to hide any portion of text by pinching it, and navigating to multiple sections of the document at same time. Although this system provides unique features of document manipulation (e.g., hiding part of document, extracting excerpts), it does not focus much on the annotation part. It requires the user to actively engage both hands while they create annotation. As discussed in Section 3.1.3, users prefer to use unimanual interactions over bimanual, therefore, we have used only unimanual gestures in GestAnnot (see Section 3.1.3). Furthermore, if the researchers consider the idea of using two panes for displaying original text and the workspace for small screen tablets, it would make the text illegible, thus inhibiting the basic goal of the reading applications.

Matulic and Norrie [49] developed an active reading system for digital tabletops that uses "Multi touch" and "Touch+Pen" [50] interactions depending upon the input types involved. A toolbar containing various annotation and navigation tools is present on the side of screen that is opposite to the user's dominant hand (i.e., on the left for a right-handed user). The users are meant to select these tools using their non-dominant hand and perform the action by the other hand holding a pen. Similar to LiquidText, the user selects the tool and maintains the press while the pen in the other hand draws ink annotations or erases it, depending upon the selected tool. In addition to ink annotations, it provides some bimanual gestures for navigation. A gesture of pressing a finger in a page corner and moving a finger of other hand to leaf through several pages of documents. The chop and spread gesture provides document overview which is executed by placing two hands vertically on the surface, palms facing, and then spreading apart [49, 51]. Although this system provides an efficient reading environment, it is not an effective design for portable tablets and reading devices, because users prefer unimanual gestures to bimanual gestures and they only use bimanual interactions if it is not possible to perform a task using unimanual in a particular application (see Section 3.1.3).

Modern portable tablet devices such as iPad[1], Samsung Galaxy Tab[2], Kindle Fire[3] also offer reading as one of their features. Most of the contemporary tablet devices forego stylus and rely instead on multi touch technology for interactions. There are many academic and commercial applications available for the tablets that provide different annotation tool along with the capability of sharing them for collaborative learning. Reading applications such as ezPDF Reader [52] and Repligo Reader [53] provide different types of annotation tools such as highlight, underline, squiggly, strike through, freehand drawing, and shapes like circle and square, line, arrow comment, and sticky notes. Additionally, such applications provide the ability to share, organize annotation and export them to text document. Golovichinsky et al. [54] developed an application that has audio annotations.

Although these tablet applications provide variety of annotation tools, which gives immense flexibility to create and manage annotations on e-document, they require more actions to switch between these tools. These applications are designed in a way that if a particular tool is selected and then an annotation is created, the tool becomes de-activated. When users wish to create another annotation, even of the same type as that of previous one, they have to select that particular tool again before using it. It seems that this issue can easily be resolved, if the current tool remain activated until the user explicitly deselect it as in Adobe Reader for desktop. However, this is not valuable on a tablet. Consider a scenario in which highlight tool is activated and the user drags his finger on the text to

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[1] http://www.apple.com/ca/ipad/
[2] http://www.samsung.com/global/microsite/galaxytab/10.1/index.html
[3] https://kindle.amazon.com/

highlight it. If this tool always remains activated and user tries to scroll the document by dragging his finger, it will produce highlighting whenever finger touches any text, which user does not intend to do. Therefore, these applications follow a two-step annotation process for each annotation i.e. select the tool and create the annotation.

2.4 MULTI-TOUCH GESTURES

Most of the prior work in multi-touch gestures design has involved the similar approach in which, human computer interaction (HCI) experts design gesture sets and then conduct user studies to verify whether these sets are natural and easy to use [55]. The multiple investigations into design of gesture sets include Wu and Balakrishnan's [56] set of multi-touch and whole-hand gestures for manipulating furniture layouts on a DiamondTouch table, Ringel et al. [57] proposed set of gestures for collaborative settings and Wu et al. [58] gesture sets for editing and manipulating photos on tabletop displays. Malik [59] and Moscovitch et al. [60] described multi-finger gesture sets for controlling objects on vertical displays (e.g. computer desktop). Morris et al. [61] proposed "cooperative gestures" wherein the gestures of various users acting in synchrony can be jointly interpreted. Morris et al. [62] and Wobbrock et al. [63] described user-generated gestures that reflect user's expectations of the actions that will be performed using particular gesture. Hinrichs and Carpendale [64] conducted a field study to investigate how users interact with large interactive table using multi-touch gestures. From the observations of this study, the authors concluded that the choice of multi-touch gestures is not only influenced by the general preferences for particular gestures but also by the interaction context and social context they occur in. In other words, gestures should not be considered in isolation from previous and subsequent gestures involved in series of actions, and different people might use different gestures for the same action depending upon the social context, their age, and their overall intention.

Another body of gesture-related research involves mode-switching techniques in pen-based user interfaces. As inking and gesturing are two major tasks in pen-based user interfaces, it is required to have a feature of switching between modes of entry for gesture and entry for ink. Li et al. [65] conducted a quantitative experimental study to evaluate the performance of different mode switching techniques (press and hold, pressure-based mode switching, pressing barrel button, using non-preferred hand and using the eraser end of a pen) and found that pressing a button with the non-preferred hand offers the fastest performance while using the pen with the other hand.

It might be difficult to recall the appropriate gesture for a particular command during the earlier use of application. In the prior studies, few techniques have been proposed that can help the user to recall the gesture and assist in how to perform a particular gesture. Kurtenbach et al. [66] proposed a system in which if user does not know which gestures are available or which gesture corresponds to a particular command, he presses the pen and waits for the *crib sheet* to appear that lists the available gestures and their corresponding commands. The Fluid Inking [67] system proposes a similar approach in which, users invoke a marking menu that lists the command name and the description of the corresponding gesture.

In a recent study by Wagner et al. [68] researchers introduced and evaluated bimanual interaction techniques for handheld tablet devices. In their study, they argued that participants preferred to use bimanual gesture with the thumb of non-dominant hand (e.g., left hand for a right-handed user) at the side of the device.

From the examination of previous research discussed in Sections 2.1 through 2.4, we observed that numerous annotation systems were developed over the past, which provided users with variety of annotation features. Although these systems have evolved over the time through technological advancements and research to provide various annotation tools, they have not been able to overcome the complications of multiple steps involved with the usage of these tools, which might deviate the user from their reading tasks. To fill this gap, we propose gesture-based interaction techniques for using the annotation tools so that the annotation task involve lesser number of steps which might reduce the cognitive load during Active Reading. Although, prior research has proposed many multi-touch gestures and many applications have incorporated them in their design, they have not been explored much in the active reading application. In tackling the contemporary challenges associated with such tablet applications, this thesis provides a practical solution that significantly enhances the active reading experience. Although this thesis mainly focuses on the annotation part of active reading, as suggested by the literature, its integration with other active reading components such as navigation and multiple display reading will likely result in an improved reading environment.

CHAPTER 3 DESIGN AND IMPLEMENTATION OF GESTANNOT

Our goal behind GestAnnot was to create a design that overcomes the limitations of existing annotation applications. In particular, our specific goals were to 1) provide tools to support different types of annotations, 2) incorporate an interaction model that support direct use of these tools without having to select them each time prior to its usage, and 3) simplify manipulation of annotations. To achieve these goals, we have created an initial design and evaluated it in a lab and then considering the users' feedback, we developed an improved version, which was further evaluated in a field study. In this chapter, we will elaborate the initial design and the next chapter will discuss its lab evaluation in detail.

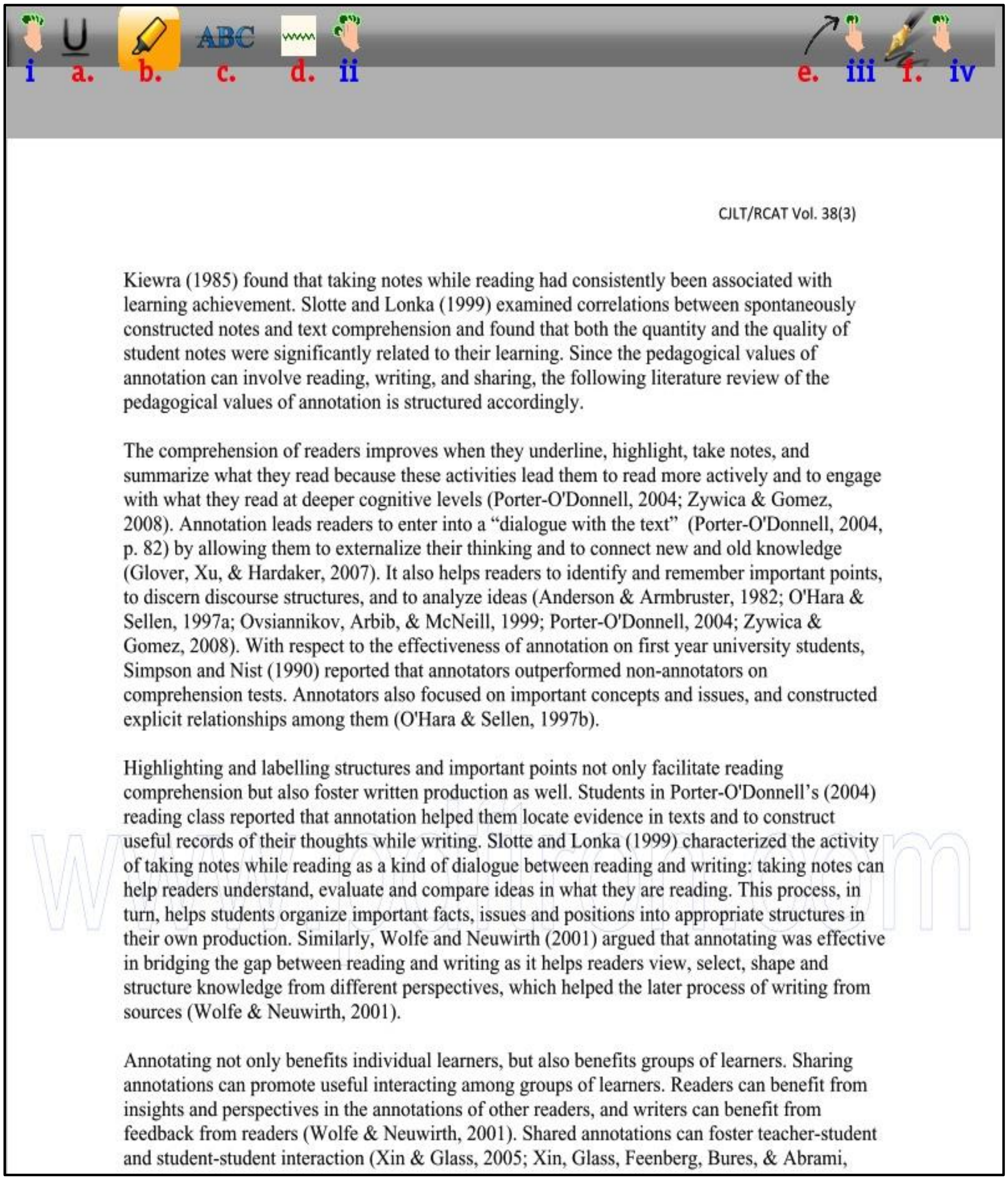
3.1 Design Requirements and Specifications

We considered the requirements for active reading grounded in the prior literature. From a careful analysis of prior literature and existing applications, we identified a certain set of tools that would be incorporated in GestAnnot to provide extensive and flexible annotation capability. The next section describes these tools in detail.

3.1.1 Screen Layout

Figure 3.16 shows the screen layout of GestAnnot. It has a menu-bar at the top of the screen that contains tools and help icons and the rest of the screen area displays the document. Left area of menu-bar shows anchor annotation tools (discussed in Section 3.1.2); (a) Underline, (b) Highlight, (c) Strike-Through, (d) Squiggly, and right area shows (e) Arrow, and (f) Freehand tool. It also shows hand gestures icons (discussed in Section 3.1.3) next to their respective tool to assist user in recalling the appropriate gesture for a particular operation. These icons are: (i) four-finger tap, (ii) five-finger tap, (iii) two-finger tap, and

(iv) three-finger tap.



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Kiewra (1985) found that taking notes while reading had consistently been associated with learning achievement. Slotte and Lonka (1999) examined correlations between spontaneously constructed notes and text comprehension and found that both the quantity and the quality of student notes were significantly related to their learning. Since the pedagogical values of annotation can involve reading, writing, and sharing, the following literature review of the pedagogical values of annotation is structured accordingly.

The comprehension of readers improves when they underline, highlight, take notes, and summarize what they read because these activities lead them to read more actively and to engage with what they read at deeper cognitive levels (Porter-O'Donnell, 2004; Zywica & Gomez, 2008). Annotation leads readers to enter into a "dialogue with the text" (Porter-O'Donnell, 2004, p. 82) by allowing them to externalize their thinking and to connect new and old knowledge (Glover, Xu, & Hardaker, 2007). It also helps readers to identify and remember important points, to discern discourse structures, and to analyze ideas (Anderson & Armbruster, 1982; O'Hara & Sellen, 1997a; Ovsiannikov, Arbib, & McNeill, 1999; Porter-O'Donnell, 2004; Zywica & Gomez, 2008). With respect to the effectiveness of annotation on first year university students, Simpson and Nist (1990) reported that annotators outperformed non-annotators on comprehension tests. Annotators also focused on important concepts and issues, and constructed explicit relationships among them (O'Hara & Sellen, 1997b).

Highlighting and labelling structures and important points not only facilitate reading comprehension but also foster written production as well. Students in Porter-O'Donnell's (2004) reading class reported that annotation helped them locate evidence in texts and to construct useful records of their thoughts while writing. Slotte and Lonka (1999) characterized the activity of taking notes while reading as a kind of dialogue between reading and writing: taking notes can help readers understand, evaluate and compare ideas in what they are reading. This process, in turn, helps students organize important facts, issues and positions into appropriate structures in their own production. Similarly, Wolfe and Neuwirth (2001) argued that annotating was effective in bridging the gap between reading and writing as it helps readers view, select, shape and structure knowledge from different perspectives, which helped the later process of writing from sources (Wolfe & Neuwirth, 2001).

Annotating not only benefits individual learners, but also benefits groups of learners. Sharing annotations can promote useful interacting among groups of learners. Readers can benefit from insights and perspectives in the annotations of other readers, and writers can benefit from feedback from readers (Wolfe & Neuwirth, 2001). Shared annotations can foster teacher-student and student-student interaction (Xin & Glass, 2005; Xin, Glass, Feenberg, Bures, & Abrami,

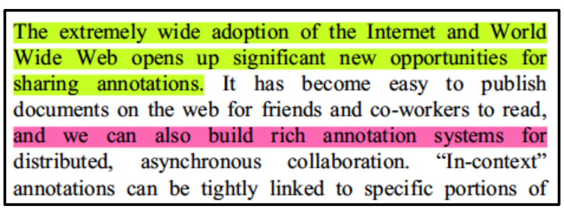
Figure 3.1: Screen Layout of GestAnnot

3.1.2 Annotation Features

GestAnnot has incorporated following annotation tools:

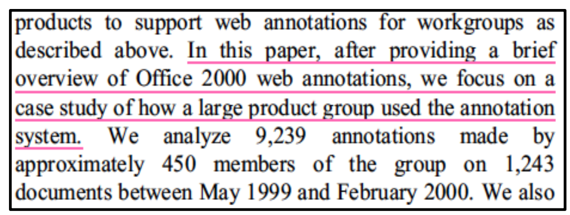
3.1.2.1 Anchor Annotations

Earlier studies have suggested that *anchor annotations* can act as a signal for further attention in subsequent readings and that marking a text as important or unimportant [5, 7]. The types of anchor annotations are highlight, underline, squiggly, and strike-through. Research also suggests that underlining or highlighting specific words, chemical reaction, equations, etc. is a way to mark the information that is needed to memorize [5]. GestAnnot offers four anchor annotation tools: highlighter (Fig 3.2 a), underline (Fig 3.2 b), strike-through (Fig 3.2 c) and squiggly (Fig 3.2 d). These tools also allow a user to add more than one anchor annotation to the same portion of original text, as illustrated in Figure 3.2 (e) and (f).



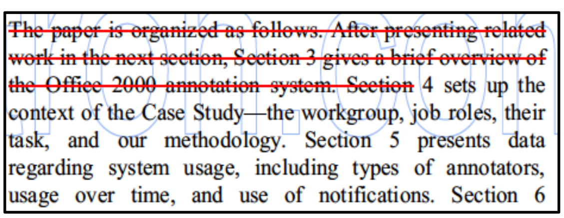
The extremely wide adoption of the Internet and World Wide Web opens up significant new opportunities for sharing annotations. It has become easy to publish documents on the web for friends and co-workers to read, and we can also build rich annotation systems for distributed, asynchronous collaboration. “In-context” annotations can be tightly linked to specific portions of

(a) Highlight



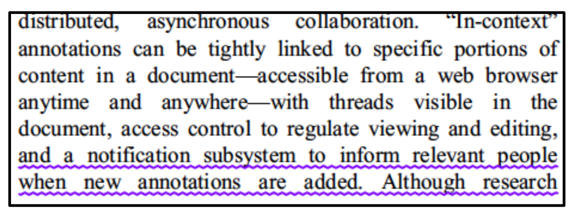
products to support web annotations for workgroups as described above. In this paper, after providing a brief overview of Office 2000 web annotations, we focus on a case study of how a large product group used the annotation system. We analyze 9,239 annotations made by approximately 450 members of the group on 1,243 documents between May 1999 and February 2000. We also

(b) Underline



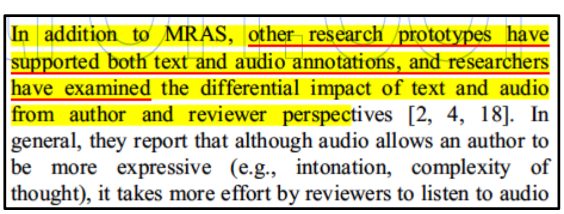
The paper is organized as follows. After presenting related work in the next section, Section 3 gives a brief overview of the Office 2000 annotation system. Section 4 sets up the context of the Case Study—the workgroup, job roles, their task, and our methodology. Section 5 presents data regarding system usage, including types of annotators, usage over time, and use of notifications. Section 6

(c) Strike-Through



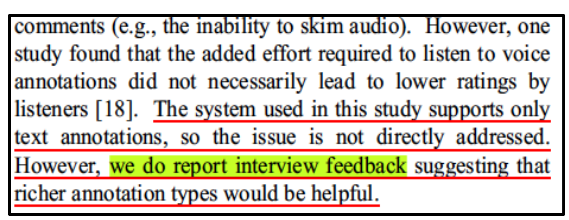
distributed, asynchronous collaboration. “In-context” annotations can be tightly linked to specific portions of content in a document—accessible from a web browser anytime and anywhere—with threads visible in the document, access control to regulate viewing and editing, and a notification subsystem to inform relevant people when new annotations are added. Although research

(d) Squiggly



In addition to MRAS, other research prototypes have supported both text and audio annotations, and researchers have examined the differential impact of text and audio from author and reviewer perspectives [2, 4, 18]. In general, they report that although audio allows an author to be more expressive (e.g., intonation, complexity of thought), it takes more effort by reviewers to listen to audio

(e) Underline within Highlighted Text



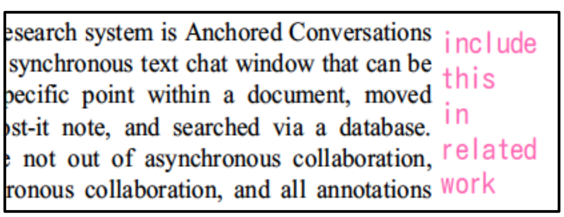
comments (e.g., the inability to skim audio). However, one study found that the added effort required to listen to voice annotations did not necessarily lead to lower ratings by listeners [18]. The system used in this study supports only text annotations, so the issue is not directly addressed. However, we do report interview feedback suggesting that richer annotation types would be helpful.

(f) Highlight within Underlined Text

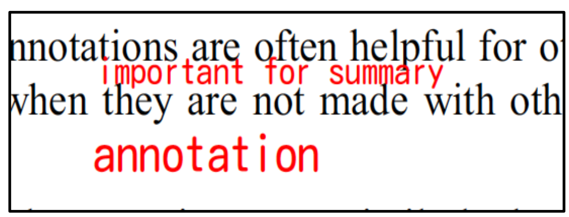
Figure 3.2: Anchor annotations created in GestAnnot

3.1.2.2 Textual Annotations

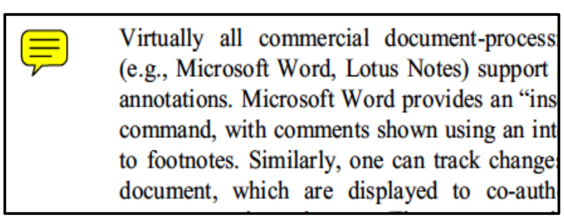
Textual annotations record interpretive activity, that is, readers add their own thoughts in the form of notes in the margins, and word or phrases between the lines of the text [5, 7]. The short phrases or words written between the lines are usually the translation of the words in foreign language, and the notes written in the margins constitute the interpretation of the structure and content in the original text [5]. GestAnnot provides the comment and sticky note tool to write textual notes in the margins or anywhere within the text. *Sticky Note* annotations allow the users to add textual annotations but unlike a comment, it appears as an icon on the original document and the user can read and edit their content by opening it. As shown in Figure 3.3, the textual comment (in colored text) appears without any background or text box, therefore the original text remains visible even if the comment is present within the lines or overlaps the text. Unlike paper annotation, sticky notes are useful for saving marginal space if there are many comments in the margins. Therefore, a feature is included in GestAnnot to convert textual comment to sticky note or vice versa.



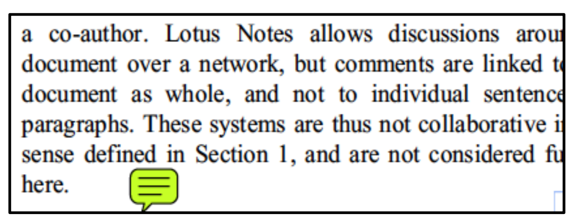
(a) Comment "include this in related work" in the marginal space



(b) Comment "important for summary" between the lines of text



(c) Sticky Note in the marginal space

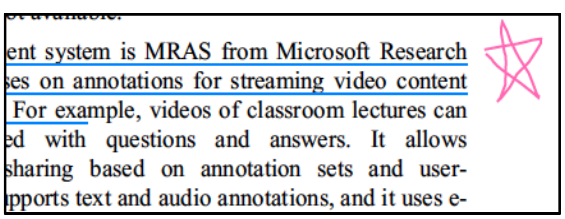


(d) Sticky Note between the lines of text

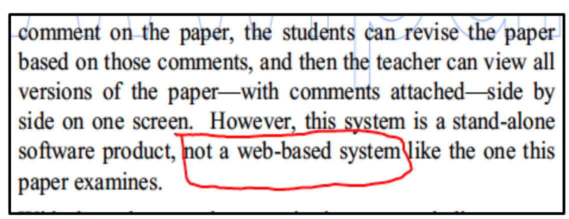
Figure 3.3: Textual Annotation and Sticky Note created in GestAnnot

3.1.2.3 Symbols and Shapes

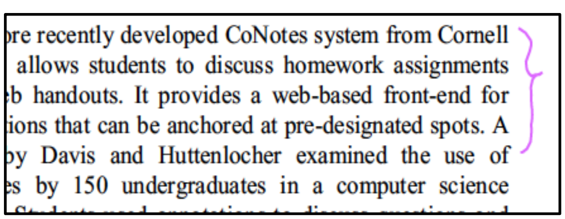
Blustein et al. [7] advocated that readers use variety of symbols and shapes to mark the text such as asterisk, star, braces, circles, squares, brackets. Moreover, these marks are completely idiosyncratic, personal and subjective and the purpose behind using such marks also differs among individual. Blustein et al. concluded in their field study [7] that most of the participants' annotations are of compound type, that is, they occur as a combination of an anchor annotation and an explicit annotation (textual). For an instance, if a participant circles a paragraph in the original document and wrote his or her interpretation next to that circle, then this circle and the comment would constitute a compound annotation. GestAnnot provides a freehand drawing tool, which can be used to draw custom shapes and symbols, such as a circle, square, or star. Figure 3.4 shows few examples of freehand annotations drawn with GestAnnot, including a star (Fig 3.4 a), rectangle (Fig 3.4 b), braces (Fig 3.4 c), and asterisk (Fig 3.4 d). As well as to the freehand tool, GestAnnot offers arrow tool, which can be used to associate a comment with the original text or anchor annotation as shown in Figure 3.5.



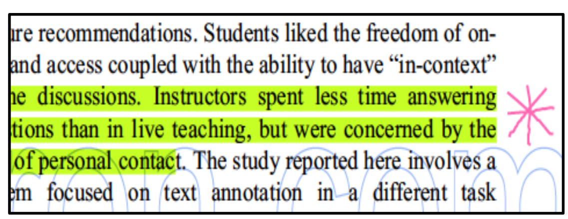
(a) Star



(b) Rectangle

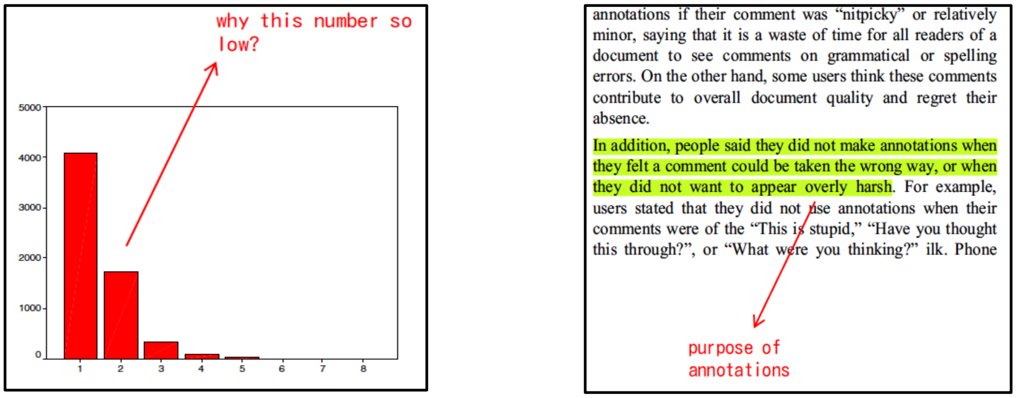


(c) Brace



(d) Asterisk

Figure 3.4: Freehand annotations created in GestAnnot



(a) Arrow signifying a link between a graph and the comment

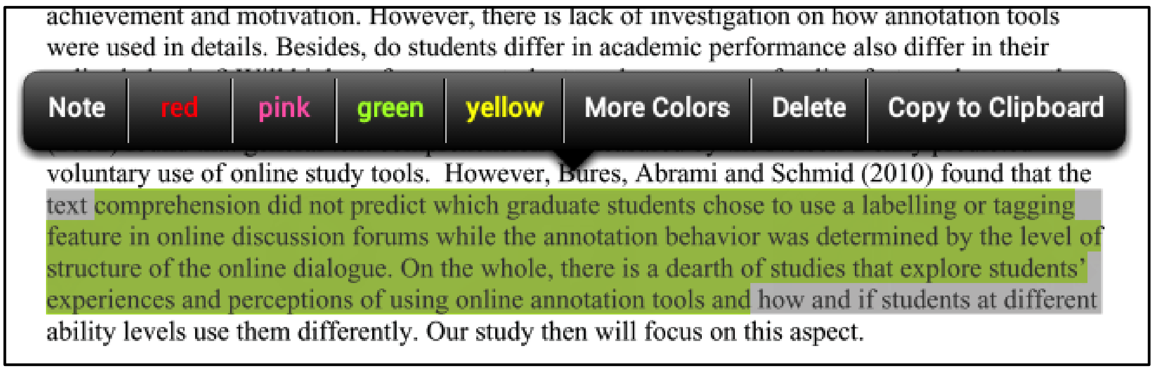
(b) Arrow signifying a link between a highlighted text and the comment

Figure 3.5: Arrow annotation created in GestAnnot

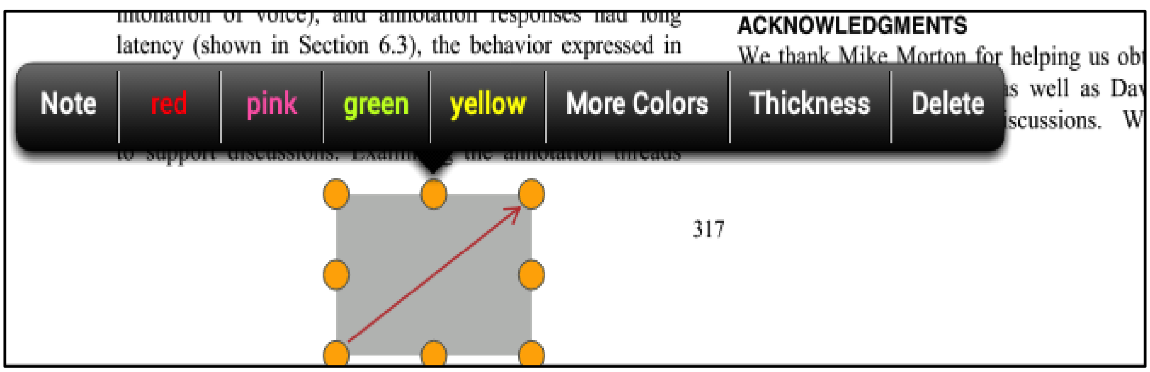
3.1.2.4 Editing Annotations

One of the major advantages of e-reading over reading from paper is that it enables the user to delete and edit the content and other attributes of annotations including its color, position, and size. In GestAnnot, a user can edit an existing annotation by selecting the appropriate option from a pop-up menu that appears when the user taps on a particular annotation, as shown in Figure 3.6 (a) and (b). Non-anchor annotations such as comments, sticky notes, arrows and freehand shapes can be resized by dragging their selection points. The selections points for an arrow annotation are shown in Figure 3.6 (b).

In the pop-up menu, four colors have been provided for quick access, along with an option of choosing more colors from a color dialog picker as shown in Figure 3.7. Research suggests that readers develop their own system of annotations in which they use multiple types of annotations for specific purposes [5]. For example, different colors might have different meanings to different readers. The efficiency of the color selection task is potentially elevated because user can quickly choose the color from the available four colors in pop-up menu, without going through multiple steps to do it. Every tool (highlight, underline, squiggly, strike-through, arrow, and freehand) in GestAnnot has its own default color, which means if user selects a particular color for a tool, it becomes the default color for that tool. Therefore, user can use different colored annotation tool at the same time. As shown in Figure 3.6, other options available in the pop-up menu enable user to adjust the text size in comment annotations, and thickness of arrow and ink-stroke of freehand annotations.



(a) Pop-up menu for highlight, underline, strike-through and squiggly



(b) Pop-up menu for arrow and freehand annotations. The orange-circles are the selection points for resizing the annotation.

Figure 3.6: Pop-up Menu for editing annotations

3.1.2.5 Saving Annotations

GestAnnot allows saving annotations along with the original document. If users try to close the document before saving it, they are prompted with a dialog box that asks them whether or not to save it.

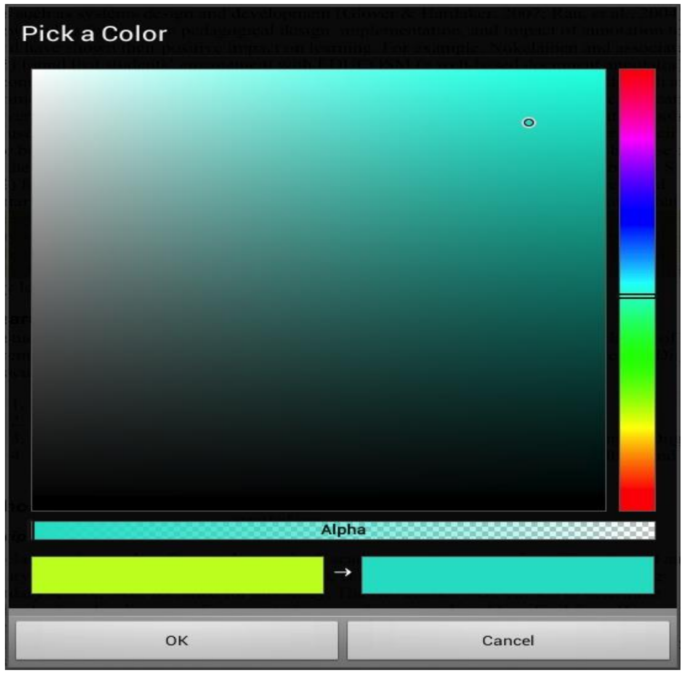


Figure 3.7: Color Dialog Picker

3.1.2.6 Exporting, Organizing and Retrieval of Annotations

In a study conducted by Tashman and Edwards [33], the authors observed that readers have difficulties in organizing their notes from multiple resources. They also mentioned that readers struggle with their notes and annotations in the retrieval process when they need a thought or excerpt about a document at a particular moment, it is hard to make these connections naturally.

As a potential solution to the above stated problem: the application allows users to assign tags to their annotations, retrieve these annotations based upon their content and tags, and trace back retrieved annotations to their original location in the particular document. For instance, when a researcher is doing the literature survey of the particular research topic, he might create notes and annotations on various articles. While making a note on an article, if he thinks that this note is related to a subtopic (say "Sub-Topic A") and it will be needed later for his thesis, he can assign "Sub-Topic A" tag to this note and later he can retrieve and organize all his notes related to this subtopic. Moreover, if the application keeps a record of all annotations created on all documents by a particular user, allows the user to do query-based search within all his annotations, and indicate in which document and at what location a particular annotation occurs, it will be very easier for readers to retrieve their notes and other annotations whenever they need it. This feature has not been implemented in the current version of GestAnnot but it should be considered in the design of any Active Reading application in future.

3.1.2.7 Increasing Marginal Space

Limited marginal space for annotations is an issue for users of both printed and digital literature [69]. If the application allows users to increase the marginal space manually or it does it automatically when the amount of annotations increases above certain level, the unnecessary constraint of limited marginal space can be overcome. This feature has not been considered in the current GestAnnot's design but it should be implemented in the future designs.

3.1.2.8 Sharing Annotations

Prior studies have revealed that annotations have a positive effect on the learning ability of subsequent readers of the annotated text [4, 70]. Therefore, the application should allow users to share their annotations with others along with the original document or only annotations on a separate document. This sharing mechanism has not been implemented in the current version but it should be provided in the future designs of Active Reading application to support collaborative learning.

The high-level requirements mentioned in the Section 3.1 are summarized in the Table 3.1.

#	Requirement	Section for Explanation	Implemented?	Comments (if any)
1	Anchor Annotation Tools Highlight, Underline, Squiggly, Strike-Through	3.1.2.1	Yes	
2	Textual Annotations: Comment, Sticky Notes	3.1.2.2	Yes	
3	Symbols and Shapes (Freehand Drawing Tool)	3.1.2.3	Yes	User can draw shapes using Freehand Tool
4	Arrow Annotation	3.1.2.3	Yes	
5	Editing Annotations	3.1.2.4	Yes	Editing Tools: Color, Text size, Resize Shapes, Edit Comment, Thickness of Strokes
6	Saving Annotations	3.1.2.5	Yes	
7	Exporting Annotations to external document	3.1.2.6, 3.1.2.8	No	
8	Organizing Annotations through Meta-Data tags	3.1.2.6	No	
9	Tracing back exported annotations to their original document(s)	3.1.2.6	No	
10	Query-Based search within Annotations	3.1.2.6	No	
11	Increasing Marginal Space for Annotations	3.1.2.7	No	

12	Sharing Annotations	3.1.2.8	No	

Table 3.1: High-Level Requirements for an Annotation Application

3.1.3 Gesture Based User Interface

Although the above mentioned annotation tools provides flexibility to users for creating a wide variety of annotations, the prominent goal of our research is to provide such interaction techniques in a way that the annotation activities can smoothly integrate with reading process. The numerous tools in GestAnnot may impede the reading experience if users will need to select and activate each tool before using it. To overcome this issue, we have adopted single-touch and multi-touch gesture techniques in the interaction design of GestAnnot. This section discusses the benefits of gesture techniques, followed by the details of how these techniques are incorporated in the design.

Some direct touch gestures have three key advantages over soft button interactions: a) a lack of visual monitoring, b) make use of muscle memory, and c) do not require dedicated screen space.

a) Some gestures have the potential to be performed with no or minimal visual monitoring, making them more robust to distractions [71] that arise from other concurrent tasks or from external source such as noise and travelling [20]. On the contrary, soft button interactions potentially degrade the performance of other concurrent tasks because they require the user to look at and press a relatively small target, thus requiring visual attention [20].

b) Research suggests that gestures can be committed to muscle memory; therefore user can concentrate on their main task [21]. *Muscle memory* involves consolidation of specific motor task through repetition. When a particular motor activity is repeated several times, muscle memory is developed that allows it to be performed in future without conscious effort and with or no minimal attention. Riding a bicycle and typing on keyboard are two examples of task employing muscle memory.

c) Unlike soft buttons, gestures do not require dedicated screen space as it can be performed on the entire screen. This saves screen space, which is limited in mobile devices [20].

From the above reasons, it is evident that gestures have the potential to reduce the attention load required by menu-based annotation tools. Research findings suggest that readers tend to annotate with the tool in the hand while reading from paper, therefore annotation task smoothly integrates with reading [5]. In existing applications, when users have to select and activate the appropriate tool before creating the annotation, it might interrupt the flow of reading. The use of gestures stems from these requirements that user should be able to use different annotation tool simultaneously without having to select them first before each use, and the annotation activity should demand less attention so that users can focus on their reading task. To incorporate the gestures in the design, we need to bind different gestures to different annotation tools so they can be performed independently from each other. Also, the choice of the gestures should be based on the insight that they should not be too difficult to learn and execute, and also they should not conflict with each other when users perform them.

As far as the number of gestures is concerned, there is wide range of gestures that can be performed using only one hand (unimanual) or using both hands (bimanual). Karlson et al. [72] concluded that users prefer to use a single hand for holding, supporting, and executing commands on smartphones. They also claim that users only use two hands when it is impossible to perform a certain task with one hand in a particular interface. Also, it is difficult to perform actions with the same hand that holds a tablet because they are bigger in size than smartphones [20]. Practically, there is only one hand available for performing actions on the screen, except when the tablet lies on a table or desk. Given these reasons, we have considered one-handed usability a priority in GestAnnot's design; therefore, it involves only unimanual gesture interactions.

Unimanual gestures can be classified into three categories; core gestures [73], mark-based gestures, and freeform path gestures [20]. *Core gestures* are the basic gestures that are used for executing most of the touch commands in smartphones and tablets [73]. It includes tap, press, double tap, multi-finger tap, pinch, drag, etc. Some of its examples are shown in Figure 3.8.

Mark-based gestures are compound path, which is comprised of axis-aligned rectilinear mark segments. As the name suggests, *freeform path gestures* comprised of compound paths that do not include axis-aligned marks [20]. Some examples of these gestures are illustrated in Figure 3.9.

The gestures incorporated in GestAnnot constitute a subset of the Core gestures, but they do not include freeform or mark based gestures because of two main reason. First, mark based and free form gestures will conflict with the scrolling operation of document. Typically, the scrolling of the document is done by a "press and drag" gesture; and the gesture can be in any direction. Therefore, freeform and mark-based gestures are impractical in this case. Second, the core gestures such as tap and double tap are very common among tablet applications. Additionally, they correspond to single click and double-click in mouse and track pad-based computers. Furthermore, other core gestures such as pinch, press-hold, and double finger tap have been incorporated in other applications of touch devices; therefore, familiarity with these gestures might mitigate the learning overload of GestAnnot interface. Given the advantages of Core gestures, a subset of these has been incorporated in GestAnnot interface, as elaborated in the following sections.

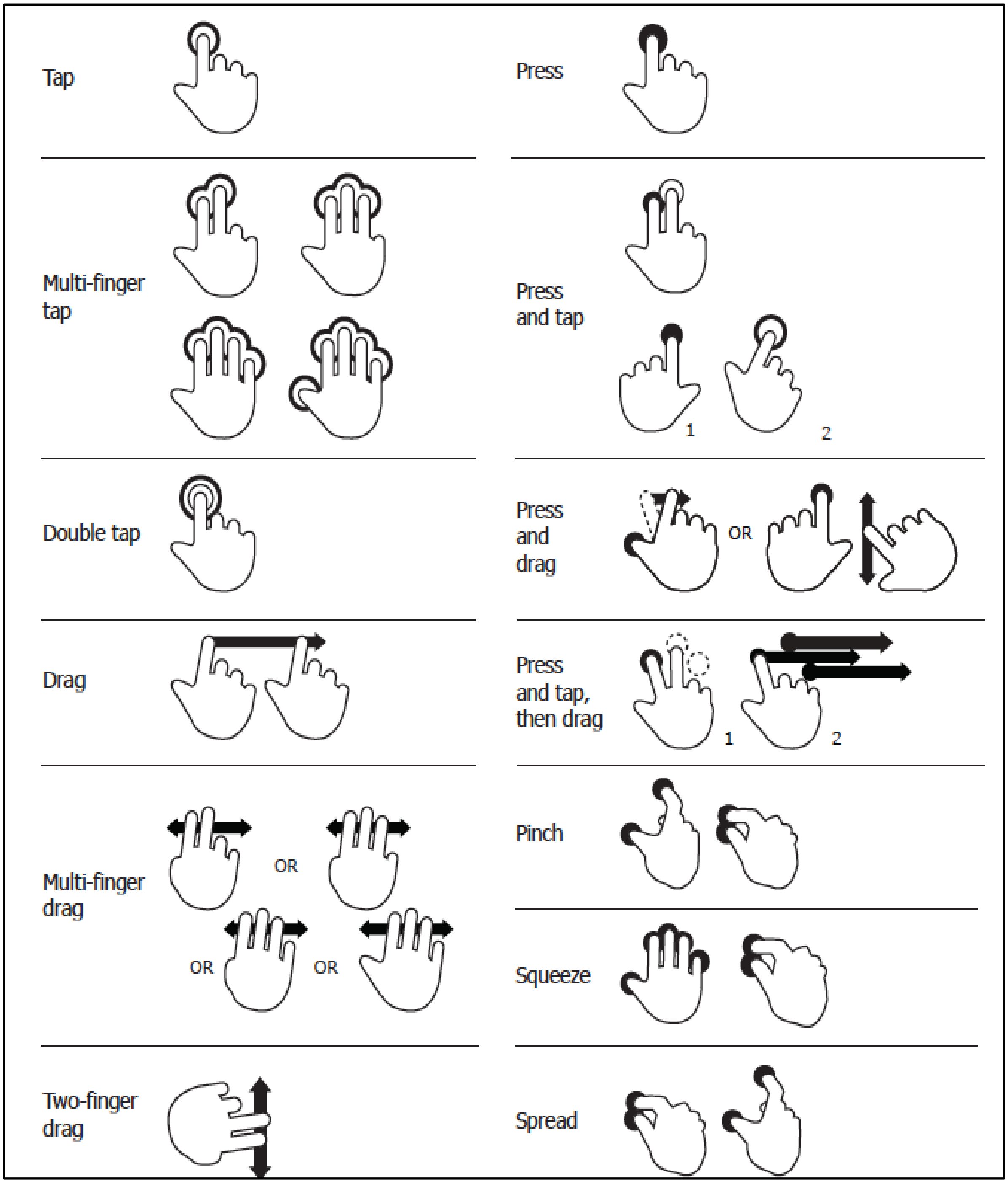


Figure 3.8: Core Gestures[4]

[4] http://static.lukew.com/TouchGestureTemplate.pdf

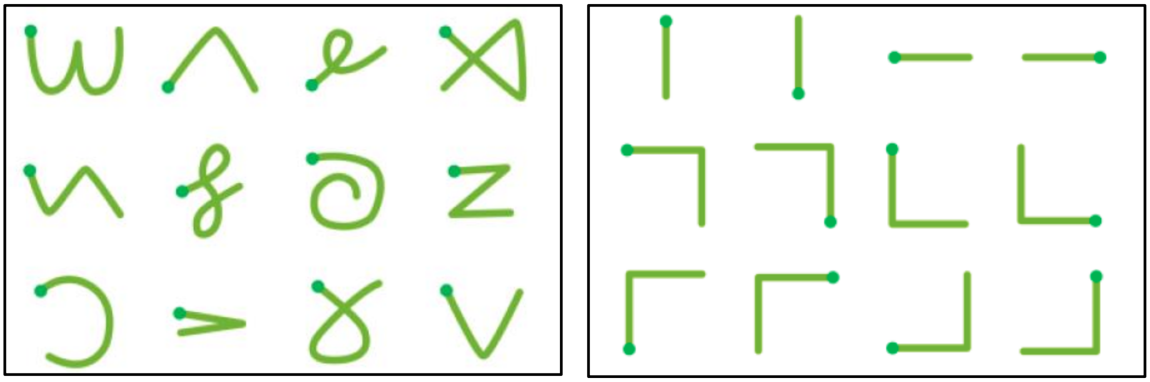
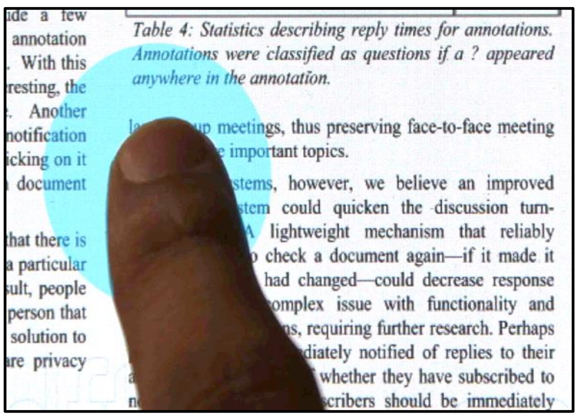


Figure 3.9: Freeform Gesture (left). Mark based gestures (right). A dot indicates the start of each gesture [20]

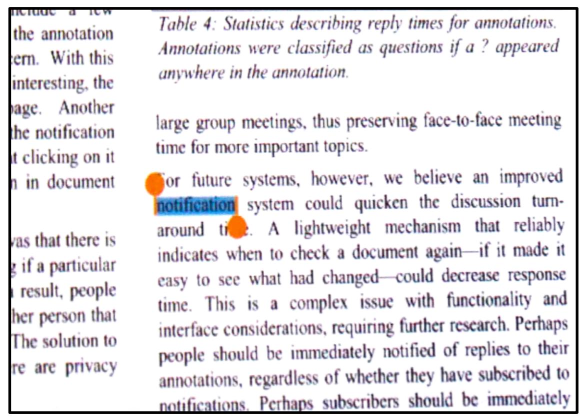
3.1.3.1 Single Tap Gesture to Highlight, Underline, Strike-Through, and Squiggly

Blustein et al. [7] concluded in their study that highlight and underline are among the most frequently used annotations. Considering these annotations as a priority, it was a necessary design requirement that the gestures utilized to create such annotations are simple so that the user can perform it frequently and easily.

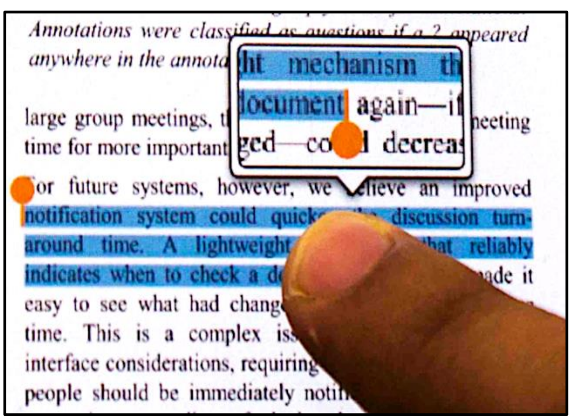
As most of the interactions in touch screen devices are done by tapping on that widgets with a finger (i.e., clicking a button or selecting an option), we chose the single-tap gesture for initiating the highlight and other anchor annotations. As shown in Figure 3.10, when users want to highlight a text, they have to tap on a word with one finger (Fig 3.10 a), which selects that word and show two selection widgets at the start and the end of that word (Fig 3.10 b). Then either of the selection widgets can be dragged to select the text (Fig 3.10 c), and when finger is lifted, the selected text is annotated with highlight or other anchor annotations depending upon the current active anchor tool in the menu bar (Fig 3.10 d). The annotation is only created when user drags the widgets and lifts the finger up. If a particular word is selected by tapping on it and then user tap anywhere else, the selected text is de-selected. If users wish to highlight only one word then they can tap on selection widget to do it. In addition, when the user presses the selection widget, a loupe box appears that shows the magnified area around that widget. This loupe box moves along the widget when users drag it thereby enabling them to accurately select the text, as it displays the words hidden under the finger.



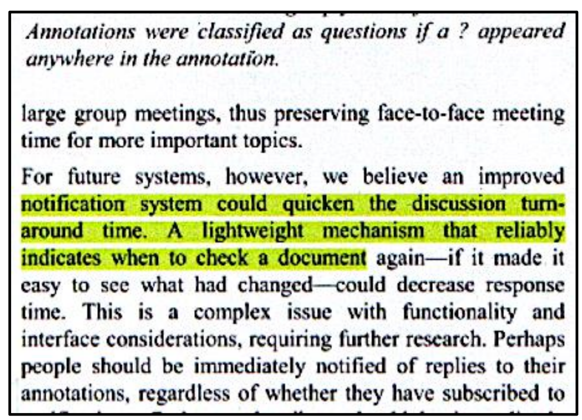
(a) Single Tap on the word to initiate highlight



(b) The word is selected automatically



(c) Drag the selection widget to select the text



(d) Selected text is highlighted when finger is released

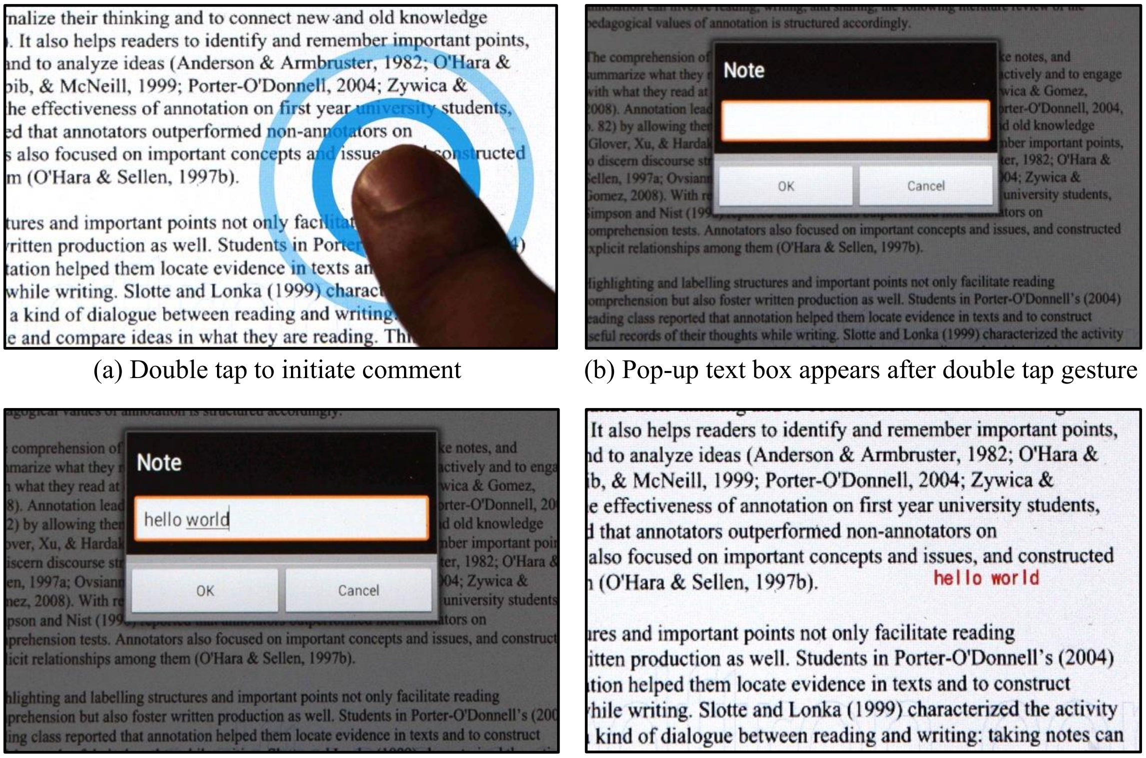
Figure 3.10: Highlight annotation created through single tap gesture[5]

[5] Note: The blue circle in Figure 3.10 (a) is only shown to demonstrate the touch interactions but they do not appear in actual interface. This condition also applies for subsequent figures in this chapter.

3.1.3.2 Double Tap Gesture to Comment

Blustein et al. [5] observed in their field study of annotations that the majority of readers' annotations involve textual comments and notes. Therefore, a simple gesture should be chosen to provide the ease of use of comment tool. One of the most common gestures is double-tap [74], which also corresponds to double click in desktop computers, making it more familiar and easy to learn. Therefore, double-tap is utilized for initiating the comment annotation in GestAnnot interface as shown in Figure 3.11. When users wish to add a comment, they can do so by tapping twice on a particular document's location (Fig 3.11 a), which brings a pop-up text dialog box into which to enter the text. When text dialog box appears (Fig 3.11 b), on-screen keyboard also pops up and after typing the text in the dialog box when users press "OK" button (Fig 3.11 c); the comment annotation appears at the same document's location where user has initiated the double tap (Fig 3.11 d). Later on, if users wish to change the color, text size or its position, they can accomplish it by tapping on comment, and selecting appropriate edit option from the pop menu. In addition, user can drag the comment to other location.

We could use text-box instead of pop-up dialogue for entering the text because it appears at the same location as the comment while user types it. However, we used pop-up dialogue instead because the on-screen keyboard covers almost half of the screen and when users create a comment in the bottom half of screen they will not see the text-box as it is hidden under the keyboard. However, the dialogue box always appears in the center of the screen so it is always visible.



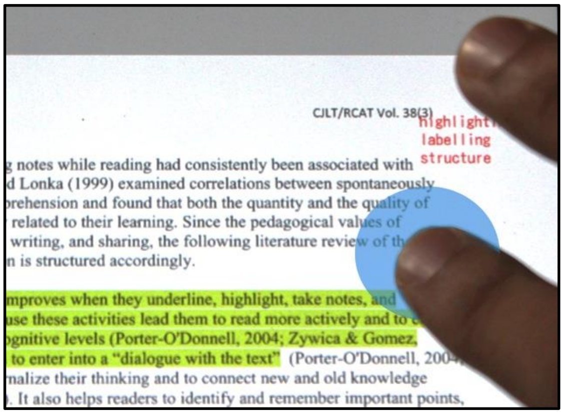
(a) Double tap to initiate comment (b) Pop-up text box appears after double tap gesture

(c) Type the content of comment (d) Comment is created at the same position

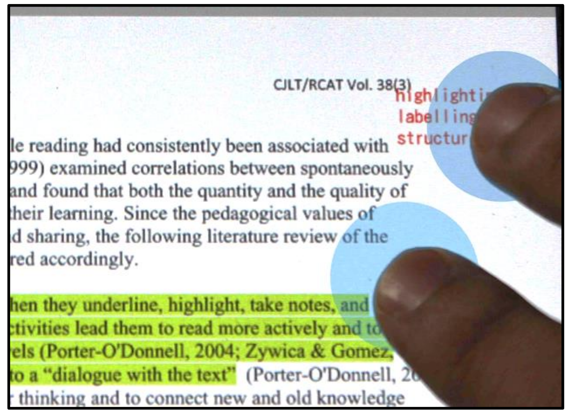
Figure 3.11: Comment annotation created through double-tap gesture

3.1.3.3 Press and Tap, and then Drag to Draw an Arrow

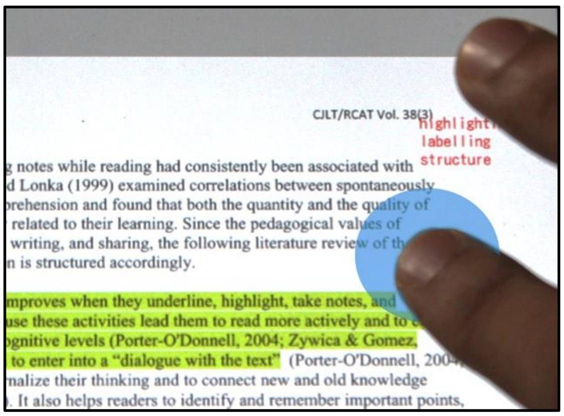
Blustein et al. [7] suggests that *compound annotations* occur more frequently than other types of annotations. Compound annotations are combination of anchor and content annotations. For an instance, if user writes the interpretation of a highlighted text in margins then that highlighted text and the comment in the margins together constitute a compound annotation. The arrow annotation might be useful in such cases where user wants to connect an anchor annotation to comment. As illustrated in Figure 3.12, this can be achieved by pressing and holding the finger at the screen point from where user wishes to start the arrow (Fig 3.12 a) and while this finger is pressed, executing single tap using second finger at any screen point (Fig 3.12 b, c). After this single tap, arrow is drawn when users drag the first finger (Fig 3.12 d) and it is finished when they lift it (Fig 3.12 e).



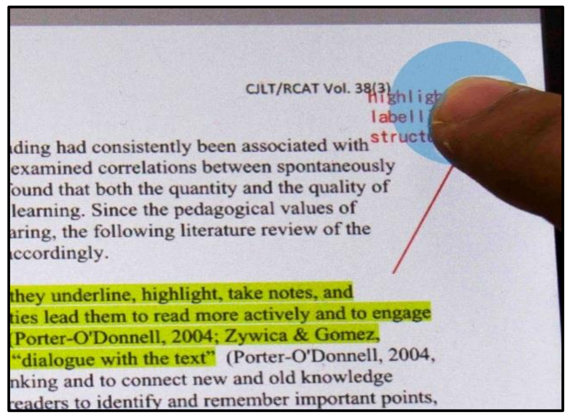
(a) First finger touch to specify the start point



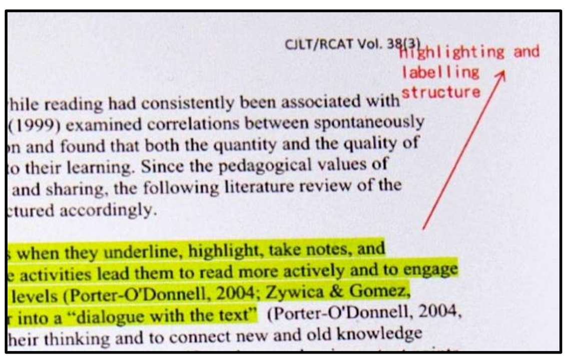
(b) Second finger touch to initiate the arrow



(c) Arrow is activated when second finger lifts up



(d) Drag the first finger to draw arrow

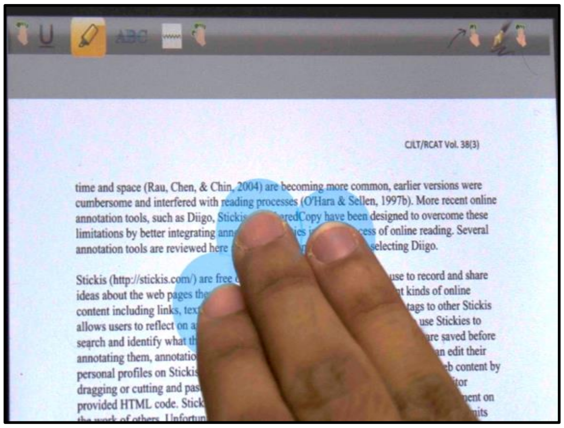


(e) Lift first finger to create the arrow

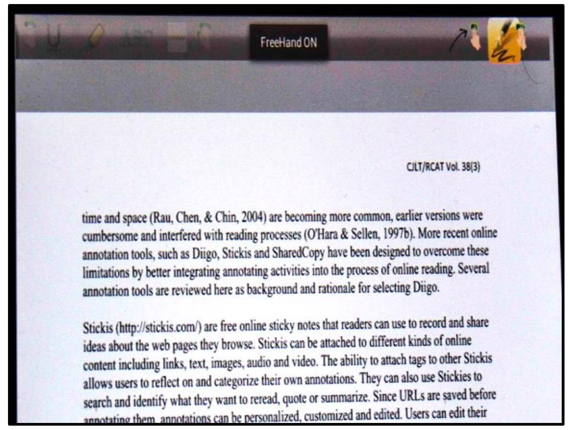
Figure 3.12: Creating arrow through two fingers tap gesture

3.1.3.4 Three-Finger Tap for Mode Switching

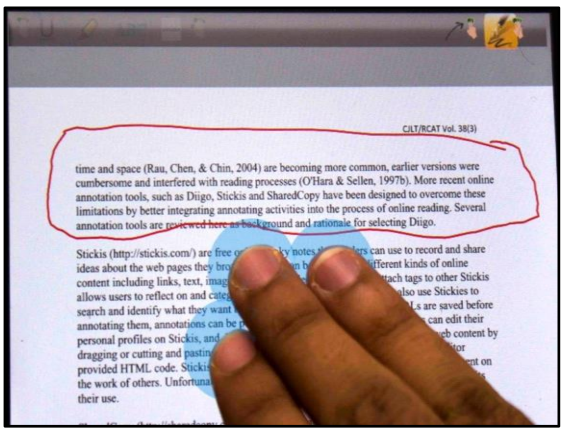
The use of other types of annotation such as asterisk, circle, box, braces, brackets, and etc. is limited but they are idiosyncratic [7]. Freehand tool can support such a wide varieties of shapes and symbols, so switching between freehand and other annotation tools should be smooth. GestAnnot allows switching between freehand drawing mode and anchor annotation mode through three-finger tap. As shown in Figure 3.13, when user tap on the screen using any three fingers, the freehand tool is activated and other anchor annotation tools become disabled automatically. To provide the feedback about this activity, the anchor annotation tools' icon become dim and the background of freehand tool changes and also a small notification pop-up appears on the top of the screen that says "Freehand ON", as shown in Figure 3.13(b). This pop-up remains for one second and then it disappears. After performing three-finger tap, users can draw any shape on the document using one finger. The freehand stroke drawn before lifting up the finger is considered as one annotation. For example, if a user draws a star in one stroke and then lifts his hand, star is considered as one annotation. After finishing the annotation, they can de-activate the freehand tool by tapping with three fingers. The anchor tools become bright and a notification pop-up appears that says "Freehand OFF", to provide the feedback of this operation. While the freehand tool is activated, arrow annotation and comment annotation tool are available to use but not the underline, highlight, strike-through and squiggly tools. This is because any interaction with single finger is utilized to draw on screen therefore, it cannot be used to initiate the anchor annotation by single tap gesture. On the other hand, comment and arrow annotation are initiated by multi-touch gestures, therefore it can be used simultaneously with freehand.



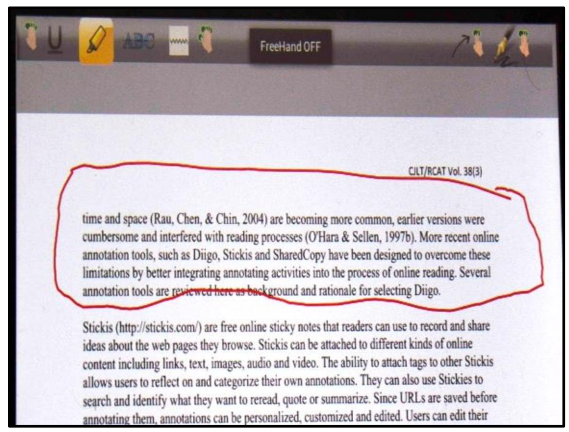
(a) Tap with three fingers to activate freehand tool



(b) Anchor annotation tools disabled when freehand is activated



(c) Tap with three fingers to deactivate freehand tool

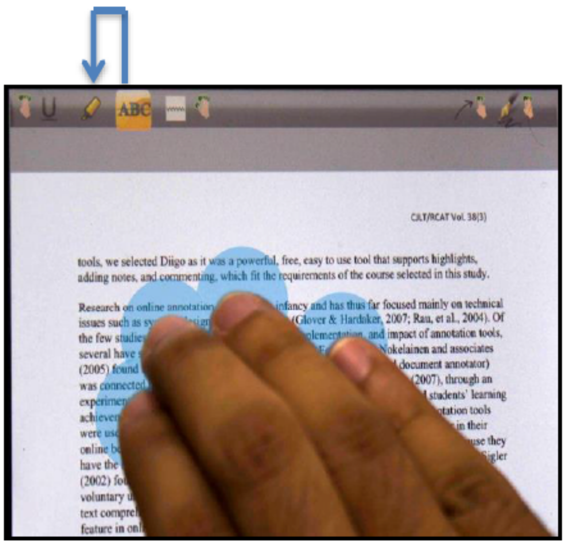


(d) Anchor annotation tools enabled

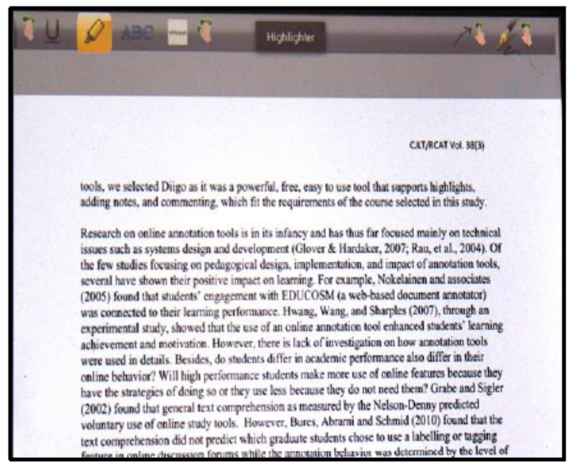
Figure 3.13: Freehand annotation created through three finger tap gesture

3.1.3.5 Four-Finger and Five-Finger Tap to Switch between Anchor Annotation Tools

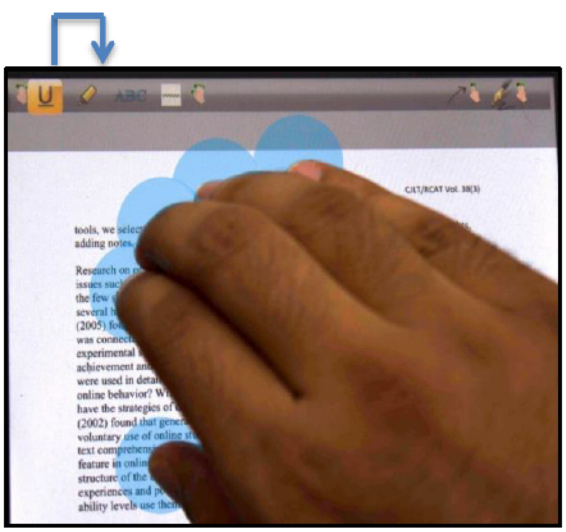
As discussed earlier in Section 3.1.3.1, single-tap gesture works as a highlighter, underline or other anchor tool depending upon the current selected tool. The user can switch between four anchor tools by directly tapping on that tool's icon present in menu bar. However, GestAnnot allows this switching through gestures too. As shown in Figure 3.14(a) and (b), user can switch between tools from right to left direction in menu bar by tapping on screen using four fingers. Similarly, switching from left to right tool can be accomplished by five-finger tap as shown in Figure 3.14(c) and (d). As described in Section 4.5.8, this technique speeds up the process if the user frequently switches between any two tools such as highlight and underline.



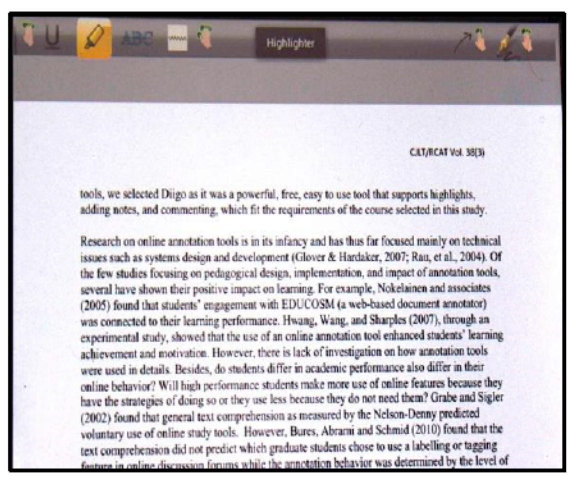
(a) Switching from Strike-Through to Highlight through four finger tap



(b) Switched from Strike-Through to Highlight



(c) Switching from Underline to Highlight through five finger tap gesture

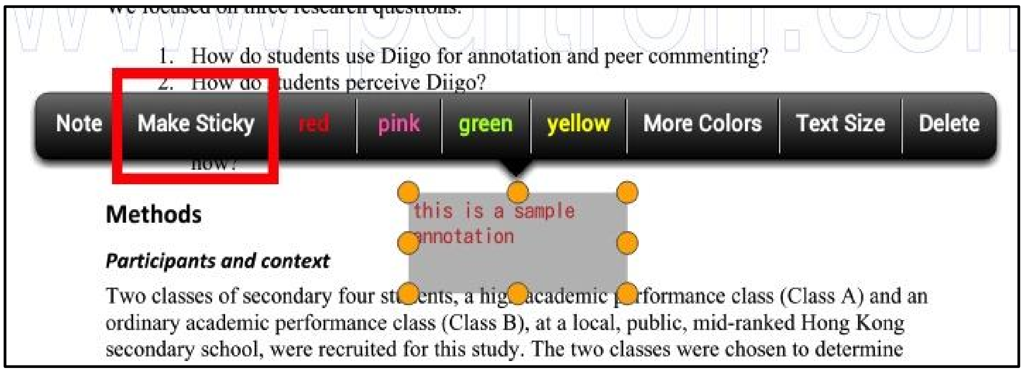


(d) Switched from Underline to Highlight

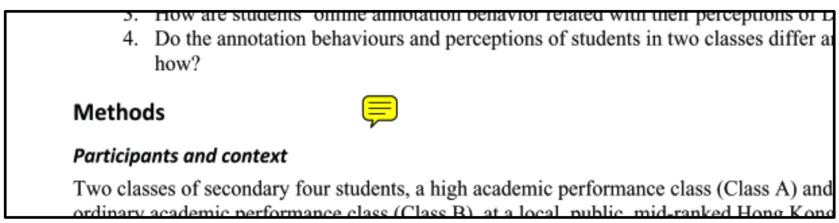
Figure 3.14: Switch between anchor annotation tools through four-finger and five-finger tap gesture

3.1.3.6 Sticky Note from Pop-Up Menu

Sticky notes can be very useful for saving space when there are many comments in the document. The user can convert a comment into sticky note by tapping on it and selecting "Make Sticky" option from pop-up menu, as shown in Figure 3.15. Similarly a sticky note can be converted to comment by selecting "Expand" option from pop-up menu, as shown in Figure 3.16.



(a) Select Make Sticky option from the pop-up menu

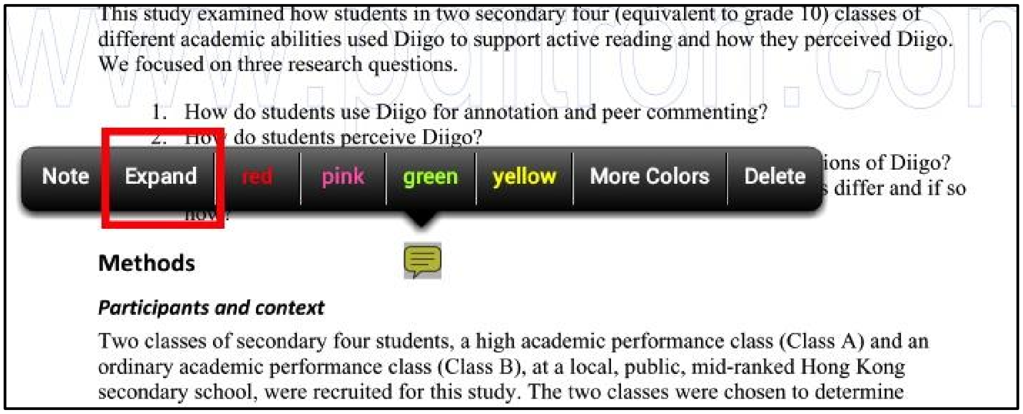


(b) Comment annotation is converted into Sticky Note

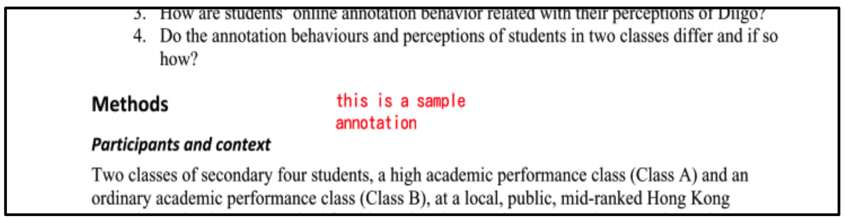
Figure 3.15: Comment to Sticky Note

3.1.3.7 Navigational Gestures

The gestures used for intra-page and inter-page navigation are the same as used by other tablet applications such as pinch for zoom, flick for turning pages, and drag for scrolling. These gestures are being used by many other applications; therefore, GestAnnot complies with these existing conventions.



(c) Select Expand option from the pop-up menu



(d) Sticky Note is converted into Comment

Figure 3.16: Sticky Note to Comment

Various features of GestAnnot's user interface are summarized in the Table 3.2.

#	Feature	How the feature is invoked?	Section for description
1	Anchor Annotation Tools: Highlight, Underline, Squiggly, Strike-Through	Single-Tap Gesture	3.1.3.1
2	Comment Annotation	Double-Tap Gesture	3.1.3.2
3	Arrow Annotation	Press, Tap and Drag Gesture	3.1.3.3
4	Switching to Freehand mode	Three-Finger Tap Gesture	3.1.3.4
5	Switching between four Anchor Annotation Tools (Highlight, Underline, Squiggly, Strike-Through)	Four-Finger Tap and Five-Finger Tap Gesture	3.1.3.5
6	Comment to Sticky Note and vice versa	Pop-Up Menu	3.1.3.6
7	Editing Annotations	Pop-Up Menu	3.1.2.4

8	Zoom-in, Zoom-out	Pinch Gesture	3.1.3.7
9	Turning Pages	Flick Gesture	3.1.3.7

Table 3.2: GestAnnot's Features and their use

3.2 Implementation of GestAnnot

GestAnnot is implemented using PDFTron Mobile PDF SDK [22], which provides Java APIs for viewing, creating, searching, annotating and editing capabilities with the PDF document [22]. GestAnnot is developed for tablets with Android[6] operating system. It can be used on any tablet having Android version 3.0 or higher. Typically, the tablets' size varies from 7 to 10.1 inches. For better annotation experience 10.1-inch tablet is recommended because it shows the text in bigger size, making the selection of text easier with fingers.

3.2.1 Implementation Challenges

Although, PDFTron SDK facilitates various APIs to customize annotations but many implementation related challenges were needed to overcome to provide a satisfactory annotation interface. These challenges are described in the Section 3.2.1.1, 3.2.1.2 and 3.2.1.3.

3.2.1.1 Event Handling of Multi-Touch Gestures

The first challenge arises from the event handling techniques for multi-touch gestures. In Android operating system, when user touches the screen with more than one finger, it fires "down" event for each finger and then it fires "up" event upon release of each finger. Consequently, it causes a problem if the annotation operations respond to "down" events.

[6] http://www.android.com/

For an instance, consider a scenario in which freehand tool is activated when "down" event for third finger occurs and anchor annotation tool switches when the "down" event occurs for fifth finger. In this case, when user taps with five-fingers, GestAnnot will activate the freehand tool as soon as third finger touches the screen followed by switching of anchor tool when fifth finger touches it. Therefore, system will consider five-finger tap as three-finger followed by five-finger tap, which will cause ambiguities in annotation operations. To cope up with this problem, the annotation operations are made to respond to first 'up' event of finger and then ignore the subsequent 'up' events. For example, when user lifts a finger, the system reckons that other four fingers are still down, thus the annotation operation responds to 'up' event of fifth finger and then ignore the subsequent 'up' events of other four fingers. In this way, we resolved the event-handling problem with multi-touch.

3.2.1.2 Overlapping Annotations

Each annotation in GestAnnot has its own bounding box. As shown in Figure 3.17, the bounding box extends between the extreme ends of an annotation and tapping at any point within this box selects the annotation, thus bringing the pop-up menu with editing options.

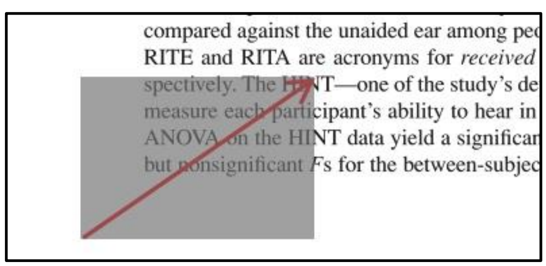


Figure 3.17: Bounding Box of an Arrow annotation

A "selection-problem" arises when two or more bounding boxes overlap. For an instance, consider a scenario of Figure 3.18, in which bounding box of a highlight, arrow and freehand annotation partially overlaps on each other.

The question is, which annotation is selected when user taps on overlapping boxes? For example, if user taps on Point 6 in Figure 3.18(c), it may result in selection of arrow or the freehand annotation or the selection of underlying text for initiating anchor annotation. To handle such situations we have developed design rules (DR) (see Table 3.1) on the basis of which we have designed GestAnnot. For instance, DR 1 considers the scenario in which the bounding box of a freehand annotation and the highlight annotation overlap, as shown in Figure 3.18(a), and the user taps on the highlight annotation to select it. In this case, GestAnnot should select highlight instead of freehand although they both are overlapping. Similar design rules have been made to ensure the selection of appropriate annotation when they overlap with each other or with the original text.

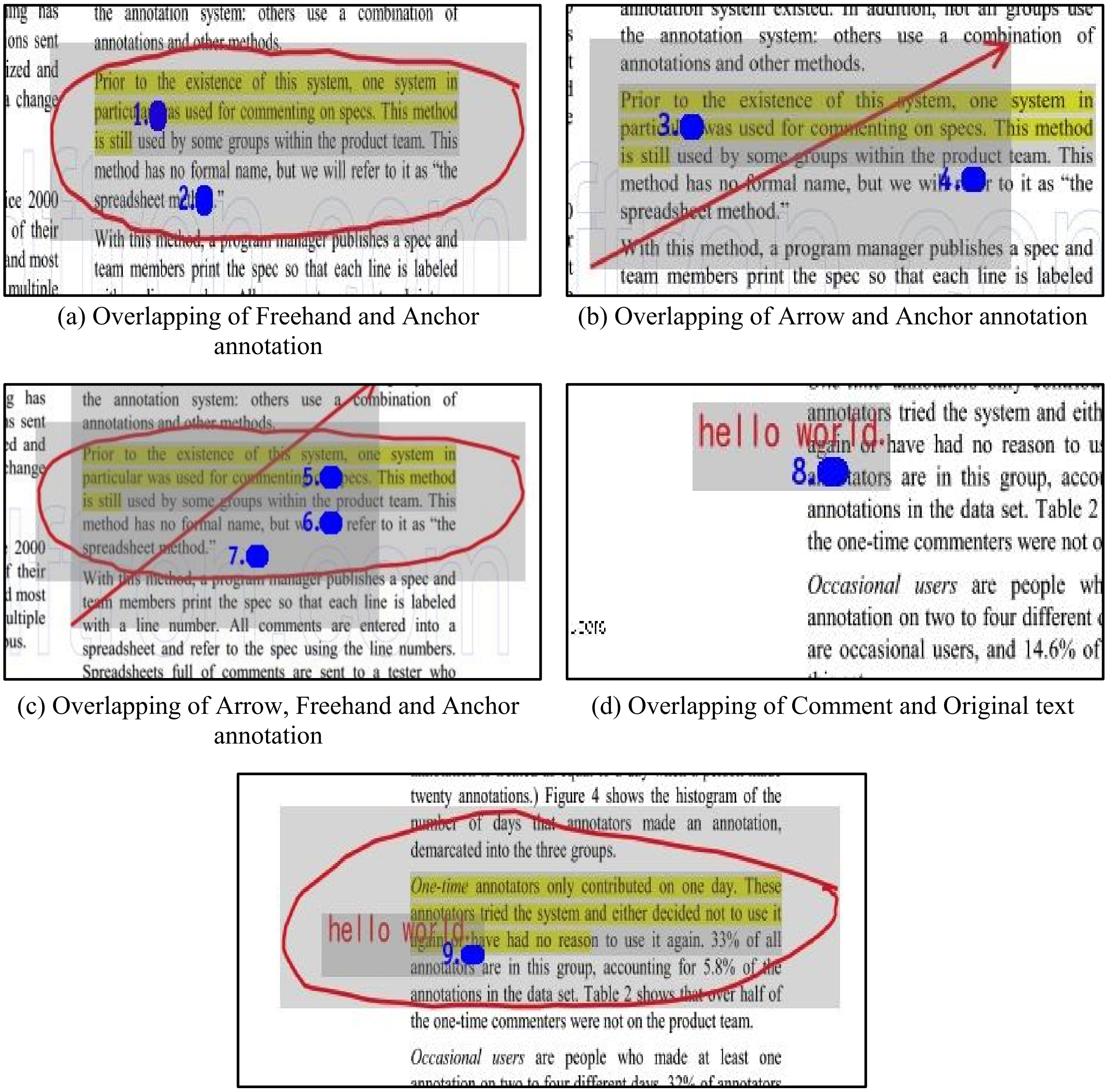
DR#	Overlapping Annotations/Text	Selected Annotation/Text	Example
1.	Anchor and Freehand	Anchor	Point 1 in Figure 3.18(a)
2.	Anchor and Arrow	Anchor	Point 3 in Figure 3.18(b)
3.	Anchor, Arrow and Freehand	Anchor	Point 5 in Figure 3.18(c)
4.	Freehand and Original Text	Original Text	Point 2 in Figure 3.18(a)
5.	Arrow and Original Text	Original Text	Point 4 in Figure 3.18(b)
6.	Arrow, Freehand and Original Text	Original Text	Point 6 in Figure 3.18(c)
7.	Comment and any other annotation(s)	Comment	Point 9 in Figure 3.18(e)

DR#	Overlapping Annotations/Text	Selected Annotation/Text	Example
8.	Comment and Original Text	Comment	Point 8 in Figure 3.18(d)
9.	Arrow and Freehand	Which is created later than other	Point 7 in Figure 3.18(c)

Table 3.3: Design Rules for overlapping annotations

3.2.1.3 Ambiguity in Freehand Annotations

When freehand strokes are made, a question arises: What should be considered as a single freehand annotation? An ink stroke made without lifting the finger can be considered as one annotation or every ink stroke made between freehand tool activation and de-activation can be treated as one annotation. In GestAnnot, we adopted the first approach because the second approach might be less suitable for some tasks. For example, if user draws two checkmarks and want to change the color of one of them, it will not be possible if we have used second approach because system would have considered both checkmarks as one annotation. However, there are some issues with the first approach too. For an instance, if user draws an asterisk using three lines (lifting finger after drawing each line), our system will consider it as three different annotations. This is the major limitation with this approach and to avoid this, some advanced techniques can be considered in future research such as combining the strokes based on their temporal order or their spatial position. These techniques are complex in terms of their implementation but they will produce better results.



(a) Overlapping of Freehand and Anchor annotation

(b) Overlapping of Arrow and Anchor annotation

(c) Overlapping of Arrow, Freehand and Anchor annotation

(d) Overlapping of Comment and Original text

(e) Overlapping of Comment, Anchor and Freehand annotation

Figure 3.18: Overlapping bounding boxes of annotations

3.3 Summary

In this chapter, we have presented the interaction design of the GestAnnot application that supports wide range of annotation activities. Given the benefits of gestures techniques, we have incorporated them in the design considering their usability and suitability to annotation tasks. GestAnnot is intended to provide more efficiency and better user experience than the existing applications and is evaluated through user studies discussed in next chapters.

CHAPTER 4 LAB EVALUATION OF GestAnnot

GestAnnot's design is based upon the premise that multi-touch gestures techniques might improve the efficiency of annotation activity, thereby reducing the cognitive load during active reading and providing a better user experience than existing menu-based applications. To evaluate the initial design, we conducted a user study that compared GestAnnot with an existing application that uses menu-based interactions only. The results of this study helped us to understand the impact of gestures techniques and other features of GestAnnot on the user experience. Moreover, the comparative analysis of the participants' feedback on gesture-based and menu-based applications helped to evaluate the relative effectiveness and the users' preferences for different aspects of these applications. This chapter describes the design of the study (Section 4.3) and its results (Sections 4.4 and 4.5) followed by the discussion and implications of the results (Sections 4.6, 4.7 and 4.8).

4.1 Research Objectives

Through the design and development of GestAnnot, we attempted to provide a better solution than existing menu-based applications. We have used gesture techniques to reduce the number of steps required to create various types of annotations in menu-based applications without compromising the ease-of-use as that in simple menu-based interactions. However, we did not know whether users would prefer using gesture-based design as in GestAnnot to the menu-based annotation application. Therefore, we needed to compare GestAnnot with one of the best available annotation application to understand whether users would prefer to use gesture-based annotation tools. We were also interested in knowing if the gesture-techniques used in GestAnnot are easy to use and easy to learn.

We also wanted to understand whether the design rules developed for the selection of overlapped annotation (see Section 3.2.1.2) have improved the selection task of overlapping annotations. One of the major objective of our research was to provide a set of general and specific guidelines, which could be followed in the future designs of annotation applications. In short, the research objectives in evaluating the GestAnnot against a menu-based application in lab include:

1. To provide a support to our claim that GestAnnot allows users to use various annotation tools in lesser number of steps than menu-based application.
2. To understand whether gesture-techniques used in GestAnnot are preferred over menu-based interactions.
3. To determine whether the gesture set used in GestAnnot is easy to use and easy to learn.
4. To evaluate the design rules developed for the selection of overlapped annotations.
5. To provide guidelines that can be followed in the design of future annotation applications.

4.2 Research Hypotheses

To achieve the above stated objectives, we considered following hypotheses:

1. GestAnnot allows users to create different types of annotations in lesser number of steps than menu-based application.
2. The gesture-techniques used in GestAnnot are easy to use and easy to learn.
3. The participants would prefer gesture-based annotation application to menu-based application.

4. The design rules for selecting overlapped annotations allow users to select any annotation among various overlapped annotations.

4.3 Study Design

Our goal behind this study is to get feedback on GestAnnot's initial design and to compare various features of its gesture-based design with a menu-based application. We wanted to observe how participants use different gestures and how it affects their annotation activity. The results of this study helped us to provide support to our hypothesis that GestAnnot provide an efficient and effective way to annotate e-document than one of the best available annotation application. To achieve this, we decided to conduct a lab study, in which participants would perform some annotation tasks using GestAnnot and a menu-based application (ezPDF Reader) and then give their feedback for both of these applications. For the purpose of comparison with GestAnnot, we have chosen ezPDF Reader application and the reasons for this choice are discussed in Section 4.3.1. The study task, study protocol, participants, study population and recruitment, and data collection are discussed in the Sections 4.3.2 through 4.3.6.

4.3.1 Why ezPDF Reader for Comparison?

We were needed to choose a menu-based annotation application for comparison with GestAnnot. It was important that it should have some of the annotation features as GestAnnot. There are four high-rated applications in the Google Play[7] store (Android application market): Adobe Reader (Ver. 10.6.1)[8], Repligo Reader (Ver. 4.0.3) [53],

[7] https://play.google.com/store
[8] https://play.google.com/store/apps/details?id=com.adobe.reader

iAnnotate PDF[9] (Ver. 1.1.4) and ezPDF Reader (Ver. 1.8.1.0) [52]. Adobe Reader has all the annotation tools of GestAnnot except for the squiggly and arrow tools that are provided in the toolbar menu at the top of the screen. Although it offers various annotation tools, it has some issues; first, selection of the text is a little slow. Second, it does not show loupe while highlighting; therefore, it is difficult to see the word that is being selected because it is hidden under the user's finger. *Loupe* is a box that displays the magnified text lying under the user's finger.

In addition to GestAnnot's tools, Repligo Reader provides a straight line, arrow, rectangle and ellipse tool but it does not have the squiggly tool. This application's response time is faster than Adobe Reader, but it has some usability problems: First, when the user taps on the screen, the toolbar disappears and to bring it back, the user has to tap again on the screen. This adds an extra step in the creation of annotations because whenever the user wishes to use some tool, he needs to tap on the screen to make the toolbar visible. Second, when users draw any annotation it asks them to press the "done" button to finish it, which adds one more step. Third, when the user taps on the annotation, it shows the edit option in a menu-bar that appears at the top edge of the screen. This forces users to navigate to the top of the screen to select the editing options for their annotations.

iAnnotate Reader offers highlight, underline, strike-through, sticky notes and freehand tools, but it does not have a comment and arrow tool. Another issue with this application is that users have to press a "done" button at the top menu bar to complete each annotation, which adds an extra step in the process.

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[9] https://play.google.com/store/apps/details?id=com.branchfire.iannotate

ezPDF Reader that offers all the tools of GestAnnot except squiggly. In addition, it offers line, arrow, rectangle, and ellipse tool in the toolbar menu that appears along the top edge of the screen. An annotation can be edited from the various options provided in the pop-up menu, which appears when users tap on the annotation. The response time for all annotation operations is very fast. Unlike Repligo Reader, it shows a loupe while selecting the text that shows the word hidden under the user's finger while selecting the text. Furthermore, it has an auto-save feature and an option to export the annotations to a text document. The number of steps involved in creating annotations is fewer than in Repligo and iAnnotate Reader. Considering these features, ezPDF is the best choice among all four applications considered. Therefore, we have chosen ezPDF as the menu based annotation application for comparing it with GestAnnot.

4.3.2 Study Task

The study employed a within-subjects design with one factor: the annotation application. Participants performed the task using each of the two applications giving two conditions in total. Due to the within-subjects design, we anticipated an exposure effect on user preference, which was minimized through counterbalancing the conditions using a 2×2 Latin Square method.

The choice of the task was challenging for this study because annotation is a subjective and idiosyncratic activity and the way of annotating differs among different users. We first thought of using a comprehension exercise in which participant would read the passage and answer some questions based on it. However, this task did not ensure that participant would use all the annotation features or even use them at all. For example, a participant might only use the highlighter, or not use any annotation during the task. Therefore, we have chosen a simple task of replicating the annotations from an article on a paper form to the electronic form.

The task consisted of an annotation exercise in which, the participants were required to replicate a given set of annotations from an article in the paper form to the electronic form using each of the two applications. We created these annotations to maximize the use of the annotation features provided in both applications. These annotations ensured the usage of highlight, underline, freehand, comment and arrow tools along with their different colors. In order to reduce the learning effect originating from a single document, we have used two different documents that are similar in style. The number and type of annotations were made similar on both documents to reduce the potential bias. Although the order of applications (conditions) was switched according to 2×2 Latin Square, the order of two documents was kept the same (Document 1 followed by Document 2).

4.3.3 Study Protocol

Each study session was divided into two parts: one for GestAnnot and another for ezPDF reader. At the beginning of the session, participants signed a consent form. Afterwards, the researcher demonstrated the first application to be used (depending upon the condition ordering) and then asked the participant to perform the demonstrated operations himself/herself before attempting the task. After this training session (lasting approximately 2 minutes for each application), participants were provided with the task and asked to complete it using the application. While participants were performing the task, the researcher took notes of any interesting behavior observed. After the completion of the task, participants were asked to fill out a post-condition questionnaire (Appendix A) to rate the application and to give their feedback. This was followed by a discussion to elicit explanation and reflection about interesting behaviors that were noted during the experiment. After the completion of the first part, participants were asked to perform the same sequence of activities using other application and other document for the task.

For the purpose of this experiment, we used a 10.1-inch Samsung Galaxy Tab 2[10] tablet for GestAnnot and ezPDF reader.

4.3.4 Data Collection

The data was collected in the form of post activity questionnaire (Appendix A) and informal notes taken during the task and the interviews. All sessions with participants were audio recorded, which were later used to clarify notes and to obtain interesting quotes. The post-activity questionnaire was consisted of two sections. The first section asked users to rate different features of the application on a 7-point rating scale and the second section consisted of background questions and open-ended questions regarding their experience with the application. The rating questions were taken from the licensed QUIS (version 7.0) questionnaire [75].

4.3.5 Study Population and Recruitment Procedures

For the study, the targeted population was Dalhousie University student, faculty, and staff members. This population contains a broad cross section of the general community including both expert and non-expert users. The inclusion criteria for recruitment were that the participant must have some experience with annotating documents on either paper or some other media, and they must have used a smartphone, tablet, or comparable mobile

[10] http://www.samsung.com/ca/consumer/mobile/mobile-phones/tablets/GT-P5113TSAXAC

device. We asked potential participants via e-mail announcements through e-mail lists (e.g. departmental e-mail lists that include students, faculty, and staff) and online bulletin boards, to express their interest for participating in the study. The interested participants were asked through e-mail correspondence, what type of active reading tasks they perform and if they have experience with using touch screen devices to make sure that they met the inclusion criteria.

4.3.6 Participants

We recruited 18 participants, which will be referred by IDs (P1 to P18) throughout this chapter. We believed that the size of the sample would be sufficient to obtain initial design feedback and to alert us to issues and desired functionality that we had not yet considered. 17 participants were students from various departments of Dalhousie University and 1 participant was a staff member.

4.4 RESULTS

This section reports the results of the user study in two sections. In the first section (4.4.1), we discussed participants' responses to the background questions asked in the post-activity questionnaire (Appendix A). The second section (4.4.2) describes the quantitative analysis of the rating questions and indicates the significant and non-significant differences between certain aspects of GestAnnot and ezPDF. Furthermore, the section 4.5 elaborates the participants' feedback given through questionnaire and post-activity discussion.

4.4.1 Background Questions

The background questions in the post-activity questionnaire (Appendix A) asked the participants about how often they perform active reading and what application they use for it. As shown in Figure 4.1, out of 18 participants, 9 indicated that they perform active reading tasks very frequently (many time a week) while 7 participants specified that they frequently (few times a week) perform such tasks. The remaining 2 participants indicated that they do active reading occasionally (few times a month) and very rarely.

Furthermore, 9 out of 18 participants reported that they use Adobe Reader for reading and annotating documents while 7 mentioned that they usually perform active reading on paper. Some participants mentioned other tablet and PC applications, as shown in Figure 4.2 and Table 4.1. This implies that the recruited participants were a mix of those users who do active reading tasks on only paper and those who use some software to do it.

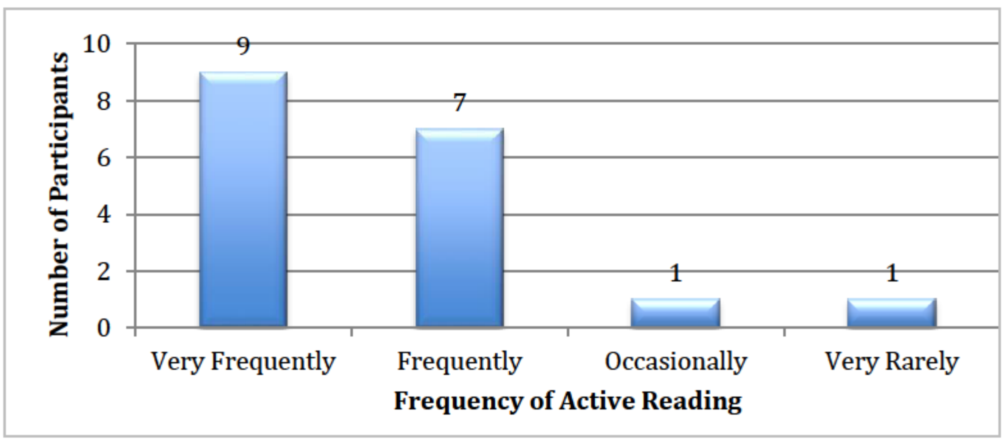


Figure 4.1: How often do participants perform active reading?

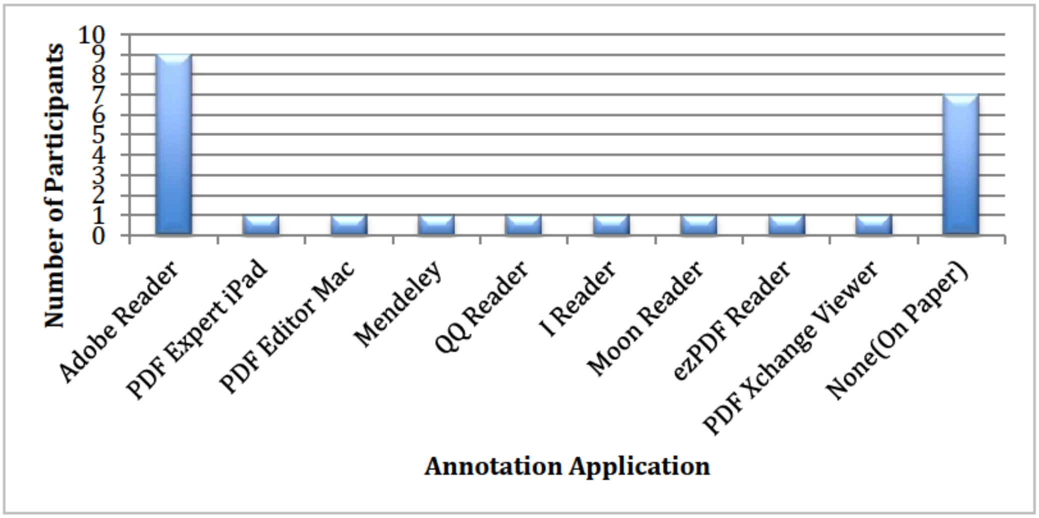


Figure 4.2: Applications used by participants for active reading

Participant ID	Applications Used by Participants for Active Reading	Frequency of Use
P1	Adobe Reader	Very Frequently
P2	Adobe Reader	Very Rarely
P3	PDF Expert iPad, Adobe Reader	Very Frequently
P4	Adobe Reader	Very Frequently
P5	None (only on paper)	Very Frequently
P6	None (only on paper)	Frequently
P7	None (only on paper)	Very Frequently
P8	PDF Editor Mac	Very Frequently
P9	Mendeley, Adobe Reader	Very Frequently
P10	Adobe Reader, QQ Reader, I Reader	Frequently
P11	None (only on paper)	Occasionally
P12	None (only on paper)	Frequently
P13	Moon Reader, Adobe Reader	Frequently
P14	None (only on paper)	Frequently
P15	ezPDF Reader	Very Frequently
P16	Adobe Reader	Frequently

P17	None (only on paper)	Very Frequently
P18	Adobe Reader, PDF X-Viewer	Frequently

Table 4.1: Participants' Characteristics

4.4.2 User Interaction Satisfaction Ratings

The first section of the questionnaire consists of 25 questions (taken from QUIS 7.0 [75]), which measures users' overall satisfaction with various aspects of the interface on a 7-point scale. These aspects include screen factors, learning factors, system capabilities, and terminology and system feedback. These questions were identical for both applications.

We applied Wilcoxon Signed Rank test (Asymptotic 2-tailed) for comparative analysis of participants' ratings for GestAnnot and ezPDF reader. For a particular question, this test was applied for 18 matched pairs (because 18 participants) to determine whether there was a significant difference between the mean ranks of these applications. The significant level chosen for this analysis is 0.05. The analysis of all the questionnaires' rating questions is given below.

1. Overall Reactions to the System

The first group of questions asked participants to provide their overall reaction to the system across 5 dimensions: a) 1=Terrible, 7=Wonderful, b) 1=Frustrating, 7=Satisfying, c) 1=Dull, 7=Stimulating, d) 1=Difficult, 7=Easy, and e) 1=Rigid, 7=Flexible.

(a) 1=Terrible, 7=Wonderful

As shown in Figure 4.3, 13 participants gave a rating of 6 or above to GestAnnot while 5 participants graded the ezPDF with ratings of 6 or above, with regard to overall reactions to the system (1=Terrible, 7=Wonderful). The results indicate that there was a significant difference in how participants rated the two applications, $z= 2.04$, $p=0.04$.The analysis suggests that the participants rated the "overall reactions" to GestAnnot as more "wonderful" (Median=6) than that of ezPDF (Median=5).

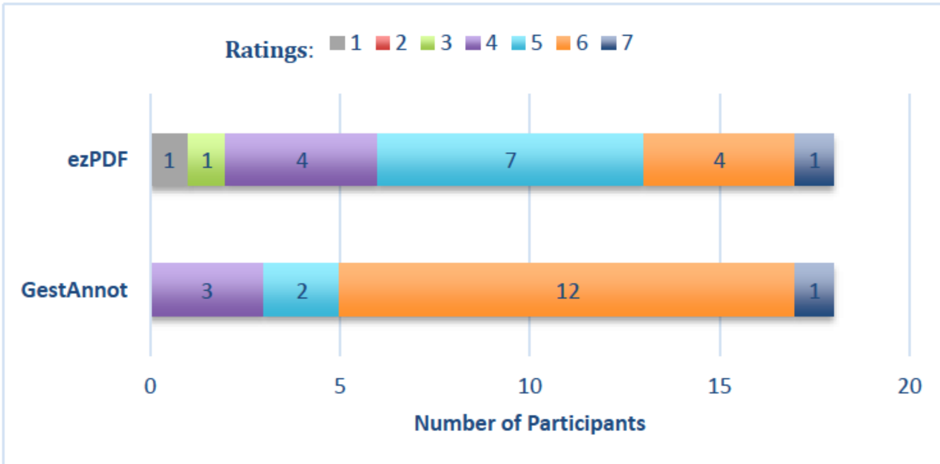


Figure 4.3: Overall Reactions to the System (1=Terrible, 7=Wonderful)

(b) 1=Frustrating, 7=Satisfying

GestAnnot received a rating of 6 or above from 11 participants; on the other hand, ezPDF received ratings of 6 or above from 2 participants with respect to the overall satisfaction of the application. The results suggest that there was a significant difference between the ratings of both applications, z=2.85, p=0.004. The analysis suggests that participants rated the "overall reactions" to GestAnnot (Median=6) as more "satisfying" than that that of ezPDF (Median=5). Figure 4.4 shows the distribution of participants' responses for this question.

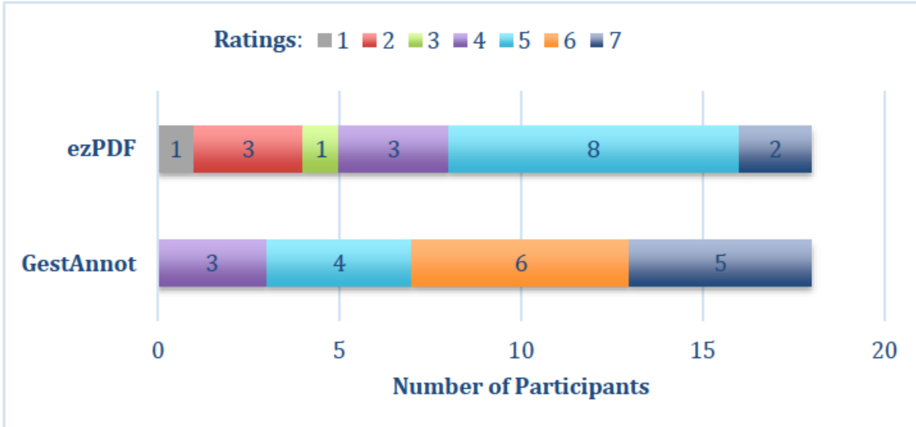


Figure 4.4: Overall Reactions to the System (1=Frustrating, 7=Satisfying)

(c) 1=Dull, 7=Stimulating

As shown in Figure 4.5, 13 participants assigned 6 or above ratings to GestAnnot while 3 participants gave these ratings to ezPDF. Moreover, 13 participants assigned 4 and 5 ratings to ezPDF. The results reflects that participants found GestAnnot (Median=6) significantly more "stimulating" than ezPDF (Median=5), z=3.00, p=0.003.

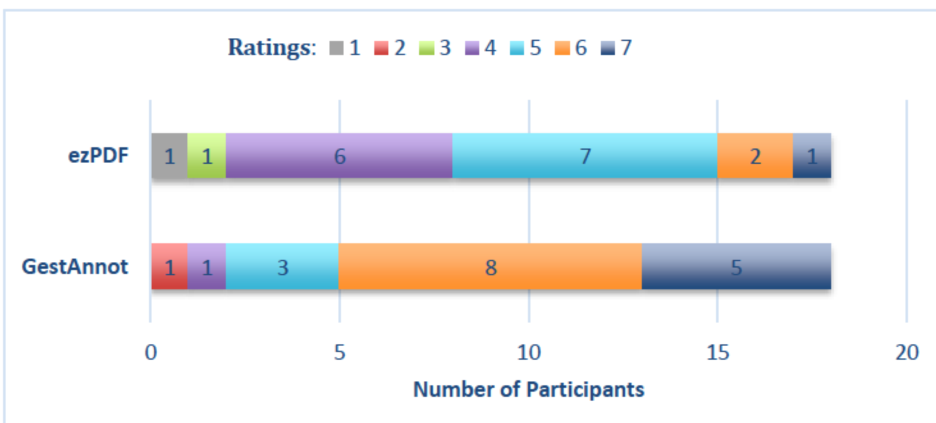


Figure 4.5: Overall Reactions to the System (1=Dull, 7=Stimulating)

(d) 1=Difficult, 7=Easy

As shown in Figure 4.6, 11 participants assigned 6 or above ratings to the ease-of-use aspect of GestAnnot whereas ezPDF received these ratings from 6 participants. The result shows that the difference between the ranking of GestAnnot (Median=6) and ezPDF

(Median=5) is not significant, z=1.91, p=0.056 for the overall ease of use. We expected that the gesture techniques used in GestAnnot would make it difficult to use than ezPDF, but the participants' ratings suggest that they found GestAnnot as easy as ezPDF.

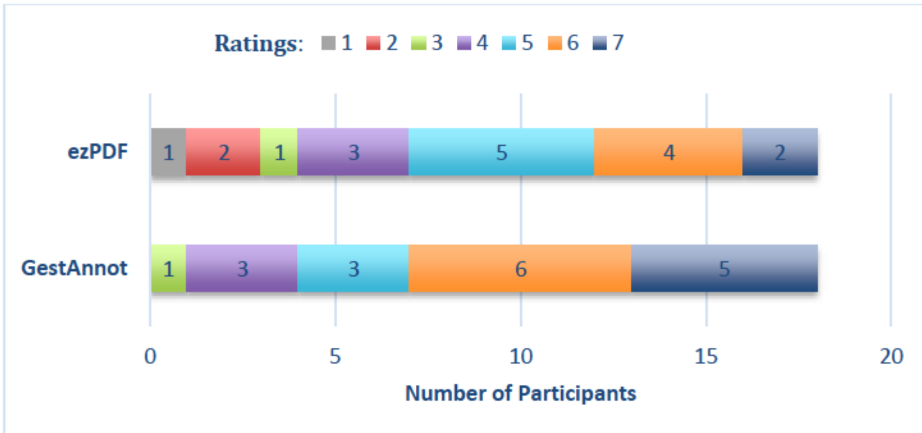


Figure 4.6: Overall Reactions to the System (1=Difficult, 7=Easy)

(e) 1=Rigid, 7=Flexible

10 participants gave ratings of 6 or above to GestAnnot while 5 participants assigned these ratings to ezPDF in terms of how flexible are these applications to use. 7 participants gave 4 and 5 ratings to GestAnnot whereas 11 participants assigned these ratings to ezPDF. The results of the analysis indicate that there is a significant difference in how participants rated the flexibility of applications, z=2.50, p=0.012. The results suggest that participants found GestAnnot (Median=6) more "flexible" than ezPDF (Median=4). The distribution of participants' responses is shown in Figure 4.7.

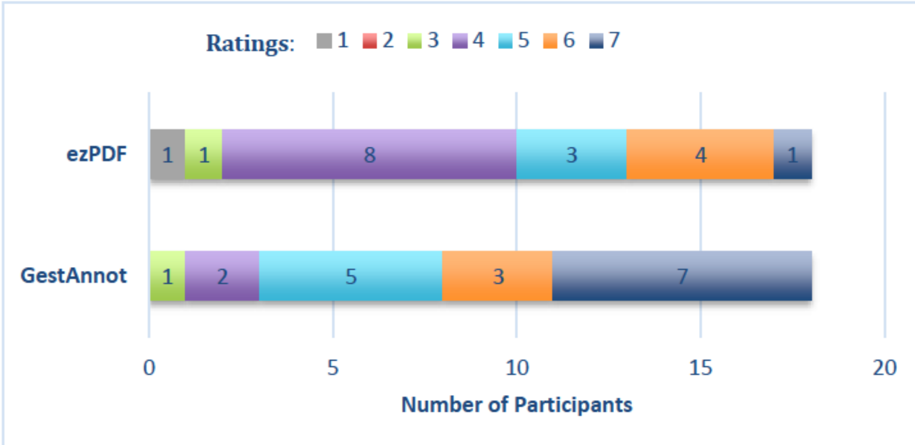


Figure 4.7: Overall Reactions to the System (1=Rigid, 7=Flexible)

Q#	Question	GestAnnot		ezPDF		Statistics	
		Mean	Median	Mean	Median	z-value	p-value
1	Overall Reaction: 1=Terrible, 7=Wonderful	5.61	6.00	4.78	5.00	2.037	**0.042***
2	Overall Reaction: 1=Frustrating, 7=Satisfying	5.72	6.00	4.22	5.00	2.850	**0.004***
3	Overall Reaction: 1=Dull, 7=Stimulating	5.78	6.00	4.56	5.00	3.002	**0.003***
4	Overall Reaction: 1=Difficult, 7=Easy	5.61	6.00	4.61	5.00	1.910	0.056
5	Overall Reaction: 1=Rigid, 7=Flexible	5.72	6.00	4.56	4.00	2.504	**0.012***

Table 4.2: Results for questions related to overall reactions toward the applications.

***Statistically Significant**

2. Learning to operate the system (1=Difficult, 7=Easy)

We expected that it would be relatively difficult to learn GestAnnot's interaction techniques than ezPDF due to the time that might be involved in learning the gestures. Surprisingly, the results did not comply with our assumption. As shown in Figure 4.8, 13 participants assigned 6 or above ratings to GestAnnot in regard to how easy it is to learn the application whereas 11 participants gave these ratings to ezPDF application. The results' analysis does not show a significant difference between the ratings of both applications (z=0.185, p=0.853), which suggests that most of the participants found GestAnnot (Median=6) and ezPDF (Median=6) almost equally easy to learn.

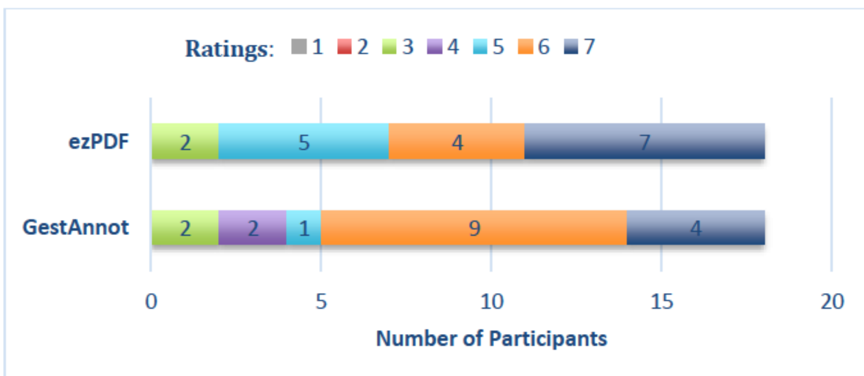


Figure 4.8: Learning to operate the system (1=Difficult, 7=Easy)

3. Exploration of the features by trial and error (1=Discouraging, 7=Encouraging)

We presumed that the exploration of features by trial and error would be less encouraging with GestAnnot as it involves some uncommon gestures (four finger tap, etc.), which are less obvious than simple menu-based interactions in the beginning of the application usage. As described in Section 3.1.1, we provided icons for gestures next to their respective tool to help in recalling the appropriate gesture for different annotation tools. This might be reason why GestAnnot received higher ratings than ezPDF for this question, as shown in Figure 4.9. GestAnnot received the top rating from 8 participants whereas ezPDF did not get this rating from any participant. Eight participants assigned ratings of 6 to ezPDF while 6 participants gave this rating to GestAnnot. The results show that there is a significant difference between the ratings of these applications, z=2.423, p=0.015, which implies that participants found "Exploration of the features by trial and error" in GestAnnot (Median=6) more "encouraging" than in ezPDF (Median=5).

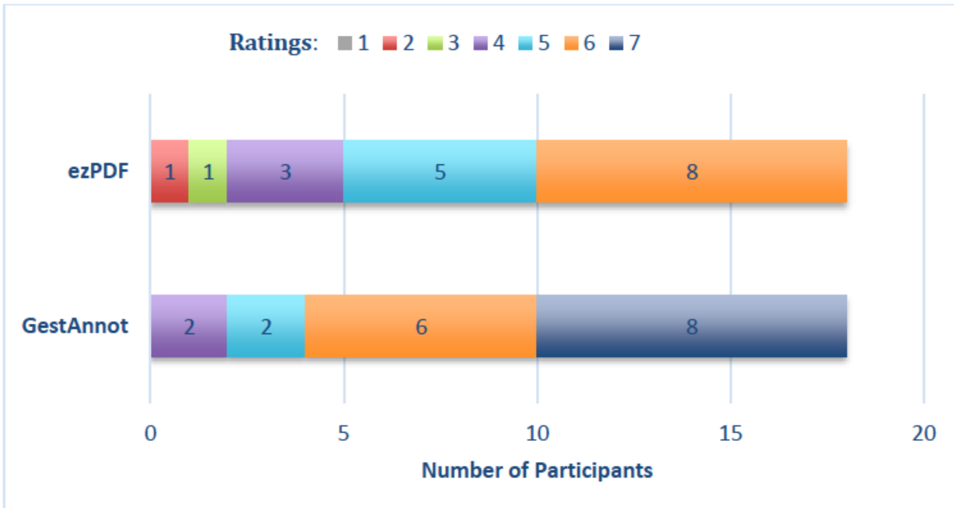


Figure 4.9: Exploration of the features by trial and error (1=Discouraging, 7=Encouraging)

4. Can tasks be performed in a straightforward manner? (1=Never, 7=Always)

Higher ratings for this question imply that most of the tasks can be performed in lesser number of steps. The distribution of participants' responses to this question is given in Figure 4.10. The results indicate that participants assigned significantly higher ratings to GestAnnot (Median=6) than ezPDF (Median=5), z=2.391, p=0.017. This suggests that participants rated "number of tasks" which can be perfomed in a straightforward manner higher in case of GestAnnot than ezPDF.

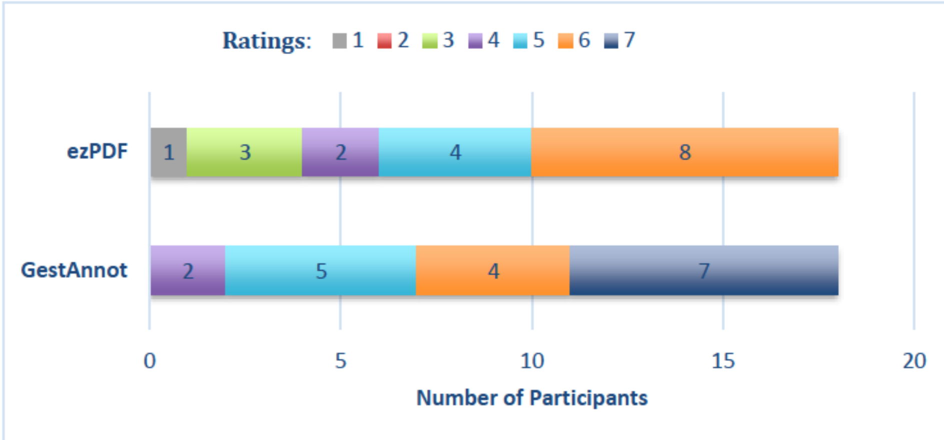


Figure 4.10: Can tasks be performed in a straightforward manner (1=Never, 7=Always)

5. Number of steps per task (1=Too Many, 7=Just Right)

The participants' ratings to this question are consistent with our hypothesis that gestures reduce a significant number of steps in creating annotations. As Figure 4.11 shows that 16 out of 18 participants assigned 6 or above ratings to GestAnnot whereas only 5 participants assigned these ratings to ezPDF.

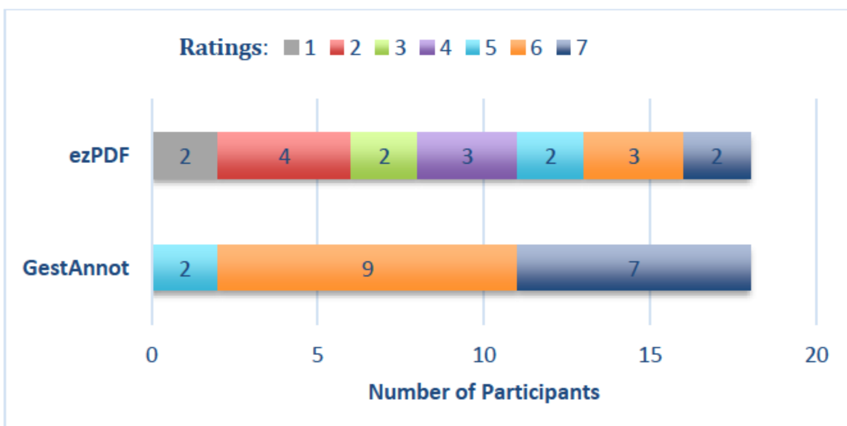


Figure 4.11: Number of steps per task (1=Too Many, 7=Just Right)

In addition, 11 participants assigned 4 or lesser ratings to ezPDF while no one gave these ratings to GestAnnot. The results show that there is a significant difference between the ranking of both applications, z=3.408, p=0.001 and participants found that the tasks can be performed in significantly lesser number of steps using GestAnnot (Median=6) than ezPDF

(Median=4).

6. Messages which appear on the screen

(a) 1=Inconsistent, 7=Consistent

In both applications, the pop-up message appears upon selecting or using an annotation tool in order to provide feedback to users about that particular operation. As shown in Figure 4.12, 16 participants assigned 6 or above ratings to GestAnnot while ezPDF received these ratings from 10 participants. The results suggest that participants rated GestAnnot (Median=7) significantly higher than ezPDF (Median=6) about the consistency of messages that appears on the screen, z=2.848, p=0.004.

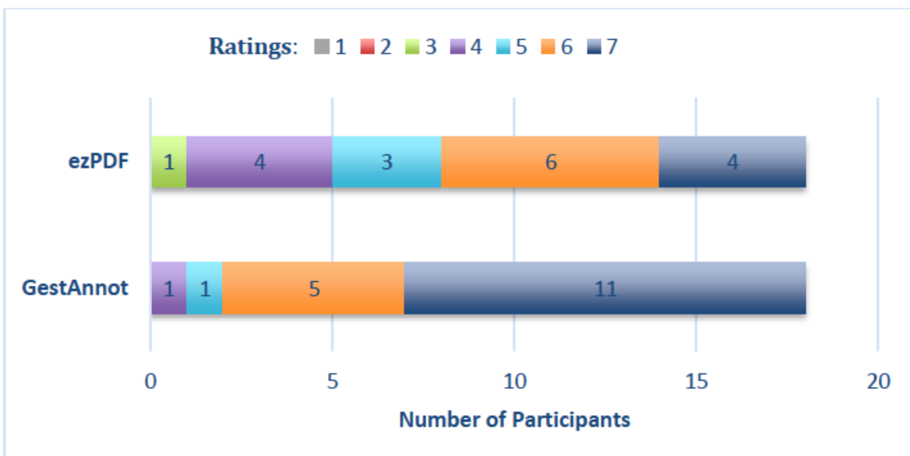


Figure 4.12: Messages which appear on the screen (1=Inconsistent, 7=Consistent)

(b) 1=Confusing, 7=Clear

This question reports the lucidity of the messages, which appears on the screen. The results indicate that the difference between the ratings of the applications is not significant, z=1.358, p=0.174. This suggests that the messages in both GestAnnot (Median=6) and ezPDF (Median=6) were clear enough to understand. The distribution of participants' responses is shown in Figure 4.13.

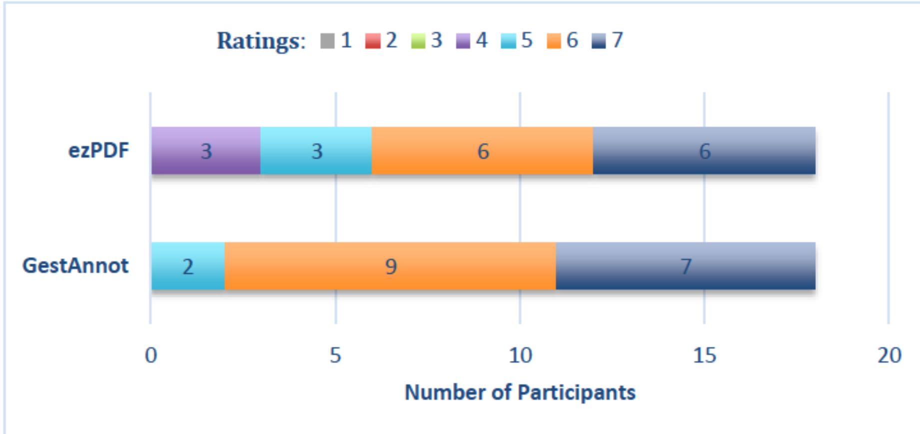


Figure 4.13: Messages which appear on the screen (1=Confusing, 7=Clear)

7. Correcting your mistakes/Ability to undo (1=Difficult, 7=Easy)

While creating annotations user can make some mistakes, such as the selection of wrong words/lines while highlighting or underlining the text, drawing unclear shapes and symbols with a freehand tool, mistyping comments, etc. As shown in Figure 4.14, most participants rated both applications with 5 or below ratings, which implies that they were not so satisfied with the undo ability of any of the two applications.

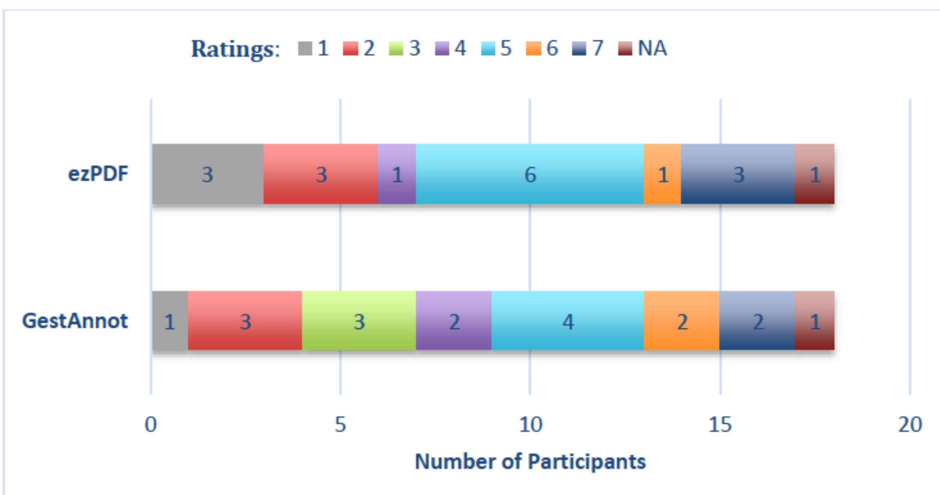


Figure 4.14: Correcting your mistakes/Ability to undo (1=Difficult, 7=Easy)

Although there was an option to delete the annotations in both applications but the undo option that could revert the users' interactions was absent. The results indicate the difference between the rankings of GestAnnot (Median=4) and ezPDF (Median=5) is not significant with regard to their ability to undo, z=0.106, p=0.915.

8. Does the system keep you informed about what it is doing? (1=Never, 7=Always)

The questions report the effectiveness of system's feedback to users about various operations such as, what tool is currently active, what should be the next step in a particular operation, etc. This might be achieved through pop-up messages on the screen to notify about operations, and highlighting the icons and options to provide the feedback of current active tool, etc. GestAnnot received 6 or above ratings from 15 participants while ezPDF received these ratings from 6 participants. The analysis indicates that the rankings received by GestAnnot (Median=7) are significantly higher than ezPDF (Median=4) with respect to their ability to provide the feedback about its various operations, z=2.849, p=0.004.

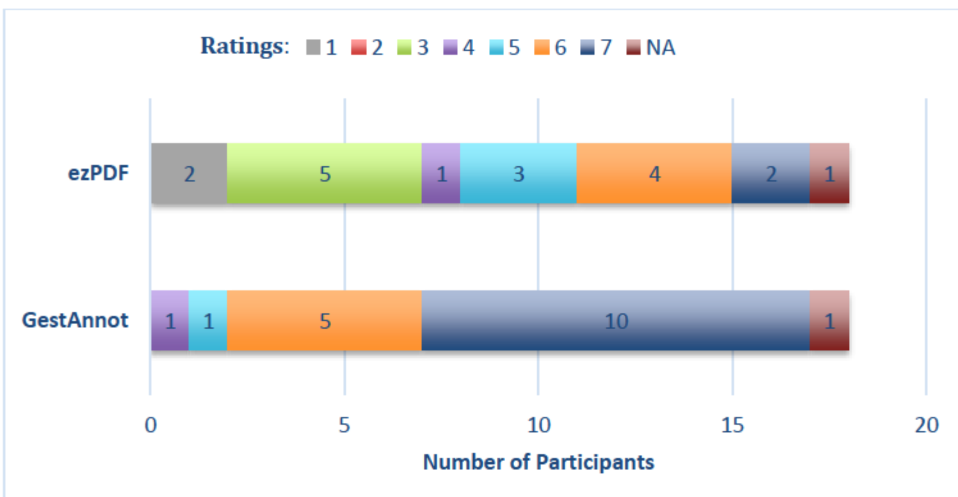


Figure 4.15:Does the system keep you informed about what it is doing (1=Never, 7=Always)

Q#	Question	GestAnnot		ezPDF		Statistics	
		Mean	Median	Mean	Median	z-value	p-value
1	Learning to operate the system (1=Difficult, 7=Easy)	5.61	6.00	5.78	6.00	0.185	0.853
2	Exploration of the features by trial and error (1=Discouraging, 7=Encouraging)	6.11	6.00	5.00	5.00	2.423	**0.015***
3	Can tasks be performed in a straightforward manner? (1=Never, 7=Always)	5.89	6.00	4.78	5.00	2.391	**0.017***
4	Number of steps per task (1=Too Many, 7=Just Right)	6.28	6.00	3.89	4.00	3.408	**0.001***
5	Messages which appear on the screen (1=Inconsistent, 7=Consistent)	6.44	7.00	5.44	6.00	2.848	**0.004***
6	Messages which appear on the screen (1=Confusing, 7=Clear)	6.28	6.00	5.83	6.00	1.358	0.174
7	Correcting your mistakes/Ability to undo (1=Difficult, 7=Easy)	3.89	4.00	3.89	5.00	0.106	0.915
8	Does the system keep you informed about what it is doing? (1=Never, 7=Always)	6.06	7.00	4.11	4.5	2.849	**0.004***

Table 4.3: Results for questions related to learning and system feedback.
***Statistically Significant**

9. Questions related to screen elements

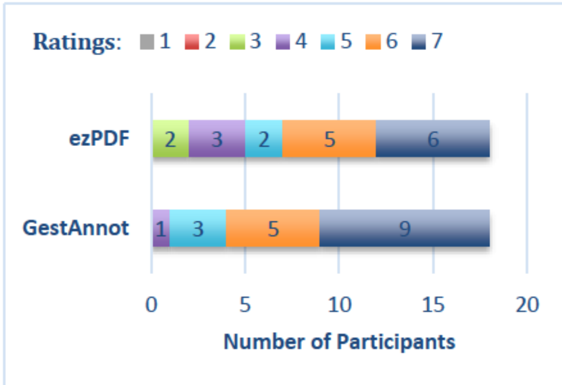
There were six question related to screen such as icons, layout, etc. These questions are listed along with the results of participants' responses and their analysis in Table 4.4. The distribution of participants' ratings is shown in Figure 4.16. The results suggest that participants found that characters on the screen were easy to read in both GestAnnot (Median=6.5) and ezPDF (Median=6), z=1.473, p=0.141. Moreover, results indicate that participants rated the "screen layouts" of GestAnnot (Median=6) as significantly more "helpful" than that of ezPDF (Median=5), z=2.970, p=0.003.

The results also suggest that participants found the arrangement of information significantly more logical in GestAnnot (Median=6) than that of ezPDF (Median=5.55), z=2.581, p=0.010. The results show that participants assigned significantly higher ratings to GestAnnot (Median=6) than ezPDF (Median=5), in terms of the lucidity of "sequence of screens", z=3.147, p=0.002.

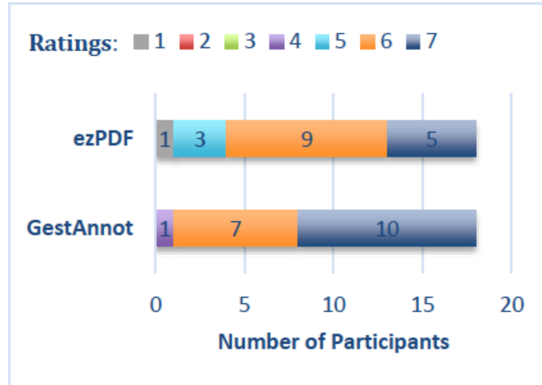
Q#	Question	GestAnnot		ezPDF		Statistics	
		Mean	Median	Mean	Median	z-value	p-value
1	Characters on the screen (1=Hard to Read, 7=Easy to Read)	6.22	6.50	5.56	6.00	1.473	0.141
2	Was the highlighting on screen helpful? (1=Not at all, 7=Very much)	6.44	7.00	5.83	6.00	1.809	0.070
3	Were the screen layouts helpful? (1=Never, 7=Always)	6.00	6.00	4.89	5.00	2.970	**0.003***
4	Amount of information that can be displayed on screen (1=Inadequate, 7=Adequate)	5.94	6.00	5.28	6.00	1.581	0.114
5	Arrangement of information (1=Illogical, 7=Logical)	6.22	6.00	5.44	5.55	2.581	**0.010***
6	Sequence of screens (1=Confusing, 7=Clear)	6.28	6.00	5.06	5.00	3.147	**0.002***

Table 4.4: Results for questions related to screen elements of systems.

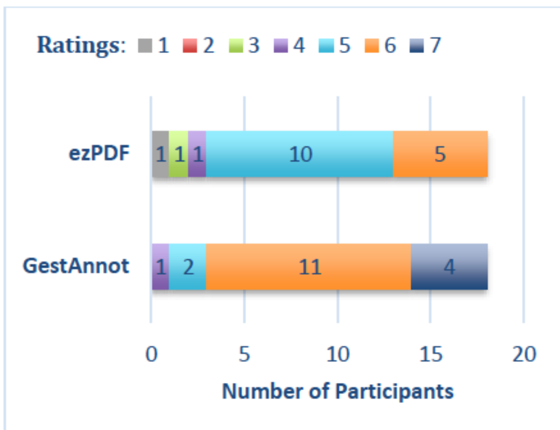
***Statistically Significant**



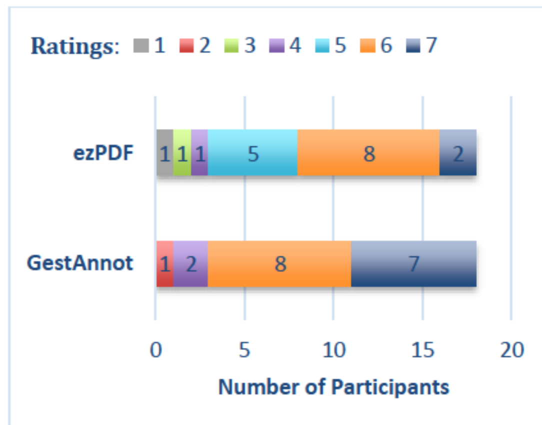
(a) Characters on the screen (1=Hard to Read, 7=Easy to Read).



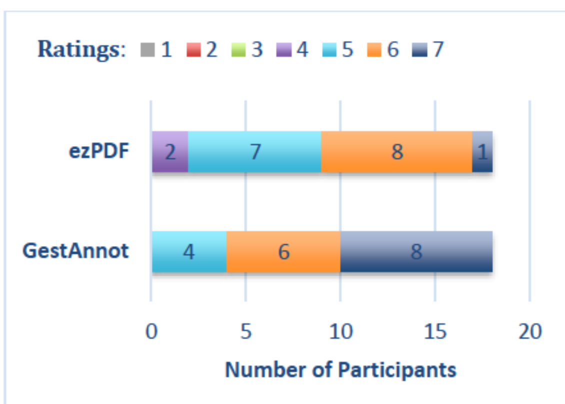
(b) Was the highlighting on the screen helpful? (1=Not at all, 7=Very much)



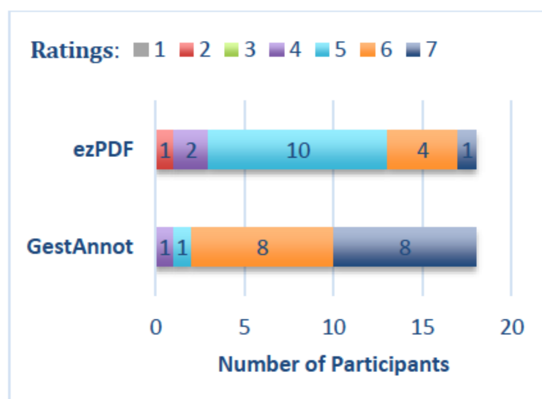
(c) Were the screen layouts helpful? (1=Never, 7=Always)



(d) Amount of information that can be displayed on screen (1=Inadequate, 7=Adequate)



(e) Arrangement of information (1=Illogical, 7=Logical)



(f) Sequence of screens (1=Confusing, 7=Clear)

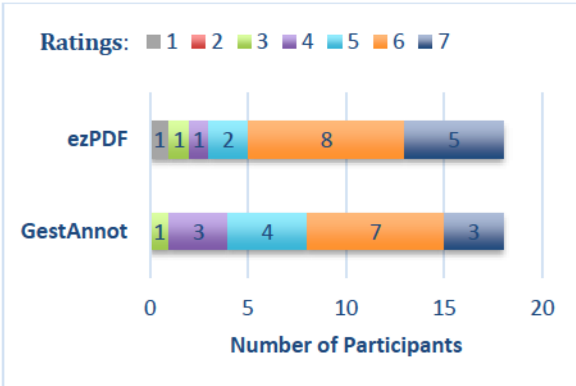
Figure 4.16: Participants' responses to the questions related to screen elements

10. Questions related to system capabilities

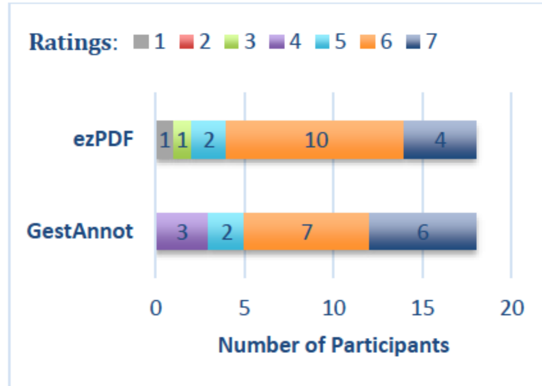
There were five questions related to system speed and its reliability in the questionnaire. These questions and the results of the participants' ratings are given in Table 4.5. The results suggest that there was no significant difference in the rankings of the applications for all five questions. The distribution of participants' responses is shown in Figure 4.17. We can notice from Table 4.4 that there is no significant difference between the ratings for questions related to system capabilities including "System Speed", "Response Time", "Rate of Information Display", "How reliable is the system" and "System Failures occurs". However, we can notice that GestAnnot received lesser ratings than ezPDF in terms of "System Failures" because it crashed few times with first five participants. However, we identified and corrected the programming error that caused this crash after the session with fifth participant.

Q#	Question	GestAnnot		ezPDF		Statistics	
		Mean	Median	Mean	Median	z-value	p-value
1	System speed (1=Too Slow, 7=Fast Enough)	5.44	6.00	5.61	6.00	0.357	0.721
2	Response time for most operations (1=Too Slow, 7=Fast Enough)	5.89	6.00	5.67	6.00	0.590	0.555
3	Rate of information display (1=Too Slow, 7=Fast Enough)	5.83	6.00	5.50	6.00	0.845	0.398
4	How reliable is the system (1=Unreliable, 7=Reliable)	5.94	6.00	5.56	6.00	0.669	0.503
5	System failures occur (1=Frequently, 7=Seldom)	5.11	5.00	6.00	6.00	1.784	0.074

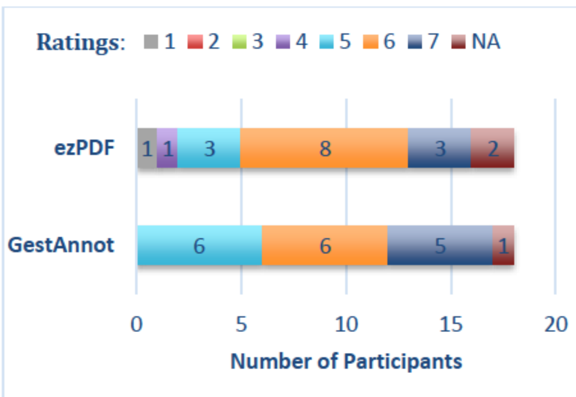
Table 4.5: Results for questions related to system capabilities



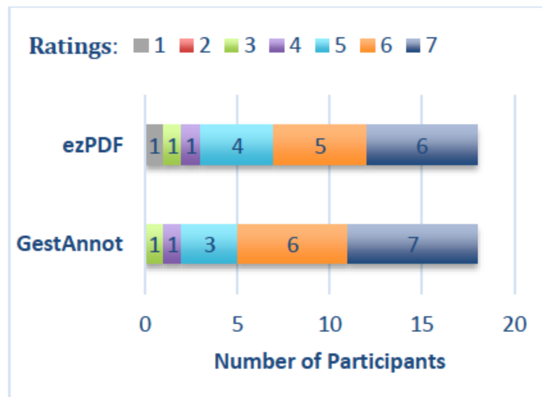
(a) System Speed (1=Too Slow, 7=Fast Enough).



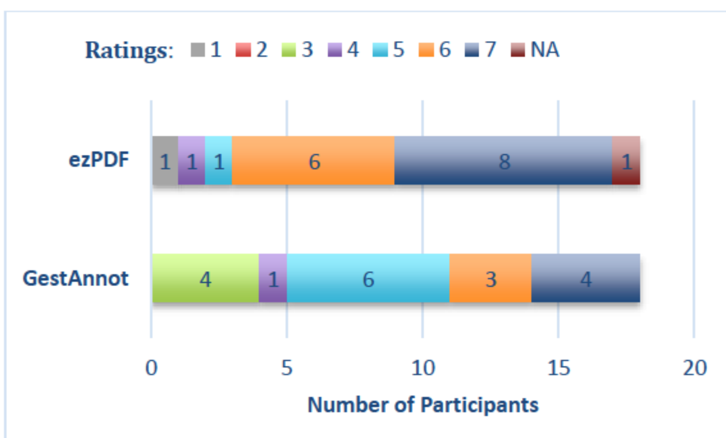
(b) Response time for most operations (1=Too Slow, 7=Fast Enough



(c) Rate of information display (1=Too Slow, 7=Fast Enough)



(d) How reliable is the system (1=Unreliable, 7=Reliable)



(e) System failures occur (1=Frequently, 7=Seldom)

Figure 4.17: Participants' responses to the questions related to system capabilities

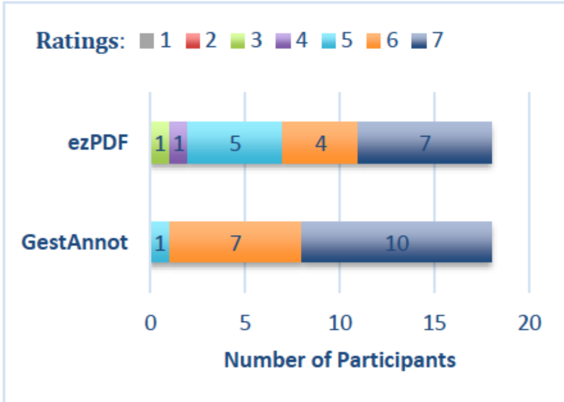
11. Terminologies used in the system

Two questions related to system terminologies are listed in Table 4.6, and the distribution of participants' responses is shown in Figure 4.18. The results suggest that there is a significant difference between how participants rated GestAnnot (Median=6.5) and ezPDF (Median=6) for "Use of the terms throughout the system (1=consistent, 7=consistent)", z=1.992, p=0.046. The results also suggest that there is a significant difference between the ratings of GestAnnot (Median=7) and ezPDF (Median=6) for "Does the terminology relate well to the work you are doing? (1=Unrelated, 7=Well Related)", z=3.270, p=0.001.

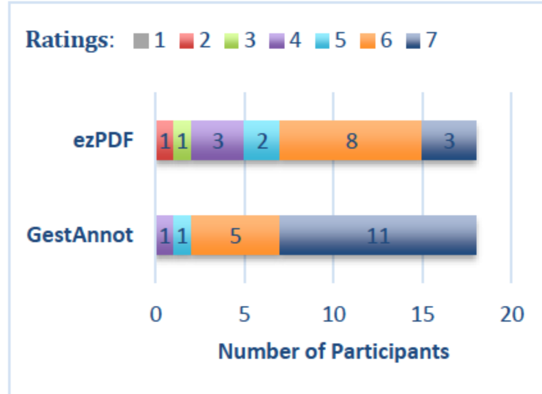
Q#	Question	GestAnnot		ezPDF		Statistics	
		Mean	Median	Mean	Median	z-value	p-value
1	Use of the terms throughout the system (1=Inconsistent, 7=Consistent)	6.50	7.00	5.83	6.00	1.992	**0.046***
2	Does the terminology relate well to the work you are doing? (1=Unrelated, 7=Well Related)	6.44	7.00	5.33	6.00	3.270	**0.001***

Table 4.6: Results for questions related to system capabilities

***Statistically significant**



(a) Use of the terms throughout the system (1=Inconsistent, 7=Consistent).



(b) Does the terminology relate well to the work you are doing? (1=Unrelated, 7=Well Related)

Figure 4.18: Participants' responses to the questions related to the terminologies used in the system

4.5 Participants' Comments and Our Observations

We conducted semi-structure interviews with each participant after the completion of the task on each of the two applications. In addition, we collected the participants' feedback through the open-ended questions asked in the second part of the questionnaires. The interview questions were related to their experience with the particular application such as, did they encounter problems while using that application, what features were more or less appealing to them, did they have any suggestions for enhancing the functionality and usability of the application, etc. Participants' responses to these questions are discussed in subsequent sections.

4.5.1 Freehand Annotation

When asked about the features that participants liked in the system, six participants (P1, P3, P4, P8, P17, and P18) mentioned that they liked freehand annotation tool, which is not present in the reading applications that they would use such as Adobe Reader. P8 stated in the GestAnnot's questionnaire, "The freehand part of the system is helpful in rounding off the text and to draw shapes." Moreover, one participant (P12) commented that she did not like the freehand tool.

One of the major differences between both applications is that there are inbuilt circle and rectangle tool in ezPDF whereas there are no such tools in GestAnnot, therefore, user will need to use the freehand tool to draw such shapes. The researcher observed that participants were struggling with the inbuilt shapes of ezPDF because it required them to reposition and resize the shapes in order to fit the desired text within it, which was a time-consuming activity. While performing the task, six participants (P1, P3, P7, P8, P10, and P12) expressed this concern by mentioning that they prefer the freehand tool to draw shapes in GestAnnot than the inbuilt shapes of ezPDF. When asked about the features that could be added to GestAnnot, four participants (P1, P7, P8, and P12) suggested that the system should automatically detect the shapes drawn with freehand and transform it into a "perfect shape." For instance, if the user draws a rectangle then application should automatically clean the strokes to produce a rectangle with straight lines, all aligned at 90-degree angle to each other and surrounding the text by stretching the rectangle between the extreme corners of user's drawn shape. P1 said, "You can draw with the freehand then…. even if you have drawn something which is not proper then properly scale it…. even while drawing it, like you have to scale it and all, that was a bit of problem…so automatic smoothening thing could be an improvement over that".

In both applications, the user is required to switch to freehand mode before initiating the freehand drawing. In GestAnnot, it can be done by three-finger tap while, in ezPDF, users have to select the freehand tool from the tool-menu. After using the freehand tool, it is required to de-activate it by using the same technique as used for its activation. While performing the task, two participants (P8, P17) explicitly reported this concern and suggested that the application should automatically de-activate the freehand tool after finishing the annotation. Even it was desired by a few participants, it might be difficult to implement, as the application cannot decide when the user has finished drawing the freehand annotations. It may be incorporated in the design that, after few seconds of inactivity, the application automatically de-activate freehand tool. This will require thorough evaluative studies to decide the threshold of the time limit of users' inactivity. Another issue with the freehand tool is that it does not let user turn page or zoom-in or out while it is active because every touch interaction on document is utilized to draw strokes; therefore, it is impossible to know whether the user wants to draw or turn the page. Two participants (P8, P17) mentioned this issue in their interview. However, this issue can be resolved by providing buttons for zooming and turning pages when the freehand tool is activated.

Another interesting behavior was noted during the study that participants tend to tap on the annotation to open its pop-up menu for changing color or other properties while the freehand tool is activated. As explained earlier, the freehand mode does not allow the users to perform other operations except freehand drawing; therefore, participants had to first de-activate the tool to open its pop-up menu. This observation gave us the idea that if the application continues to listen to single-tap event even when the freehand mode is on, then it could open pop-up menu if the user performs single tap on any annotation. However, if this technique is used then application will not allow the users to draw a dot on any existing annotation using the single tap, and in order to do it, user will need to draw a small circle instead of a dot. If users do not find it difficult to draw dots in this manner then, it will provide more flexibility in the application.

As we have mentioned in the Section 3.2.1.3 that GestAnnot considers one ink stroke as one annotation, three participants (P1, P2, and P12) reported about this concern, when they asked about the features that they did not like in GestAnnot. After drawing asterisk using 3 to 4 lines, when they tried to change its color, it considered individual line as separate annotation; therefore, participants had to change their color individually. As mentioned in the Section 3.2.1.3, this can be resolved by considering the temporal order and spatial properties of individual strokes to combine them into freehand annotations.

Besides the freehand shapes and symbols, some participants suggested that they would prefer to use the freehand tool for creating other types of annotation as well. Two participants (P6, P9) mentioned that they did not like typing on the screen; therefore, they would prefer freehand tool to write comment and notes on the screen. Furthermore, three participants (P3, P6, and P7) said that they would prefer to use freehand for underline using stylus.

4.5.2 Selecting Color

While performing the task, almost every participant mentioned that it was fair easier to use different colors in GestAnnot than ezPDF. P4 stated, "Usage of multi-color for annotation are very very easy to operate". On the other hand, all participants said that ezPDF required many steps in changing the color. These responses clearly indicates that providing few colors in a pop-up menu is a good design feature for an annotation application as users can use different colors for different purposes with lesser number of steps.

When asked about the features that they liked in GestAnnot, four participants (P1, P3, P4, and P9) commented that they liked the default colors provided for quick-access in the pop-up menu. They indicated that they mostly use these colors in their actual reading tasks. Although five participants (P2, P9, P10, P12, and P17) suggested that, the application should allow them to choose their preferred quick-access colors in a pop-up menu. One participant (P14) suggested, when user selects a color from “Color Dialog Picker”, which appears upon selecting “More Colors” from the pop-up menu in GestAnnot; the lastly chosen color should automatically appear in quick-access colors so that the user can use it later without going to “Dialog Color Picker” again.

In GestAnnot, every tool has its own color, and when user selects a particular color, it becomes the default color of that particular tool. This feature was not present in ezPDF, therefore, when participants selected a color; they had to set that color explicitly as default. While performing the task, two participants (P10, P12) reported this concern that ezPDF should save the last used color for the tool. Moreover, one participant (P5) said that application should allow users to switch between two modes. In the first mode, there should be one global color for all types of annotation, and when user changes the color, it should become the default color for all tools and in the second mode, each tool should have its own default color as it was in GestAnnot. P5 also suggested that there should be an option to copy colors from one annotation to another if possible by some gesture, for an instance, if the user places one finger on an annotation and another finger on other annotation then it should copy the color from first one to the second.

4.5.3 System Feedback

In ezPDF, when the user selects any particular tool, a notification text appears at the bottom of the screen, but no animation appears on the tool icon. For example, upon selecting highlighting tool, the notification pop-up says, "Drag text on the screen." While performing the task and when asked about the features not liked in ezPDF, nine participants (P1, P2, P3, P4, P6, P9, P10, P12, and P17) commented on this issue. P4 said, "Not highlighting icon, so not able to recognize which operation I am doing." P6 said, "No animation for buttons (depressed) – have to always rely on text messages." Three participants (P5, P6, and P9) reported that the bottom messages were not helpful because they often miss seeing it. P5 said, "I didn't really notice that the feedback was being given at the bottom…. my eye starts looking at the top… so maybe you want to bring it closer to my point of view." One participant (P16) commented that the messages were not clear. He said, "I don't like the messages popping up, It doesn't make any sense, instead there should be some proper messages that you are doing this, you are doing that because I don't have idea what I am doing…was very confusing, It should be clear…There is no connection between the messages, there is no indication what I am doing."

In GestAnnot, notification messages appear at the top-center of the screen and the background of icon changes when it is selected either by gesture or by tapping on it. In addition, the message displays the name of the tool, which is currently activated. Two participants (P2, P9) commented on this feature, when asked about the features that could be added to GestAnnot. P2 suggested that the messages should appear near the point where he taps on the screen because that where he looks at. P9 said that she did not notice the message feedback for anchor tools but noticed for arrow and freehand tool, therefore, feedback messages for anchor tools should appear next to the tools' icons.

4.5.4 Comment Annotation

When asked in discussion and questionnaire about features that participants likes in

GestAnnot, all participants said that they liked the double-tap gesture for comment, and we observed that no participant had any trouble using this gesture. As we presumed that the double tap corresponds to double click of the personal computers, therefore, it would be easy to use; the results comply with our expectations.

Participants provided us with certain suggestions for comment annotation, which will potentially enhance the usability of an annotation application. In both applications, when users create a comment annotation in the margins, some part of the comment might go outside the edge of the screen. In this case, they have to drag the comment to reposition it and then adjust the font size and annotation box in order to fit the comment within the margin. While performing the task, nine participants (P2, P5, P7, P8, P9, P10, P12, P14, and P17) suggested that when they create a comment, it should automatically fit within the margins. To address this issue, the application should be capable of measuring the margins' size, and then it should auto resize the font and the annotation box so that the comment can fit within the margins instead of spanning outside the screen edge. This could be a remarkable improvement in the application, as it will significantly save the users' effort.

Two participants (P2, P7) suggested that the application should allow them to rotate the comment annotation, which is not present in either of the GestAnnot or ezPDF. This feature might help to align the comment along the graph's axis or pictures. Two participants (P2, P3) suggested that instead of tapping on comment annotation and then selecting the "note" option from the pop-up menu, it should allow them to initiate the edit option when they tap on the comment. However, tapping on the comment brings the pop-up menu so it cannot be used to initiate the edit option. Although we can utilize double-tap gesture to do this i.e. when user double tap on a comment, application will directly open the dialogue box for editing the text instead of showing the pop-up menu. Furthermore, one participant (P8) suggested that "OK" button that appears on the dialog box, on which they type the text for comment, should also be given on the keyboard to increase their efficiency.

In GestAnnot, when users move the comment by dragging it, the annotation box moves along the finger. When they release their finger, the comment appears at the new position. While performing the task, two participants (P3, P7) mentioned that the text should also move with the annotation box so that they can know exactly where it is going to be positioned when they release their finger. This feature is present in ezPDF. In GestAnnot, when user selects the "Text Size" option from the pop-up menu of comment, it shows a pop-up menu with five available text sizes; 8, 11, 16, 24, 36. Participants said that it was easier to change text size in GestAnnot than ezPDF. One participant (P2) suggested that it should also allow users to set any custom size for the comment. It can be done by providing a text box in the same pop-up in which user can type any size for the comment.

4.5.5 Highlighting

In the interview and the questionnaire, when participants were asked about the features that they liked in GestAnnot, and the features they did not like in ezPDF, all participants mentioned that they found highlighting through tap and drag gesture easier in GestAnnot than ezPDF. P12 mentioned in the questionnaire that, in GestAnnot, she liked, "the style of highlighting-selecting a word and then dragging from there." P2 said, "Easier to select text having a fixed tool selected." In GestAnnot, when user taps on the word, it becomes selected, and two selection widgets appear at the start and the end of that word (see Section 3.1.3.1). One of these widgets can be dragged to select the text, which is then highlighted upon releasing the finger. However, in ezPDF, it does not automatically select the first word, instead when user selects the highlighting tool and then start dragging on text; the highlight might start from the middle of the word. While performing the task and when asked about the features liked in GestAnnot, five participants (P2, P3, P5, P9, and P18) mentioned that they liked this feature of GestAnnot because, in ezPDF, they had to delete the highlight annotation and recreate it whenever the highlight started from the middle of the word, which was not expected. Moreover, one participant (P12) suggested that when the users lift their finger after dragging the widget, it should also automatically select the whole last word even if the user stopped dragging it at the middle of the word. P2 said, "When highlighting/underlining, if the selected area could automatically resize to the closest word that would be cool. (I doubt you would ever need to highlight half a word in an article or text)".

While performing the task, four participants (P3, P7, P12, and P14) suggested that they should be able to extend or shorten the existing highlight or any other anchor annotation when necessary. We observed that sometimes participants would miss some words when highlighting the text, which have to be included in it. In such cases, they have to delete the annotation and then highlight it again to cover the missing words in both applications. P14 mentioned in the questionnaire that one of the features he felt lacking in the system is "Ability to change the length of the underline or highlight." It can be resolved by allowing them to resize the highlight after completing it. Furthermore, five participants (P5, P6, P7, P8, and P11) suggested that the applications should allow them to convert a highlight annotation into underline or vice versa.

4.5.6 Arrow Annotation

The selection problem of the arrow, when it overlaps the original text in GestAnnot, was one of the major problems we noticed during the study. While performing the task, seven participants (P1, P2, P6, P9, P11, P13, and P15) reported about this issue. As mentioned in Section 3.2.1.2 (and summarized in Table 3.3), we developed some design rules for the selection of annotation when two or more annotations or original text overlaps. In case of arrow and text (see Design Rule 5 in Table 3.3), we have given the priority to text, which led to this problem. However, if we have prioritized the arrow then, it would not have allowed the user to select the text that is present under the annotation box of arrow. To resolve this issue, we propose that the arrow should be given high priority when it overlaps the original text and to allow users to select the underlying text; the annotation box should be optimized as shown in Figure 4.19, so that it overlaps the lesser area of text.

In ezPDF, the arrow is drawn from the pointed end towards to un-pointed one. While performing the task, all participants felt this direction of arrow as unexpected and suggested that it should start from non-pointed end as it is done in GestAnnot.

In GestAnnot, once the arrow is created it cannot be rotated, but it can be rotated while drawing. While performing the task, three participants (P8, P12, and P14) reported this concern and said that it should also allow them to rotate after it is drawn.

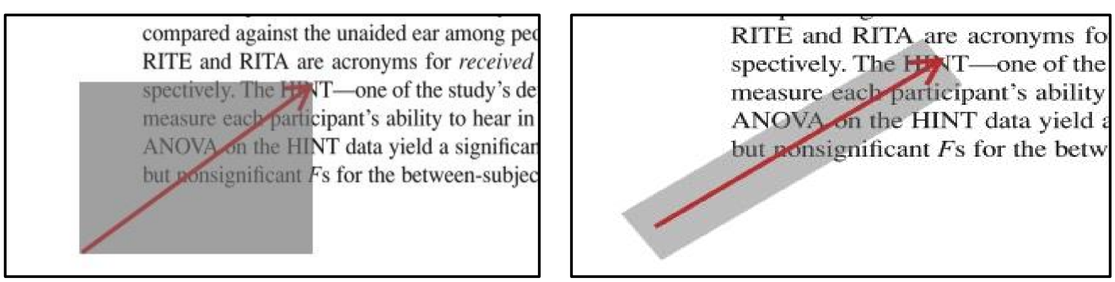


Figure 4.19: Optimizing the annotation box of an arrow. Non optimized annotation box (Left), Proposed optimized annotation box (Right)

4.5.7 Icons and Help

In GestAnnot, we did not provide an icon for comment; consequently, six participants (P2, P8, P9, P10, P11, and P12) mentioned that it should be included along with the help icon for its gesture, when asked about the features that could be added to GestAnnot. P8 stated, “I would like to have a callout symbol in the top menu which can help in enabling comment section.” Furthermore, one participant (P3) suggested that the icon for “squiggly” is not clear as it shows a wavy line alone instead it should show that line under a letter symbol so that they can know that it behaves like a wavy underline. Moreover, one participant (P9) indicated that the icon for highlight is not clear. He suggested that instead of a highlighter pen, this icon should show the highlighted text.

As mentioned in Chapter 3, icons for gestures were provided in the menu-bar to help participants in recalling the appropriate gestures for different tool. Five participants (P3, P5, P9, P12, and P18) suggested, when they tap on any gesture’s icon, it should show some kind of animation or help that describes how to perform that particular gesture. Another participant (P10) suggested that the icons for gestures are small and sometimes it is hard to see the number of fingers involved in it, therefore, a superscripted number should be present on such icons to signify the number of fingers involved in it.

While performing the task using ezPDF, three participants (P6, P11, and P12) said that the number of options in its pop-up menu is overwhelming; therefore, it should use icons instead of the textual-labels for such options. In addition, most participants mentioned that the icon size in ezPDF is small and sometimes they accidentally select the wrong tool, therefore, the icon size and the spacing between the tools should be increased.

4.5.8 Gestures

In the questionnaire and the discussion, when participants were asked about their experience with GestAnnot and ezPDF, sixteen participants mentioned that they strongly preferred gestures technique to the menu-based interactions because it allows them to use different annotation tools without having to first select before using them. P6 stated that the feature of the system he liked the most is “Multi-touch gestures to quickly access the annotation tools.” P12 mentioned in the questionnaire that he liked “the speed of the shortcut methods for highlighting and underlining.” P15 stated, “I did not have to click each time the menu to select the tools, just using taps on the screen + number of fingers I could select them”. P16 said, “Switching by tapping was very nice functionality and putting comments were easy to do.” P5 stated, “You don’t have to move your finger from one edge of the screen to another instead you can add text almost instantaneously by double tapping, and you can do so for highlighting and underlining as well.” P5 also commented, “you can concentrate on the paragraph at where you are working without worrying about different controls.”

4.5.8.1 Learnability of Gestures

In the discussion, when participants were asked about the gestures that they found difficult to learn or use, thirteen participants (all except P3, P12, P14, P16, and P17) commented on the overall learnability of the gestures. Twelve participants mentioned that initially it required some time to learn about what gesture perform which particular annotation, but later on, it was very convenient and efficient to create different types of annotations. P8 said, “Initially it may take some time, but you can learn easily.” P11 stated in GestAnnot’s questionnaire, “All features were easy to learn, and that is the best part of this application.”

P15 stated, "It took some time for me to get used to it, like the number of fingers and the stuff but then it was lot easier to use…." One participant (P13) found these gestures difficult to learn; consequently, she struggled with them while performing the task. Interestingly, P13 mentioned in the interview that she does not use touch screen devices, which might be the reason why P13 had trouble using multi-touch gestures.

4.5.8.2 Four and Five-Finger Tap Difficulty

While performing the task, and when participants were asked about the gestures that they found difficult to learn or use, nine participants (P1, P2, P9, P10, P12, P14, P16, P17, and P18) indicated that they had confusion between four and finger-tap gesture to switch between anchor tools. As mentioned in Chapter 3, four-finger tap can be used to switch from right to left anchor tool and five-finger tap can be used to switch in the opposite direction. Participants mentioned that they had confusion between the directions in which the particular gesture switches the current anchor tool. Moreover, the researcher observed during the study sessions that few participants had trouble using more than three fingers because the little finger and the thumb would not reach the screen, therefore, system was responding to three-finger tap instead. P10 said, "It was taking much more time to learn how to use different amounts of fingers to change the tools." P12 suggested, "I guess that the switching between… like the highlight and the underlining that could be a better gesture". P14 said," I think the five and four could have been change to some simpler gesture because it is too much to do." To resolve this issue, P2 suggested that two or three-finger slide gesture can be used instead of four and five-finger tap gesture because it would be more intuitive to switch between anchor tools in right or left direction using slide gesture in the right and left direction respectively. In addition, it would be easier to use two or three fingers than four and five fingers.

4.5.8.3 Gesture for Making an Arrow

While performing the task, and when participants were asked about the gestures that they found difficult to learn or use, nine participants commented on 'press, tap and drag' gesture to make an arrow annotation. Four participants (P4, P10, P13, and P17) mentioned that they found arrow annotation easy to use using press, tap and drag gesture. Five participants (P2, P5, P6, P10, P11) indicated that it was little difficult to use "press and tap and then drag" gesture for arrow. P2 said, "Drawing arrows feels unnatural." P11 stated, "Arrow feature is a bit tricky." During the study sessions, the researcher also observed that this gesture was relatively challenging to execute than other gestures because some participants tend to perform two-finger tap instead of tap and drag gesture.

4.5.9 Miscellaneous

a. Four participants (P1, P2, P7, and P9) suggested that the applications should have some inbuilt symbols, which they can use it by simple drag and drop interaction such as, braces, brackets, star, asterisk, etc. In addition, P7 mentioned that the users should be able to save their hand drawn symbols and comments so that if they are marking an assignment or test, they can simply drag and drop those comment and symbols to grade these assignments.

b. P5 suggested there should be a composite annotation, which is composed of an arrow and a comment and can be initiated by some gesture. He argued that he usually uses arrow and comment together, therefore, instead creating these two annotations separately; one composite annotation can save the effort.

c. Some participants suggested that GestAnnot should have an auto save feature as in ezPDF so that the annotations are saved even if they forget to save it or accidentally exit the application without saving them.

d. One of the most common concerns about both applications was the undo option. Both applications allow users to delete any annotation, but it does not provide the undo operation. All participants mentioned that this option is required especially to undo the freehand annotations. Two participants (P7, P18) said that an eraser tool for freehand annotation might help in undoing some unclean drawings.

e. P3 suggested that tapping on an annotation should also bring a button (e.g., a button with a close sign on it) at the corner of that annotation for deleting it so that users do not have to find the delete option in the pop-up menu. P3 also said that if there were a recycle bin in the application in which the user could drop the annotation by dragging it then it would be an easier way to delete the annotations.

f. P15 suggested an interesting feature that can be included in the GestAnnot. She mentioned that it should allow the user to export all the annotations created on an article to a Word or PDF document along with the title and the author name of that article. It will help the researchers and readers to create the notes about the article, which they can refer later for their thesis or other research work. She said that sometimes she forgets the name of the article in which she has annotated something, and if these features were provided then it would enable the user to use query- based search within the annotations, which will eventually provide the articles' title.

g. During the study, we observed when participants tap on a word to select it (using GestAnnot), there were few times when they either missed that word or selected the wrong one. However, it almost reduced to zero when they used the tablet in landscape mode. This observation indicates that the selection problem was happening due to small font and small screen size.

4.6 Did GestAnnot Performed Better than ezPDF?

From the careful analysis of the literature and existing annotation applications, as discussed in Section 4.3.1, we found that ezPDF is one of the best applications currently available. We considered this application to be benchmark against which we compared GestAnnot in this study. Although ezPDF provided many features including different annotation tools in a simple toolbar menu and easy manipulation of annotations, we were able to identify many functional and usability problems through our study (see Sections 4.5.1 - 4.5.9). From this comparative study of the two applications, we observed that GestAnnot was successfully able to overcome some of these issues thus providing a better user experience. This claim is supported by the fact that there was a significant difference in the user satisfaction ratings for both the applications on different aspects including, the number of steps involved in creating the annotations and system feedback.

4.6.1 Reduction in Number of Steps

As discussed in Chapter 1, research suggests when users have to perform numerous steps for creating annotations using a tablet, it imposes cognitive load on working memory resources; furthermore, comprehension building level decreases when cognitive load increases [14, 17-19]. Therefore, if the number of steps were reduced for creating annotations, it would be a significant contribution towards making Active Reading task more natural using a tablet. Considering this guideline, GestAnnot has attempted towards reducing the number of steps through the following features. Our claim is further supported by the users' satisfaction ratings, which indicates that participants also perceived that the number of steps involved in annotations tasks is significantly lesser in case of GestAnnot than ezPDF (see Figures 4.10 and 4.11).

4.6.1.1 Highlight Annotation

While reading from a paper, users can highlight the text by simply dragging the writing tool (e.g., a pen or a highlighter) over the desired text. In GestAnnot, the user can create highlight annotations on very similar principles by tapping on the first word and dragging the selection towards the end of the desired text to be highlighted. On the contrary, in ezPDF, the highlight annotation tool has to be activated first by clicking on the highlight button on the toolbar present on the upper edge of the screen followed by dragging over the text to create the highlight annotation. This process involves four steps: 1) Navigation to toolbar menu, 2) Locating and selecting the appropriate tool in the menu, 3) Navigating back to the text from where the user has left, and 4) Dragging the selection. This ezPDF's technique to create highlight is not natural as it might deviate users from the text being read when they have to perform these four steps every time they wish to highlight. This issue was also raised by most of the participants during the study and they mentioned that it was easier to create highlight annotation in GestAnnot, as discussed in Section 4.5.5. If multiple highlight annotations were to be created, the tool needed to be activated every time and we observed that the participants selected wrong tool in many cases, which could not be an issue in GestAnnot.

Thus, we can safely conclude that GestAnnot performed better in creating highlight annotations than ezPDF and is closer to the way users highlight text on the paper.

4.6.1.2 Comment Annotation

In case of ezPDF, comment annotation can be created in a similar way as highlight by first activating the tool and then tapping on the point where the comment has to be created, which pops open the dialogue box for typing the text. These steps might also deviate the user from the text in the same way as the highlight does. While GestAnnot allows users to create comment by just a double-tap on the screen, thus reducing the number of steps involved from four (see Section 4.6.1.1) to one. The participants' comments in Section 4.5.4 support our claim that it is easier to create comment annotation in GestAnnot than ezPDF.

4.6.1.3 Arrow Annotation

In the same way as discussed above, ezPDF required the participants to first select the arrow tool from the toolbar menu before drawing an arrow. This process involves four steps: 1) Navigating to Toolbar Menu, 2) Locating and selecting the arrow tool in the menu, 3) Navigating back to the original location where the user wished to create arrow, and 4) Drawing the arrow by dragging the finger. However, in GestAnnot, an arrow can be created using "Press, Tap and Drag" gesture in just one step (see Section 3.1.3.3). As discussed in Section 4.5.8.3, this feature was liked by the participants and they mentioned that it was easier to draw arrows using this gesture than in ezPDF. However, a few participants mentioned that this gesture was somewhat difficult to learn but once learnt it was suitable for drawing an arrow.

Therefore, we can conclude that once learnt this gesture was easier to operate and it has reduced a significant number of steps in the creation of an arrow.

4.6.1.4 Selecting Color

As discussed in Section 3.1.2.4, research suggests that the readers develop their own system of annotation in which, different color means different to them. We have noticed that the existing applications (including ezPDF and Repligo Reader (see Section 4.3.1)) involves many steps in the process of selecting color thus hindering the ability of users to use their annotations with flexibility. Therefore, we have provided four quick-access colors in the pop-up menu, which appears when the user taps on an annotation. Almost all participants mentioned that they liked this design feature and mentioned that it was very easy to use different colored annotations in GestAnnot than ezPDF (see Section 4.5.2). In GestAnnot, users can choose one of the four colors in two steps (1) Tap to open pop-up, 2) Select quick-access color), and other colors in three steps (1) Tap to open pop-up, 2) Select "More Colors", 3) Select the color from color dialog picker). While in ezPDF, users can choose recently used colors as well as more colors in four steps: 1) Tap to open pop-up, 2) Select "properties," 3) Select "color," 4) Select the color.

Additionally, participants noted that GestAnnot remembers the last used color for a particular tool while they had to do it explicitly in ezPDF. For example, in GestAnnot, if the participants have changed the color of highlight annotation to green and when they would create other highlight annotation, it would appear in green color. On the contrary, in ezPDF, the participants had to make the color as a default color for a tool, which was negatively pointed out by many participants (see Section 4.5.2).

From the discussion given in this section, we can conclude that the number of steps involved in selecting colors was lesser in GestAnnot than ezPDF.

4.6.1.5 Mode Switching

In both applications, the participants were required to switch from annotation tool mode to freehand mode for creating freehand annotations, as discussed in Section 4.5.1 and 3.1.3.4. In ezPDF, this operation required three steps: 1) Navigating to toolbar menu, 2) Locating and selecting freehand tool, 3) Navigating back to the location where the user wished to draw an annotation. While GestAnnot allows this operation to be performed in just one-step i.e. using three-finger tap gesture (see Section 3.1.3.4). Almost every participant mentioned that three-finger tap was easier and more efficient technique for mode switching than ezPDF's technique (see Section 4.5.8).

We can safely conclude that three-finger tap enhanced the speed and efficiency of mode switching operation between annotation tool mode and freehand drawing mode, thus providing a better technique than ezPDF.

4.6.1.6 Summary

From the described analysis in Sections 4.6.1.1 through 4.6.1.5, it is evident that GestAnnot has enhanced the efficiency of various annotation operations by reducing a significant number of steps, which is a very important aspect of any Active Reading application. The user satisfaction ratings suggests that participants rated GestAnnot significantly higher than ezPDF in terms of "number of steps (1=Too Many, 7=Just Right)", $z=3.408$, $p=0.001$ (see Figure 4.11). These means that participant also perceived that GestAnnot involves lesser number of steps in creating and manipulating annotation than ezPDF. Moreover, it can also be concluded that the gesture techniques used for the above-described operations were easy to learn and use, thus providing better user experience than ezPDF. This claim is also supported by user satisfaction ratings, which indicates that GestAnnot was easier to use (see Figure 4.6) and learn (see Figure 4.8).

4.6.2 Design Rules for Selection of Overlapping Annotations

As discussed in Section 3.2.1.3 and summarized in Table 3.3, every annotation has a bounding box, which acts as a canvas for the digital ink of annotations. The user can select an annotation by tapping anywhere inside this bounding box. One of the major issue we have noticed in the existing annotation application was the selection issue for overlapping annotations. If two or more annotations overlap then their bounding boxes also overlap. When the user taps on the point within the overlapped area, ezPDF selects last created annotation (on the topmost layer), even if the user wants to select the underlying annotation. This situation is worse when the underlying annotation(s) lie completely under the topmost annotation and in this case, the user cannot select the underlying annotation(s) because the bounding box(s) of these annotation(s) are hidden under the topmost layer.

To address this issue, we formulated nine design rules (summarized in Table 3.3) that considered all the possible cases of overlapping annotations, which were incorporated in the GestAnnot's design. Based on our personal experience, we formulated these design rules to ensure the selection of underlying annotations in many cases of overlapping bounding boxes. In this study, we have observed that these design rules performed well except in two cases. First, when arrow annotation box completely overlapped the original text. Second, when freehand annotation box completely overlapped the original text. In these cases GestAnnot did not allow the participants to select the arrow or freehand because the Design Rule 4 and 5 (see Table 3.3) states, if arrow annotation box (or freehand annotation box) overlaps the original text then priority will be given to original text. In the above-mentioned two cases, no area of arrow annotation box (or freehand annotation box) was lying outside the original text, therefore when the participants tapped on the arrow annotation box to select it, the underlying text were selected. This issue and its potential solution are described in our discussion of arrow annotation (see Section 4.5.6).

Our observations from this study indicate that GestAnnot has made a successful attempt to resolve the selection problem in case of overlapping annotations. However, the effectiveness of these design rules can be formally validated in the future studies.

4.6.3 System Feedback

Another feature that participants noted in GestAnnot was the system feedback. As discussed in Section 4.5.3, most of the participants mentioned that they did not notice the notifications appearing at the bottom of the screen, in ezPDF. While in the case of GestAnnot, such notifications appeared at the top-center of the screen, which they have noticed during the tasks. This might be due to the reason that the notifications were obscured by the active hand, which was making the touch interactions on the screen. However, participants also mentioned that the notifications should appear closer to the location where they interact with the screen so that the notification is both visible and noticeable.

From the results of this study, it is evident that the notifications appeared at better position in GestAnnot than in ezPDF, however, there is still a room for improvements. This claim is supported by user satisfaction ratings, which suggests that GestAnnot was significantly better ($z=2.849$, $p=0.004$) in keeping the user informed about the operations (see Figure 4.15).

4.6.4 More Accurate Highlighting

The ezPDF application created the highlight from the first point of contact with the screen irrespective of whether or not that first point of contact lies in the middle of the word. This case is improbable that a user would wish to highlight a part of a word in a sentence, which was also pointed out by few participants, as described in Section 4.5.5. In many cases, the participants had to delete the highlight annotation and recreate it to include the earlier partially highlighted word. While, in case of GestAnnot, tapping on the word selected the entire word, which lied under the first point of contact. This design feature ensured that the selection would start from a complete word, however the user was then free to drag the selection in both the directions as they wished, thus overcoming ezPDF's drawback. The related discussion can be found under Section 4.5.5.

4.6.5 Grouping Anchor Annotations in Single Gesture

In GestAnnot, we deployed "Single-Finger Tap" gesture to create the highlight annotation and we have used this same gesture for underline, squiggly and strike-through annotations, since all four of these annotation types fall under the same category of anchor annotations, as discussed in Section 3.1.2.1. Assigning a separate gesture for each of these annotations might have increased the complexity and learning demand of the interface; therefore, we kept a single gesture for each of them with an option to switch between them easily through "Four-Finger Tap" and "Five-Finger Tap" gestures, as described in Section 3.1.3.5.

The notion of keeping one single gesture for four annotations was appreciated by most of the participants (see Section 4.5.8); however, they found that the gestures assigned for switching between these annotations (four and five-finger tap) were confusing and difficult, as described in Section 4.5.8.2. While in case of ezPDF, the participants had to follow the same steps for activating all anchor annotations from the toolbar menu in the same way as the other tools, which they strongly disapproved of (see Section 4.5.8).

Therefore, on one hand we can safely conclude that the idea of choosing one single gesture for multiple types of anchor annotation tools was justified to be beneficial for users; however, we still need a better alternative gesture to switch between these tools.

4.6.6 Summary

From the above discussion in Section 4.6.1 through 4.6.5, it is evident that GestAnnot preferred to be better than ezPDF in many aspects, which include the increased efficiency through decreased number of steps, system feedback, selection of overlapping annotations, and accuracy of highlighting and grouping of anchor annotations in one gesture. Our claims are supported by the participants' comments and users' satisfaction ratings. Although some of the users' satisfaction ratings questions were not directly related to the annotation task, they are important in knowing the overall impression the system creates on the participants (see Section 4.4.2).

#	Task	GestAnnot		ezPDF	
		# Steps	Sequence of Steps	# Steps	Sequence of Steps
1	Highlight, Underline, Squiggly, Strike-Through	2	1) Tapping on first or last word, 2) Dragging the selection	4	1) Navigation to toolbar menu, 2) Locating and selecting the appropriate tool in the menu, 3) Navigating back to the text from where the user has left, and 4) Dragging the selection

#	Task	GestAnnot		ezPDF	
		# Steps	Sequence of Steps	# Steps	Sequence of Steps
2	Comment	2	1) Double Tap, 2) Typing the comment	4	1) Navigation to toolbar menu, 2) Locating and selecting the appropriate tool in the menu, 3) Navigating back to the text from where the user has left, and 4) Typing the comment
3	Arrow Annotation	1	1) Press, Tap & Drag Gesture	4	1) Navigation to toolbar menu, 2) Locating and selecting the appropriate tool in the menu, 3) Navigating back to the text from where the user has left, and 4) Drag to draw arrow
4	Quick Access Colors	2	1) Tap on Annotation, 2) Choose color from pop-up menu	6	1) Tap on Annotation, 2) Selection Properties from pop-up, 3) Select Color, 4) Choose Color, 5) Press Ok to close Color Dialog, 6) Press Ok to Close Properties Dialog
5	Other Colors	4	1) Tap on Annotation, 2) Select other-color from pop-up menu, 3) Choose Color, 4) Press Ok to close Color Dialog Picker	6	1) Tap on Annotation, 2) Selection Properties from pop-up, 3) Select Color, 4) Choose Color, 5) Press Ok to close Color Dialog, 6) Press Ok to Close Properties Dialog
6	Mode Switching between Freehand mode and Annotation tool mode	1	1) Three Finger Tap	3	1) Navigation to toolbar menu, 2) Locating and selecting the appropriate tool in the menu, 3) Navigating back to the text from where the user has left

Table 4.7: Comparison of Number of Steps in GestAnnot and ezPDF

4.7 Revisiting Hypotheses

In this section, we will revisit our hypothesis mentioned in Section 4.2 and will discuss how these hypotheses communicate with our findings.

Hypotheses 1*: GestAnnot allows users to create different types of annotations in lesser number of steps than menu-based application.*

From the discussion given in Section 4.6.1, it is evident that GestAnnot has reduced many steps in the process of creating different types of annotations, which involves highlight, underline, squiggle, strike-through, comment, arrow, freehand and selecting color. In addition, the user satisfaction ratings suggest that the participants rated GestAnnot significantly higher than ezPDF in questions "Number of Steps (1=Too Many, 7=Just Right)" and "Can task be performed in straightforward manner (1=Never, 7=Always)" (see Table 4.3). This means that participants also perceived that they had to perform lesser steps to create annotations in GestAnnot.

Therefore, we can conclude that our findings are in concordance with our first hypotheses that GestAnnot allows users to create different types of annotations in lesser number of steps than menu-based application.

Hypotheses 2*: The gesture-techniques used in GestAnnot are easy to use and easy to learn.*

From the discussion given in Section 4.5.8, it is evident that all gesture-techniques were easy to use and learn except four and five-finger tap gesture for switching between anchor annotation tools, and "Press, Tap and Drag" gesture for making arrow annotation tool. As discussed in Section 4.5.8.2, participants have difficulty in remembering the direction in which the four and five-finger tap switches the anchor annotation tool. Moreover, they had difficulty in using four and five-finger tap gesture; therefore, they suggested using other simpler gestures (see Section 4.5.8.2). Although “Press, Tap and Drag” gesture was later learnt by the participants during study, it was little difficult to learn in the beginning of the sessions (see Section 4.5.8.3). However, the user satisfaction ratings suggest there was no significant difference in the ratings of GestAnnot and ezPDF for questions “Overall Reactions to the System (1=Difficult, 7=Easy)” and “Learning to operate the system (1=Difficult, 7=Easy)” (see Table 4.2 and Table 4.3). This means that participants found GestAnnot as easy as ezPDF to learn and use.

We can say that few gestures were difficult to learn and use. Therefore, we can conclude that our findings are in partial concordance with our hypotheses that the gesture-techniques used in GestAnnot are easy to use and easy to learn.

Hypotheses 3*: The participants would prefer gesture-based annotation application to menu-based application.*

As discussed in Section 4.5.8, most of the participants explicitly mentioned (in their interviews and questionnaires) that they would prefer to use gesture-techniques to menu-based approach. In addition, the user satisfaction ratings suggest that participants rated GestAnnot significantly higher than ezPDF for the questions related to overall satisfaction with the system (see Table 4.2). Therefore, we can conclude that our findings are in concordance with our hypotheses that the participants would prefer gesture-based annotation application to menu-based application.

Hypotheses 4: *The design rules for selecting overlapped annotations allow users to select any annotation among various overlapped annotations*

As discussed in Section 4.6.2, two Design Rules (#4 and #5 in Table 3.3) did not perform well in two cases when the arrow or freehand annotation completely lied on original text. Therefore, we can conclude that our findings do not support our hypothesis that the design rules for selecting overlapped annotations allow users to select any annotation among various overlapped annotations.

4.8 Proposed Guidelines for an Active Reading Application on Tablet

From the results of the study, we are able to formulate general and specific guidelines, which any future Active Reading application can incorporate. The following guidelines have been proposed and can be used in future annotation applications.

1. Anchor Annotations

- *The application should allow the user to highlight (or use other anchor annotation tool) the text without having to navigate throughout the screen space.* A possible solution could be the "Single-Tap" gesture technique as used in GestAnnot (refer to Section 4.5.8.1).
- *The anchor annotations should begin and end enclosing the entire word and not a part of it* (refer to Sections 4.5.5 and 4.6.4).
- *All anchor annotations should be grouped under same gesture with an ability to easily switch between them.* The gesture used for switching between these tools should reflect the direction of switch e.g., left-swipe and right-swipe gestures (refer to Sections 4.6.5 and 4.5.8.2).
- *The application should allow users to extend or shorten the existing anchor annotations*

to include or exclude some part of text in the same annotation (refer to Section 4.5.5).

2. **Comment**

- *The application should allow the user to initiate the comment without having to navigate throughout the screen space.* A possible solution could be the "Double-Tap" gesture technique as used in GestAnnot (refer to Section 4.6.1.2).
- *The comment should adjust itself within the available marginal space without the need to resize and reposition it explicitly* (refer to Section 4.5.4).
- *The application should allow the users to rotate the comment if they wish to align it in some other orientation than horizontal* (refer to Section 4.5.4).

3. **Arrow**

- *The application should allow the user to initiate the arrow without having to navigate throughout the screen space.* The "Press, Tap and Drag" gesture used for creating annotation in GestAnnot was little difficult to operate, therefore a simpler gesture should be considered in future designs (refer to Sections 4.6.1.3 and 4.5.6).
- *The arrow should be drawn from the non-pointed end to the pointed end, when users drags their finger on the screen* (refer to Section 4.5.6).

4. **Freehand Annotation**

- *The application should allow the user to switch between annotation tool mode and freehand drawing mode without having to navigate throughout the screen space.* A possible solution could be the "Three-Finger Tap" gesture technique as used in GestAnnot (refer to Sections 4.6.1.5 and 4.5.1).
- *The application should combine individual freehand strokes into one annotation based upon their proximity and temporal order.* (refer to Section 3.2.1.3)

- *During the freehand drawing mode, users should be able to turn and scroll the page and to perform zoom in or zoom out.* A possible solution could be providing dedicated buttons for these operations, which should appear while the freehand mode is active (refer to Section 4.5.1).

5. Shapes and Symbols

- *The application should provide some built-in symbols such as asterisk, stars, question mark, which users can use by simple drag and drop operation from a symbols menu* (refer to Section 4.5.9).
- *We found that the participants preferred drawing shapes with freehand rather than using inbuilt rectangle, ellipse, and circle. Therefore, shapes drawn with freehand tool should be auto-converted to the geometrically cleaned shapes such as rectangle, circle, and ellipse* (refer to Section 4.5.1).

6. Editing Annotations

- *The application must allow user to select any annotations from the overlapping annotations.* As a possible solution, the bounding box should be optimized to cover minimum possible area and application should ask the user to choose one from all the overlapped annotations (refer to Sections 3.2.1.2 and 4.6.2).
- *The application must allow users to undo any number of previous steps* (refer to Section 4.5.9). It depends upon the application if it chooses to allow users to go back a certain number of steps, or to the last saved point or to the beginning of annotation task on the document.
- *The application should allow users to change the default color to a different color for each annotation tool and save it as their preferred choice for that particular tool until*

they change to some other color (refer to Sections 4.5.2 and 4.6.1.4).

- *The application should provide few colors for quick-access and users should have the freedom to choose the number and choice of these quick-access colors.* As a possible solution, these colors can be provided in the pop-up menu that appears when the user taps on an annotation, as incorporated in GestAnnot (refer to Sections 4.5.2 and 4.6.1.4).

7. Miscellaneous

- *There should be sufficient help for users, which would help them in recalling the appropriate gesture for a particular operation.* As a possible solution, gesture icons can be provided alongside their respective tools, as incorporated in GestAnnot (refer to Section 3.1.1).
- *There should be sufficient training tutorials for the beginners, which should guide them about the proper usage of gestures.* A possible solution could be an interactive tutorial that demonstrates the gestures and then ask the user to repeat it until they get it right (refer to Section 4.5.7).
- *The application should allow users to export their annotations to an external document and each exported annotation should have identification information of the source text so that users can trace back their exported annotations to their original documents* (refer to Section 4.5.9).

4.9 REFLECTIONS ON METHODOLOGY

In this study, we have compared a gesture-based annotation application (GestAnnot) to a menu-based one (ezPDF). Our primary objective behind this study was to know which of the two techniques was preferred by the participants and what aspects affected their decisions. For the purpose of this study, we chose ezPDF as a benchmark of menu-based applications. It is possible that participants might have assigned lower ratings to ezPDF than GestAnnot not only because they believed that it required more number of steps to perform annotation task, but due to other reasons such as look and feel of the interface. Moreover, the results of this study are solely based upon the user-reported data, which reflects participants' perceptions of both applications but may or may not indicate their actual effectiveness. To address these issues, the following methodology could be adopted to conduct this study.

We could develop two versions of GestAnnot – the first version having gestures techniques and the second version having menu-based technique for creating annotations. Both the applications would have same number and type of features and would differ only in a way these features were used i.e. using gesture or menu. This might have helped us in performing an accurate evaluation of the two techniques (gesture-based vs menu-based) without inducing any bias from the differences between other features present in any of the two applications.

Using this approach, we could have recorded participants' interactions in both the applications such as how many times they used the delete option in a particular application, how many times they used the help. This would have provided us with additional data to find which of the two applications performed better, rather than just relying on user reported data.

4.10 Summary

In this chapter, we present the results of our study, which compares GestAnnot with a menu-based annotation application (ezPDF Reader). The results of this study show that GestAnnot provides better user experience by enabling the user to perform annotation task with lesser number of steps and more flexibility than ezPDF. The analysis shows that there is a significant difference between the overall user satisfaction and other aspects of these applications and most of the participants preferred to use GestAnnot for annotations. The various suggestions of the participants can be taken into account to improve the design and to further enhance the user experience.

CHAPTER 5 THE IMPROVED GESTANNOT

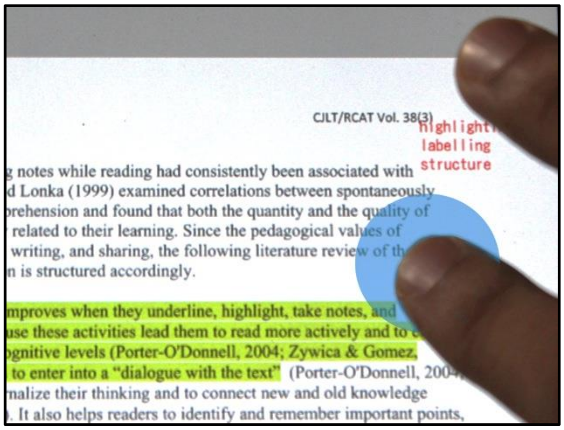
We formulated design guidelines based upon the feedback collected in the lab evaluation, as discussed in the previous chapter (see Section 4.8). Considering these guidelines, we have improved some design features with the goal of providing better user experience. The Table 5.1 shows these guidelines which were considered to make improvements in GestAnnot's design. Table 5.1 also shows that some of these guidelines were not implemented in the improved design. This is because the API (PDFTron Mobile PDF SDK [22]) used for developing GestAnnot does not provide necessary libraries to do so. The improved features of GestAnnot are described in Sections 5.1 through 5.5.

#	Guidelines	Implemented in Improved Design?	Section for Explanation
1	The application should allow users to extend or shorten the existing anchor annotations to include or exclude some part of text in the same annotation	✓	5.4
2	The comment should adjust itself within the available marginal space without the need to resize and reposition it explicitly	×	-
3	The application should allow the users to rotate the comment if they wish to align it in some other orientation than horizontal	×	-
4	The application should allow the user to initiate the arrow without having to navigate throughout the screen space. The "Press, Tap and Drag" gesture used for creating annotation in GestAnnot was little difficult to operate, therefore a simpler gesture should be considered in future designs	✓	5.1

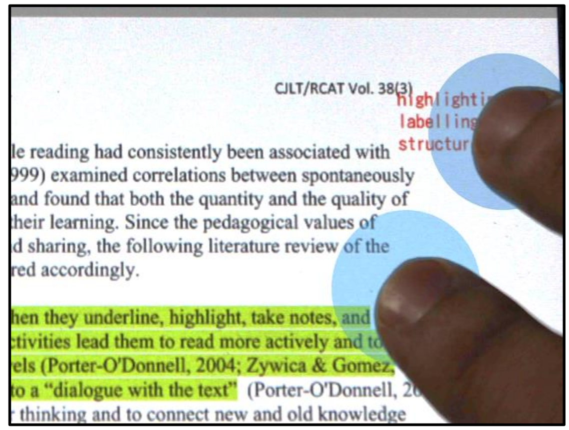
#	Guidelines	Implemented in Improved Design?	Section for Explanation
5	All anchor annotations should be grouped under same gesture with an ability to easily switch between them. The gesture used for switching between these tools should reflect the direction of switch e.g., left-slide and right slide gestures	✓	5.2
6	There should be sufficient training tutorials for the beginners, which should guide them about the proper usage of gestures	✓	5.3
7	The application should combine individual freehand strokes into one annotation based upon their proximity and temporal order	✗	-
8	During the freehand drawing mode, users should be able to turn and scroll the page and to perform zoom in or zoom out.	✗	-
9	The application should provide some built-in symbols such as asterisk, stars, question mark, which users can use by simple drag and drop operation from a symbols menu	✗	-
10	Shapes drawn with freehand tool should be auto-converted to the geometrically cleaned shapes such as rectangle, circle, and ellipse	✗	-
11	The application must allow users to undo any number of previous steps	✗	-
12	The application should allow users to export their annotations to an external document and each exported annotation should have identification information of the source text so that users can trace back their exported annotations to their original documents	✗	-

Table 5.1: Guidelines for the improvement of GestAnnot's design

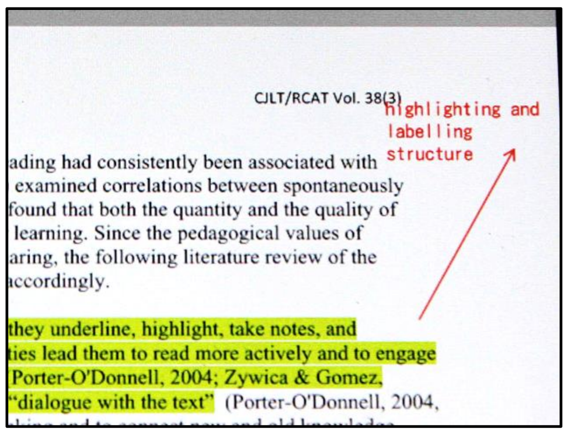
5.1 Two-Finger Tap Gesture for Arrow



(a) First finger touch to initiate arrow



(b) Second finger touch to complete arrow



(c) Arrow created after both fingers lift up

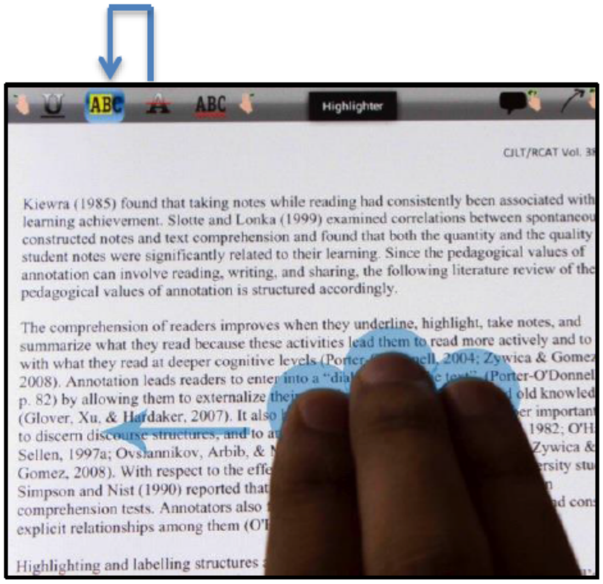
Figure 5.1: Creating arrow through two-finger tap gesture[11]

As discussed in Section 4.5.8.3, some participants found "press and tap then drag" gesture little difficult to operate, therefore, we have changed this gesture to a simpler one. In the new design, user can draw an arrow using two-finger tap gesture. The finger that first touches the screen, specify the starting point of the arrow and the finger that touches the screen later, specify the end (pointing end) of arrow, as shown in Figure 5.1.

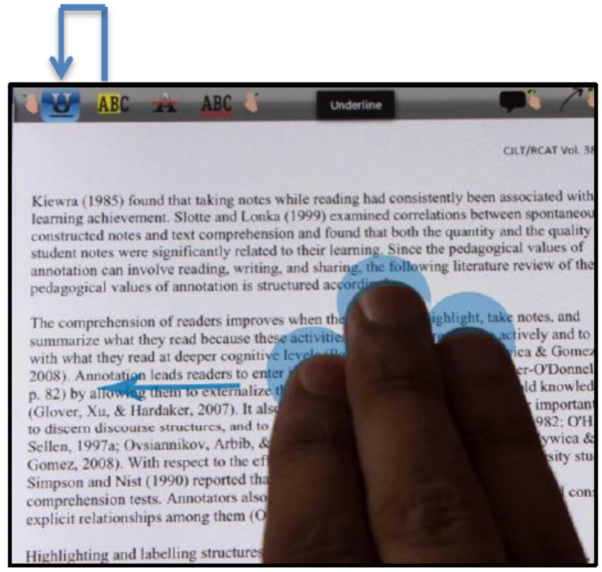
[11] Note: The blue circles in Figure 5.1 are only shown to demonstrate the touch interactions but they do not appear in actual interface. This condition also applies for subsequent figures in this chapter.

5.2 Three-Finger Swipe to Switch Between Anchor Annotation Tools

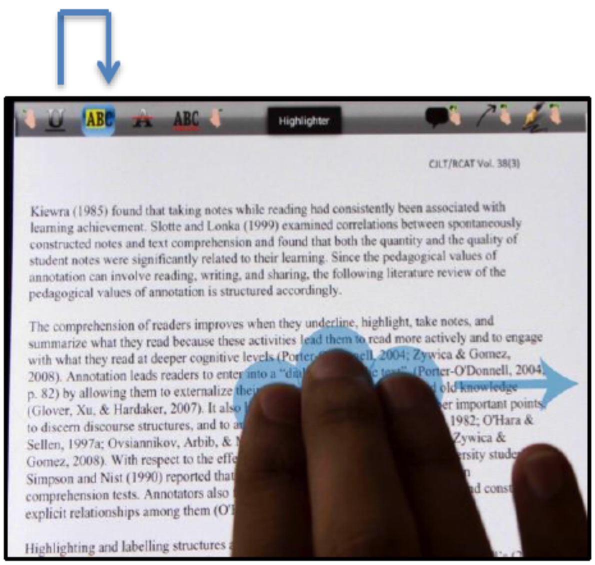
As mentioned in Section 4.5.8.2, most of the participants said that they had difficulty using the four and five-finger tap gestures. Moreover, they were getting confused between the directions in which, these gestures perform the switch between anchor annotation tools. Therefore, we decided to change these gestures to more simple gestures. In the improved design, four and five-finger tap has been changed to three-finger left swipe and three-finger right swipe gesture respectively, as shown in Figure 5.2. We have chosen these gestures because no participant has reported difficulty with three-finger tap and the direction of the swipe gesture is intuitive in specifying the direction of switching between anchor tools.



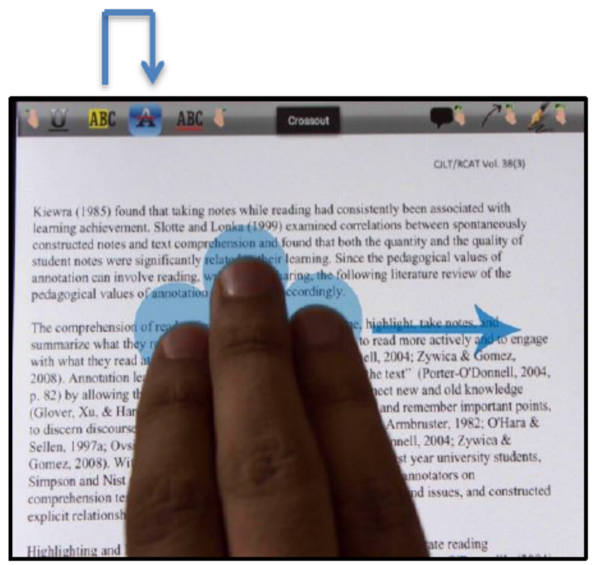
(a) Switching from Strike-Through to Highlight using three-finger left swipe gesture



(b) Switching from Highlight to Underline using three-finger left swipe gesture



(c) Switching from Underline to Highlight using three-finger right swipe gesture

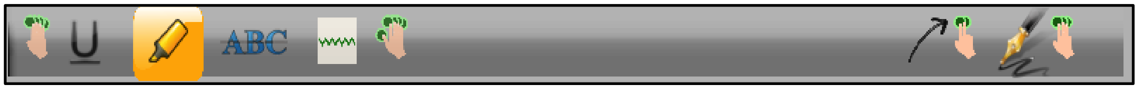


(d) Switching from Highlight to Strike-Through using three-finger right swipe gesture

Figure 5.2: Switch between anchor annotation tools through three finger swipe gesture

5.3 Icons and Help

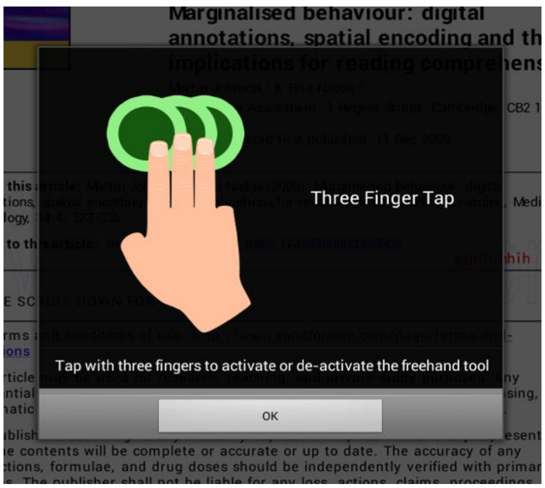
As shown in Figure 5.3 (b), icons for highlight and squiggly has been changed as suggested by some participants in the study. To maintain consistency, we have also modified icons for the underline and strike-through tool. Moreover, the comment icon is now included along with its gesture's help icon. In addition, three and four-finger tap gesture icon has been replaced by three-finger left swipe and right swipe icons respectively.



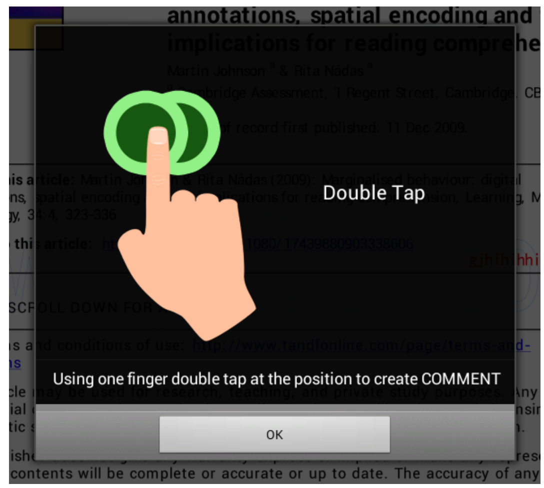
(a) Initial Design

(b) Improved Design

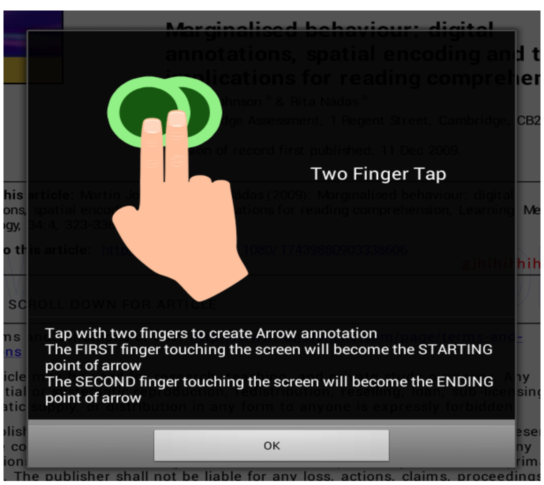
Figure 5.3: Toolbar Menu of GestAnnot



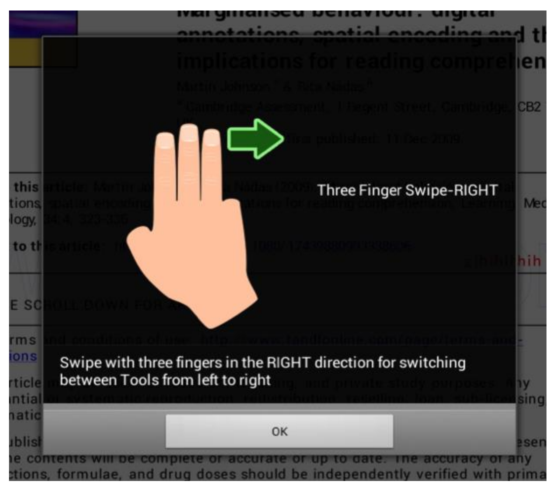
(a) Help for three-finger tap gesture



(b) Help for double-tap gesture



(c) Help for two-finger tap gesture



(d) Help for three-finger tap gesture

Figure 5.4: Help Pop-Up appears when user taps on gesture's icon

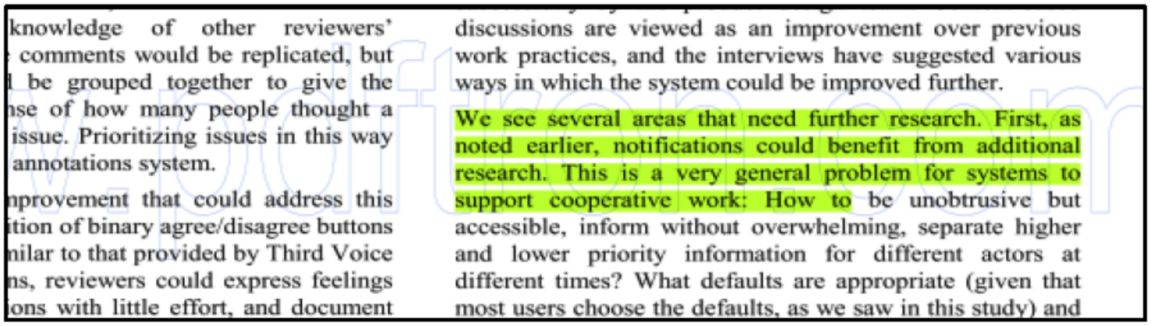
In this improved design, we have also provided help for all gestures. When the user taps on gesture icons, the help pop-up appears which shows the image of that gesture with the description of how to use it. The help pop-up are shown in Figure 5.4.

5.4 Extending Highlight

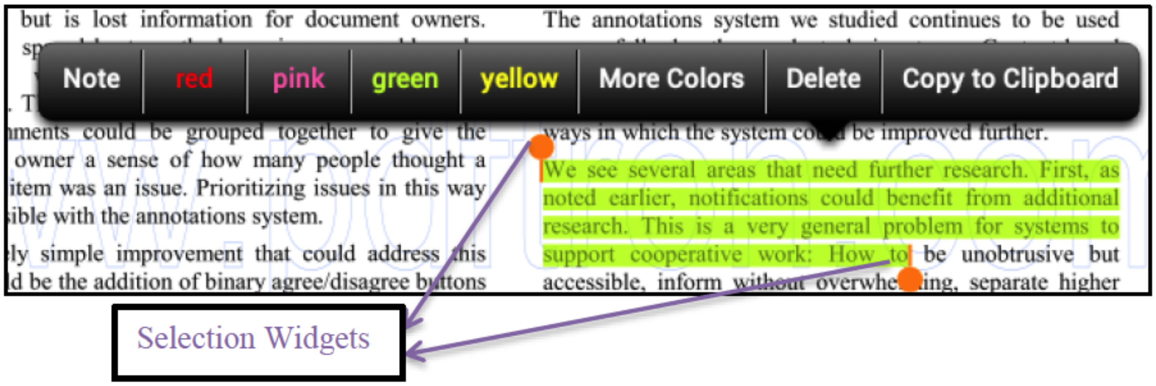
As discussed in 4.5.5, users should be able to extend or shorten the existing highlight or any other anchor annotations. In the improved version, when the user taps on a highlight or other anchor annotation, two selection-widgets appear at the start and the end of the highlight. Either of these widgets can be dragged to extend or contract the highlight, as demonstrated in Figure 5.5.

5.5 Color Feedback

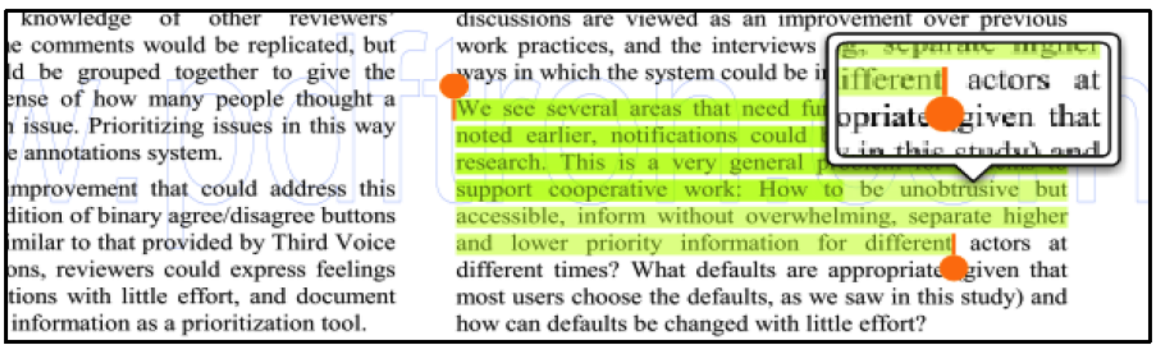
In the initial design, when the user would tap on a word, it was selected, and that selection would appear in the blue color. When the user dragged the selection widget, the selection was shown in the same color. However, when the user released their finger, the selected text was highlighted (or other anchor annotation) with the color of that tool. In this scenario, users could not know the current color of the tool before releasing the finger. To address this issue, we have changed the selection color to the same color as that of the tool. For instance, in Figure 5.6, the current color of the highlighter tool is green; therefore, the selection also appears in the green.



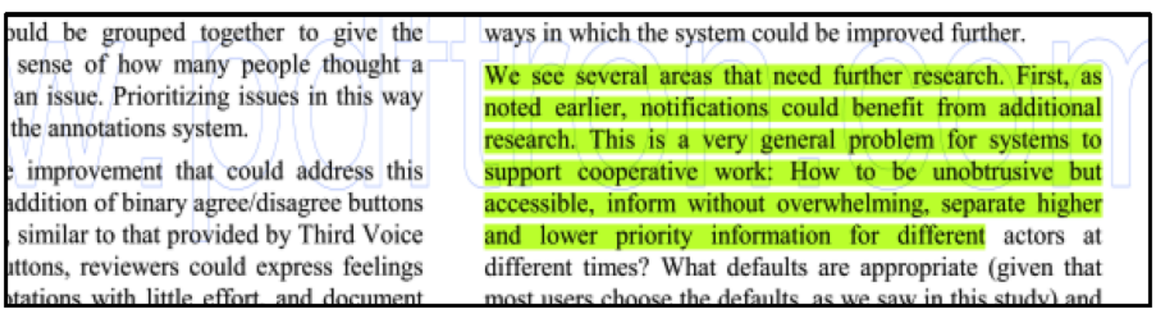
(a) Highlight Annotation



(b) Selection widgets and pop-up appear upon tapping on highlight annotation

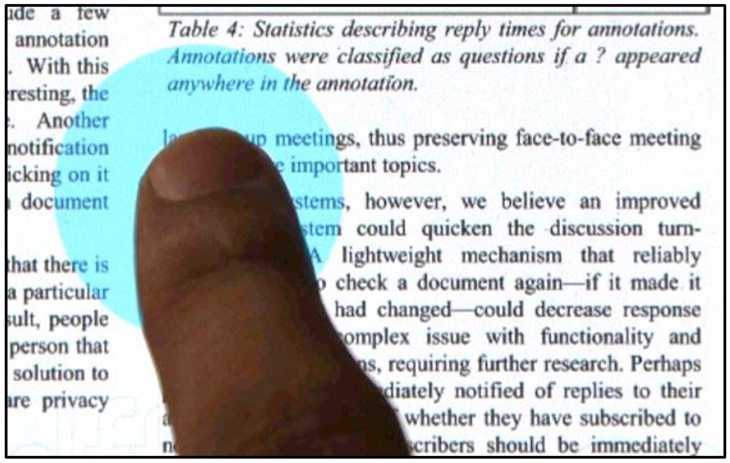


(c) Dragging the selection-widget

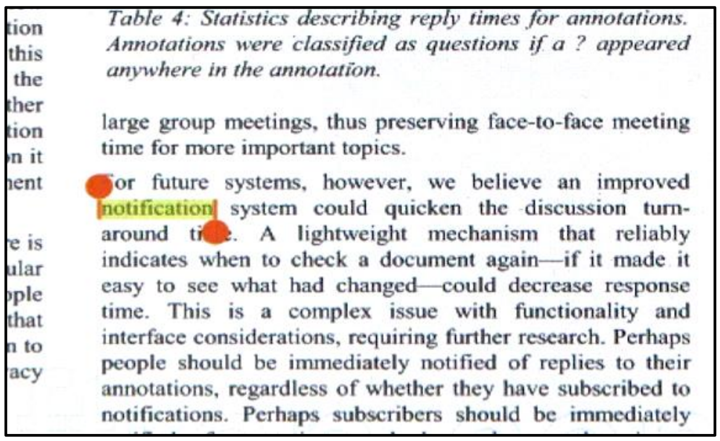


(d) Extended highlight annotation

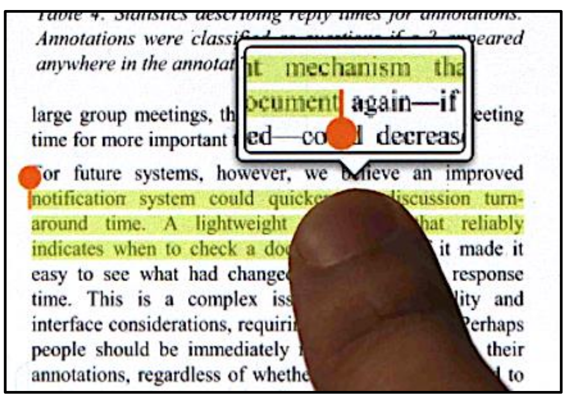
Figure 5.5: Extending or contracting existing highlight by dragging the selection widget



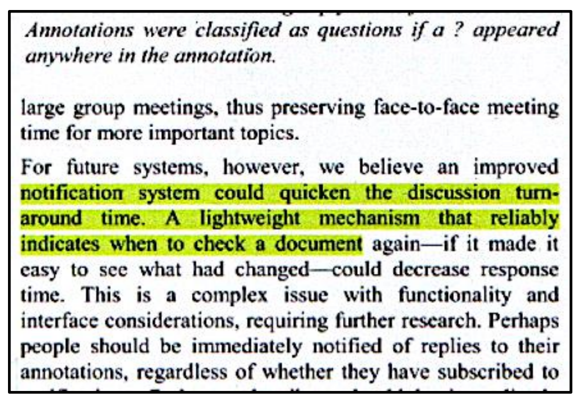
(a) Single Tap on the word to initiate highlight



(b) The word is selected automatically



(c) Drag the selection widget to select the text



(d) Selected text is highlighted when finger is released

Figure 5.6: Text Selection is shown in the tool's color

5.6 SUMMARY

In this chapter, we described changes we made to the design of GestAnnot. Considering participants' feedback, we changed the four and five-finger tap to three-finger slide gestures, and "press and tap then drag" to two-finger tap gesture. In addition, we modified the icons and provided the help for various gestures used in this application. Additionally, we added the feature of extending the existing anchor annotation and provided the color feedback in text-selection. This design was then evaluated in a field study, which is discussed in the next chapter.

CHAPTER 6 FIELD EVALUATION OF GestAnnot

Active Reading activities often involve reading with critical thinking into which the annotation activities must successfully integrate [5]. This means that the controlled lab studies must be supplemented with the real world studies to provide a credible evaluation of whether the application is effective in supporting active reading activities in the real-word scenario. In this chapter, we describe the design and results of a field study, which was conducted with 9 participants who used GestAnnot for 2–5 days for their reading tasks.

6.1 RESEARCH OBJECTIVES

The lab study provided us with the feedback on the gesture design of GestAnnot and helped us in evaluating the relative effectiveness of various aspects of GestAnnot and a menu-based application.

In the experimental task of the lab study, no reading activity was involved as we asked participants to replicate certain set of annotations using both applications. Moreover, the annotations involved in this task do not represent actual annotation activities of the users in their regular reading tasks because individuals might not use all kind of annotations provided in the task, or they might use some different types of symbols, shapes, or other annotations, which we did not include in the task. Therefore, we conducted a field study to assess if the application performs effectively as required by the users during the real-world reading tasks.

In this field study, we evaluated this application in real-world scenario and collected the feedback on user experience and satisfaction. The results from this study helped to determine if the application allows the participants to perform the annotation tasks as required by them during their normal active reading tasks. In addition, the outcome of this study indicated what particular features of the application are more or less appealing to the participants. Furthermore, the feedback gained from this experiment will help to improve the software in terms of its functionality as well as its usability.

6.2 Study Design

This study was divided into three sessions. All participants were required to participate in all three sessions. In the initial session, we briefly explained the study process after which the participants signed a consent form to participate in the study. After signing the consent form, we demonstrated various features of the application and then asked the participants to repeat the demonstrated operation to themselves. This training phase lasted for 2 – 3 minutes. In this session, we asked participants to bring their tablets (with Android OS) on which we installed the GestAnnot app so that participants could take it home to use it for their reading tasks.

During the field trial, the participants were asked to use the application for their reading activities over a period of 2–5 days. During this period, they were required to use GestAnnot for at least 2 sessions of half an hour each.

After the completion of the field trial, we asked participants to meet the researcher for a follow-up session to discuss their experiences with the application. In this session, they were asked to fill a post-activity questionnaire followed by a semi-structured interview. At the end of the interview, we uninstalled the application and copied the software logs from the participants' tablets.

6.3 Recruitment Procedures and Inclusion/Exclusion Criteria

For the study population, we targeted Dalhousie University students, faculty and staff, and members of the larger university community (family, friends). This population contains a broad cross section of the general community including both expert and non-expert users. We asked potential participants to express their interest in the study via e-mail announcements and online bulletin boards. To participate in the study, participants were required to have some experience with annotating the documents either on paper or some other media, and they must have used a smartphone, tablet or comparable mobile device, and be fluent in English. The participants must have an android tablet that they brought in the initial and the follow-up session. The participants must be engaged in active reading tasks presently, and they must use the application for at least 2 sessions of half-an-hour each during the field trial.

After considering the responses, we contacted interested participant via e-mail correspondence to make sure that they have met the inclusion criteria. We recruited 9 participants who were Masters and PhD students from various departments of Dalhousie University. We believe that the number of participants would be sufficient for evaluating various aspects of the application. In this chapter, we will refer to these 9 participants with their IDs (P1–P9).

6.4 Data Collection

The data was collected in the form of software logs, post-activity questionnaire, and the notes taken during the interview with the participants. The software logs recorded the time stamped interaction with the application such as, what annotation tool was used and what particular gesture was performed. The post-activity questionnaire was similar to the questionnaire used for the lab study, which had two parts. In the first part, there were same ratings questions as asked in the lab study and the second part consisted of open-ended questions regarding their experience with the GestAnnot. In addition, the interviews in the follow-up session were audio recorded which were referred later to clarify notes and to obtain interesting quotes.

6.5 RESULTS

In this section, we discuss the results from the field evaluation of GestAnnot, which is subdivided into three sections. In the first section, the background questions are discussed. The second section describes the log-data recorded during the field trial. The third section reports the user satisfaction ratings for various questions asked in the questionnaire.

6.5.1 Background Questions

In the questionnaire, we asked the participants, how often do they perform active reading task? The distribution of participants' responses to this question is shown in Figure 6.1. Four participants reported that they do active reading tasks very frequently (many times a week), and other 4 said that they do this frequently (few times a week). Only 1 participant reported that he rarely performs active reading activities.

They were also asked about how much time they used GestAnnot for their reading tasks. As shown in Figure 6.2, 6 participants mentioned that they used the GestAnnot for one to three hours; 1 participant used it for more than 5 hours while 2 participants used it for less than an hour. These responses were later confirmed by the log-data as it recorded the time stamped activities of participants with the application.

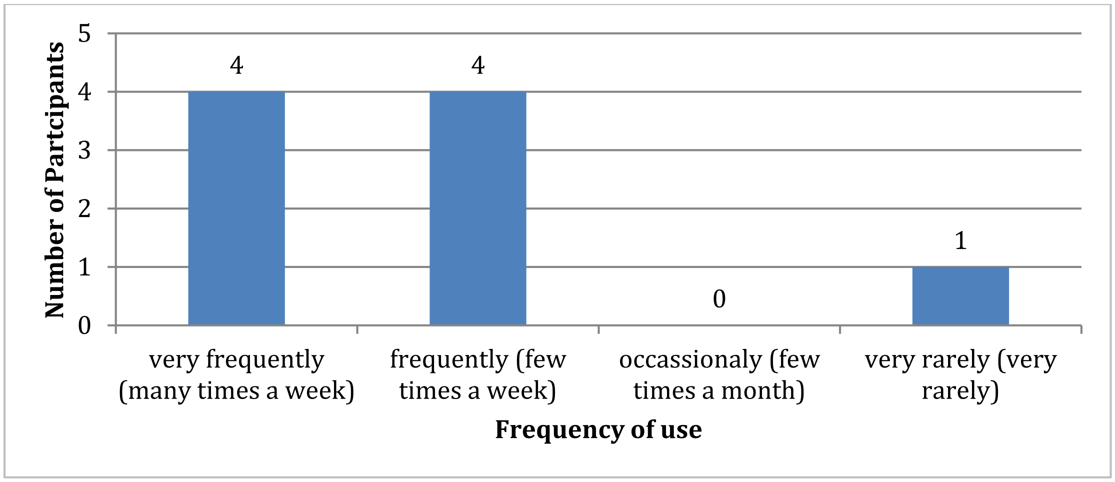


Figure 6.1: How often do you perform Active Reading?

Participant #	Frequency of Use
P1	Very Frequently
P2	Frequently
P3	Frequently
P4	Frequently
P5	Very Frequently
P6	Very Frequently
P7	Very Rarely
P8	Frequently
P9	Very Frequently

Table 6.1: How often do participants perform Active Reading?

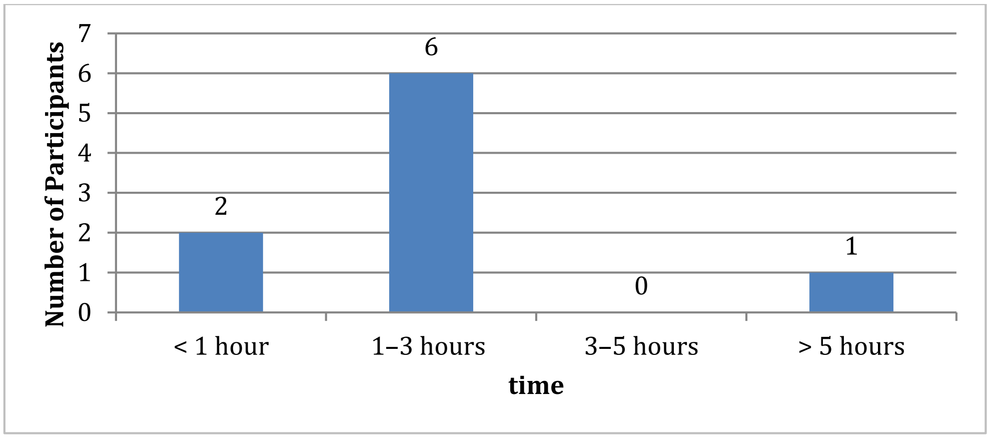


Figure 6.2: How long did you work with this application?

Participant #	Time Spent During Field Trial (hours)	Total Number of Annotations
P1	>5	139
P2	<1	33
P3	1-3	138
P4	1-3	141
P5	1-3	128
P6	1-3	60
P7	1-3	156
P8	1-3	103
P9	<1	154

Table 6.2: Participants' characteristics during field trial

6.5.2 Log Data Analysis

The software logs recorded the time stamped interactions with the application such as, what features the participants have used during the field trial, what gestures they performed, etc. The chart in Figure 6.3 and Table 6.3 shows the annotation features used by nine participants during their reading tasks. The most common annotations used by all participants were highlight, arrow, comment, and freehand drawings. It is evident from the Figure that participants have used different colors for annotations. Furthermore, two participants (P5 and P3) used more number of underline annotations than all other participants. However, the squiggly and strike-through were among the least used annotations, and only few participants used more number of these annotations than the rest of the participants. This data confirms the previous studies that the number and types of annotation usage varies among individuals; therefore, the application should provide all necessary tools, which can support this broad range of annotations with minimal user effort.

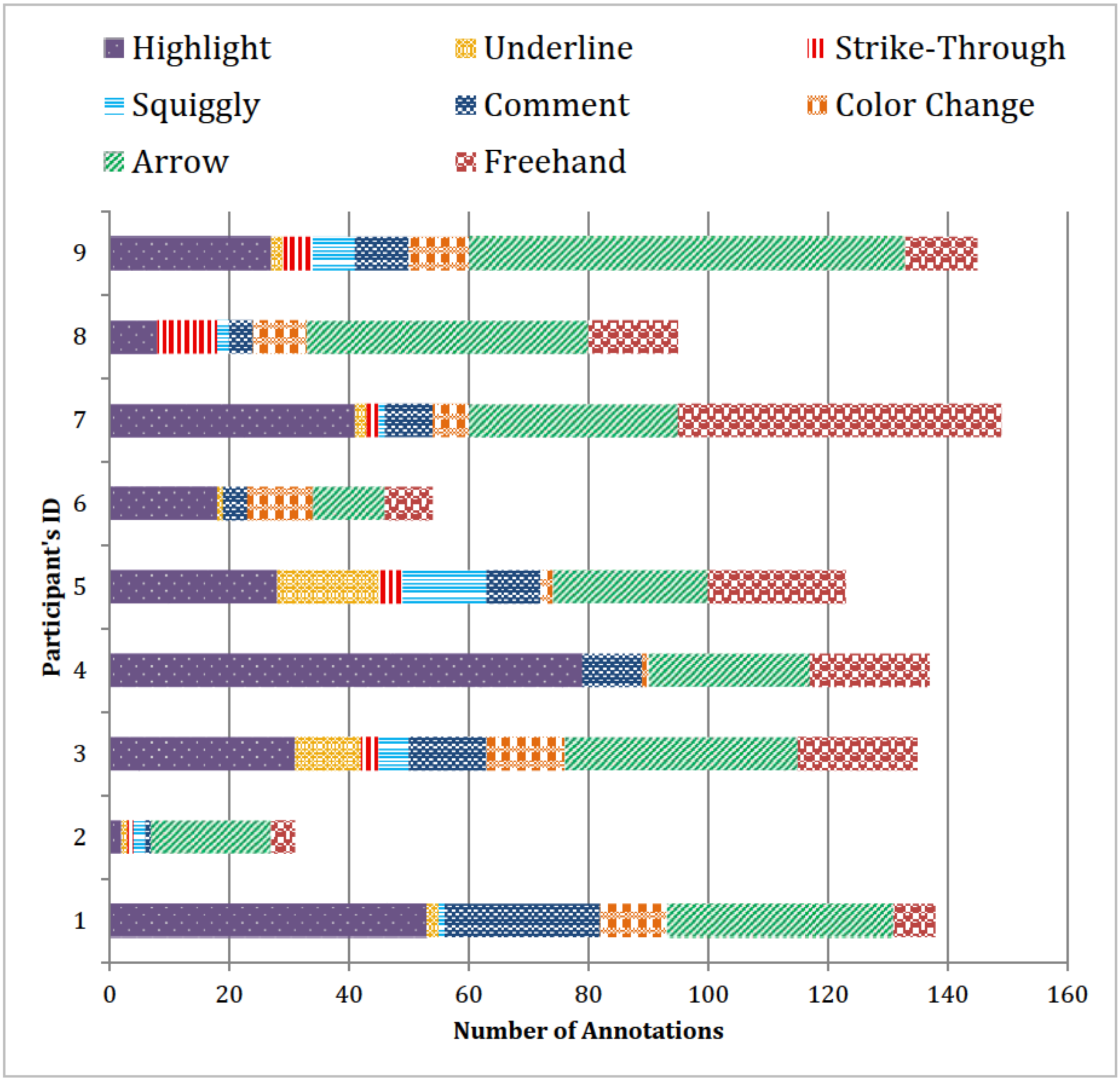


Figure 6.3: Visualization of Log Data recorded during the field trial of nine participants

Participant #	Highlight	Underline	Strike-Through	Squiggly	Comment	Color	Arrow	Freehand	Total
1	53 (38.13%)	2 (1.44%)	0 (0%)	1 (0.72%)	26 (18.70%)	11 (7.91%)	38 (27.39%)	7 (5.03%)	139
2	2 (6.06%)	1 (3.03%)	1 (3.03%)	2 (6.06%)	1 (3.03%)	0 (0%)	20 (60.60%)	4 (12.12%)	33
3	31 (22.46%)	11 (7.97%)	3 (2.17%)	5 (3.62%)	13 (9.42%)	13 (9.42%)	39 (28.26%)	20 (14.49%)	138
4	79 (56.03%)	0 (0%)	0 (0%)	0 (0%)	10 (7.09%)	1 (0.71%)	27 (19.15%)	20 (14.18%)	141
5	28 (21.88%)	17 (13.28%)	4 (3.12%)	14 (10.94%)	9 (7.03%)	2 (1.56%)	26 (20.31%)	23 (17.97%)	128
6	18 (30%)	1 (1.67%)	0 (0%)	0 (0%)	4 (6.67%)	11 (18.33%)	12 (20%)	8 (13.33%)	60
7	41 (26.28%)	2 (1.28%)	2 (1.28%)	1 (0.64%)	8 (5.13%)	6 (3.85%)	35 (22.43%)	54 (34.61%)	156
8	8 (7.77%)	0 (0%)	10 (9.71%)	2 (1.94%)	4 (3.88%)	9 (8.74%)	47 (45.63%)	15 (14.56%)	103
9	27 (17.53%)	2 (1.30%)	5 (3.25%)	7 (4.54%)	9 (5.84%)	10 (6.49%)	73 (47.40%)	12 (7.79%)	154

Table 6.3: Log Data recorded during the field trial of nine participants

6.5.3 User Interactions Satisfaction Ratings

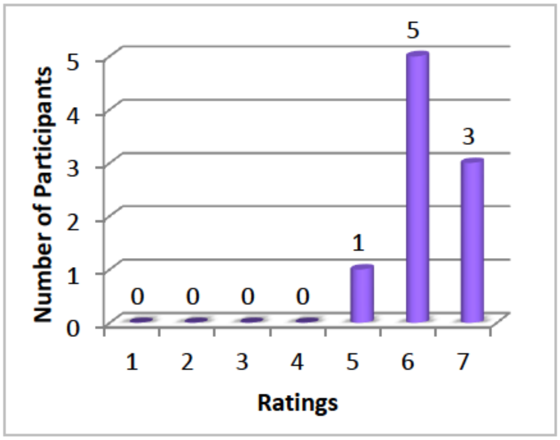
In the questionnaire, there were twenty-five ratings scale questions related to various aspects of the application, which were taken from the QUIS (Questionnaire for User Interaction Satisfaction) [75]. This section elaborated the participants' ratings assigned to these questions on the 7-point rating scale.

1. Overall Reactions to the System

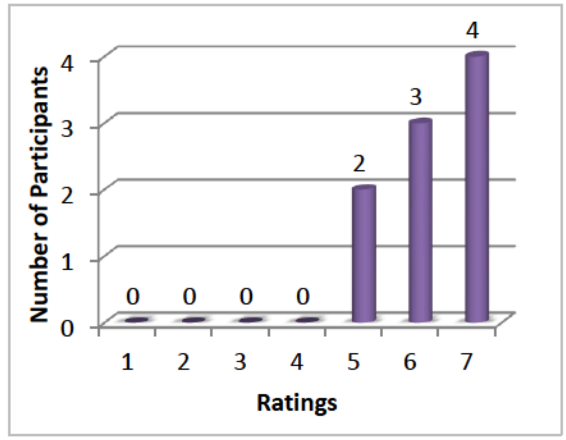
The first five questions asked the participants to provide the overall reactions to the five different aspects of the application. The distribution of participants' responses is graphically shown in Figure 6.4, and the results of their ratings are listed in Table 6.4. The median of these ratings for all five questions is 6, which suggests that the participants were quite satisfied with the overall usability of GestAnnot. As shown in Figures 6.4(d) and (e), most of the participants assigned 6 and 7 ratings, which suggests that they found it very easy and flexible to use.

#	Question	Median	Mean
1.	1=Terrible, 7=Wonderful	6	6.22
2.	1= Frustrating, 7=Satisfying	6	6.22
3.	1= Dull, 7=Stimulating	6	6.11
4.	1=Difficult, 7=Easy	6	6.11
5.	1=Rigid, 7=Flexible	6	6.00

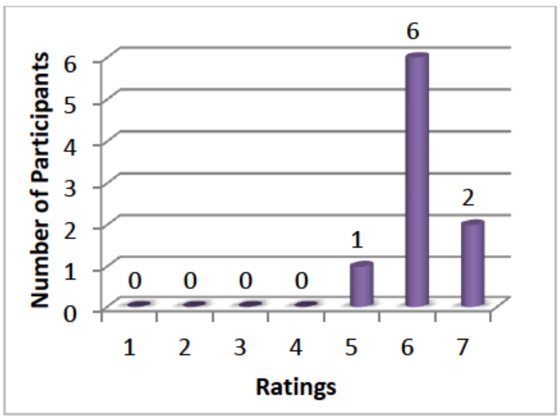
Table 6.4: Overall Reactions to the System



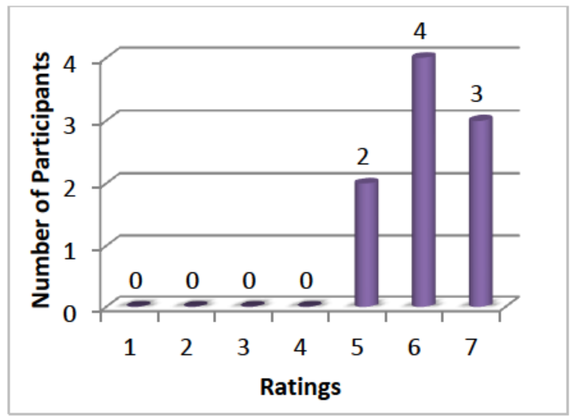
(a) (1=Terrible, 7=Wonderful)



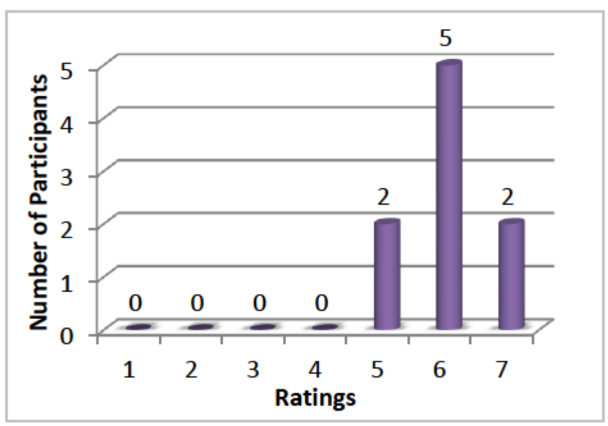
(b) (1= Frustrating, 7=Satisfying)



(c) (1= Dull, 7=Stimulating)



(d) (1=Difficult, 7=Easy)



(e) (1=Rigid, 7=Flexible)

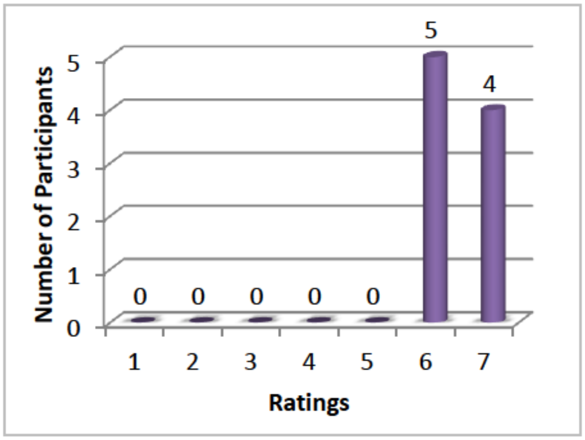
Figure 6.4: Overall Reactions to the System

2. Learning

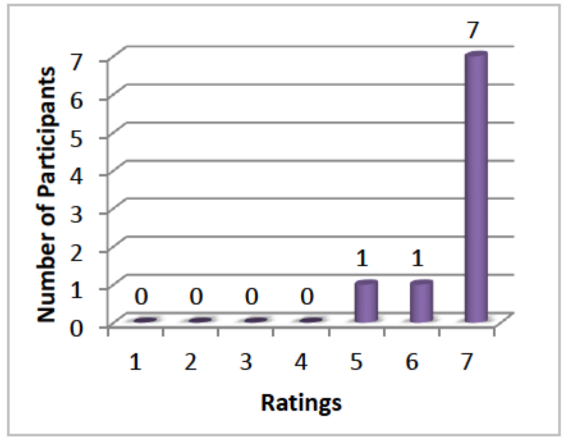
As the system involves various gestures interactions, we were interested in knowing about how easily participants learn these techniques to operate the system. It is indicated by the median 6 that they found GestAnnot easy to learn. In addition, the results in Table 6.5 suggest that the number of steps involved in various annotation operations is very less, and its features can easily be explored by trying the interface. It also indicates that the help messages on the screen, and the help provided for various gestures were clear to understand. The distribution of participants' ratings is shown in Figure 6.5.

#	Question	Median	Mean
1.	Learning to operate the system (1=Difficult, 7=Easy).	6	6.44
2.	Exploration of features by trial and error (1=Discouraging, 7=Encouraging)	7	6.67
3.	Can task be performed in a straightforward manner (1=Never, 7=Always)	7	6.33
4.	Number of steps per task (1=Too Many, 7=Just Right)	7	6.67
5.	Help Messages on screen (1=Confusing, 7=Clear)	6.5	6.38
6.	Tutorials for beginners (1=Confusing, 7=Clear)	7	6.57

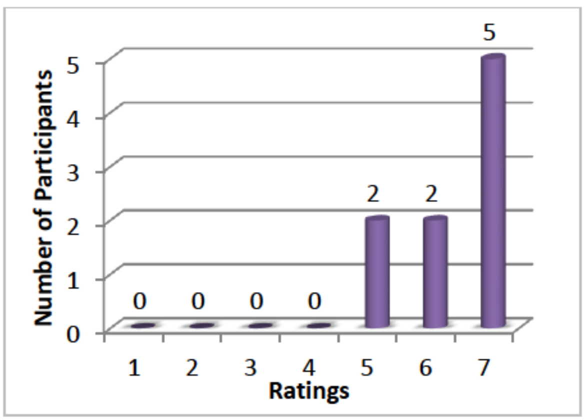
Table 6.5: Questions related to learning



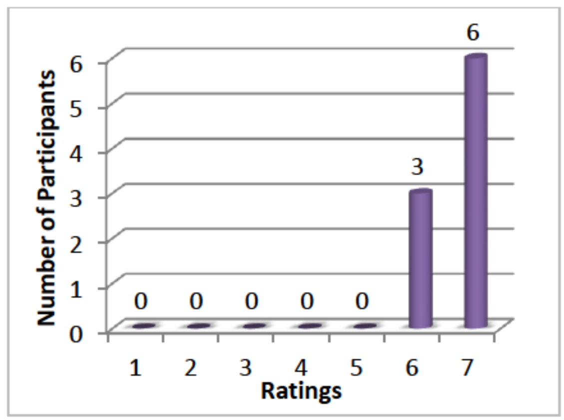
(a) Learning to operate the system (1=Difficult, 7=Easy).



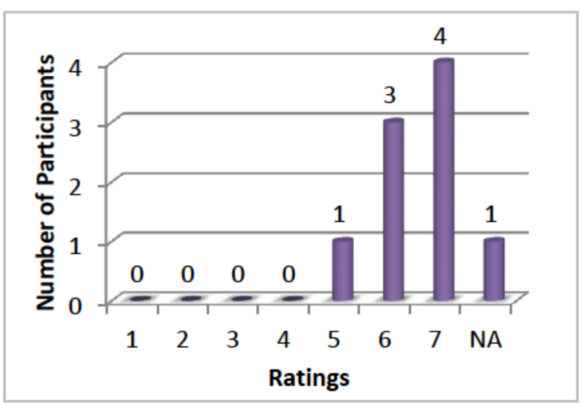
(b) Exploration of features by trial and error (1=Discouraging, 7=Encouraging)



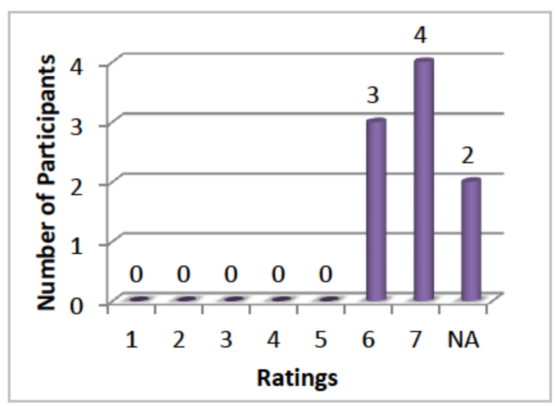
(c) Can task be performed in a straightforward manner (1=Never, 7=Always)



(d) Number of steps per task (1=Too Many, 7=Just Right)



(e) Help Messages on screen (1=Confusing, 7=Clear)



(e) Tutorials for beginners (1=Confusing, 7=Clear)

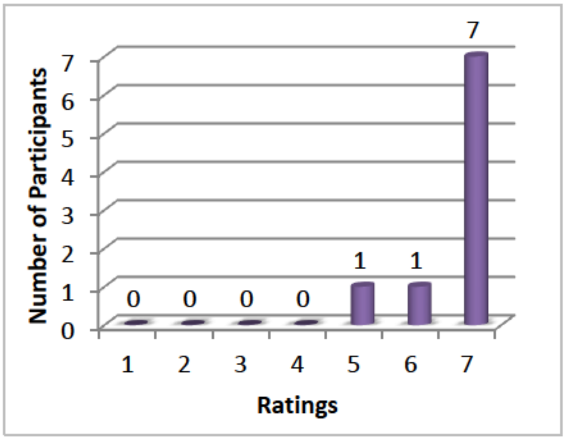
Figure 6.5: Participants' responses to the questions related to learning

3. System Terminologies and System Information

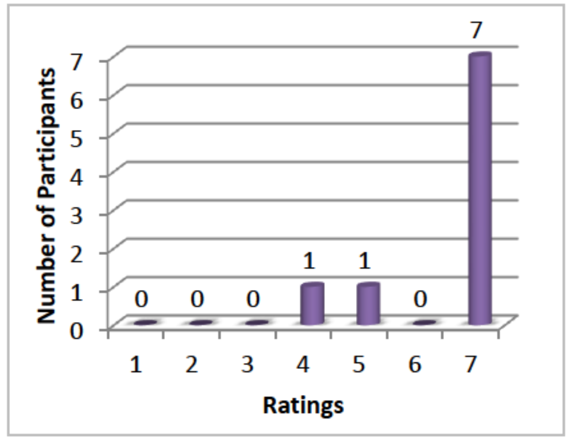
The five questions under this category asked the participants about the effectiveness of system feedback and the terminology used in the application. Median 7 for the first two questions in the Table 6.6 indicates that the terminology used in the GestAnnot was consistent and relevant to the annotation task. In addition, the Median 6 for third and fourth questions in Table 6.6 suggests that the messages that appear on the screen are consistent and clear. The ratings distribution of participants for these questions is graphically shown in Figure 6.6.

#	Question	Median	Mean
1.	Use of terms throughout the system (1=Inconsistent, 7=Consistent).	7	6.67
2.	Does the terminology relate well to the work you are doing? (1=Unrelated, 7=Related)	7	6.44
3.	Messages which appear on the screen (1=Inconsistent, 7=Consistent)	6	6.22
4.	Messages which appear on the screen (1=Confusing, 7=Clear)	6	6.33
5.	Does the system keep you informed about what it is doing? (1=Never, 7=Always)	7	6.56

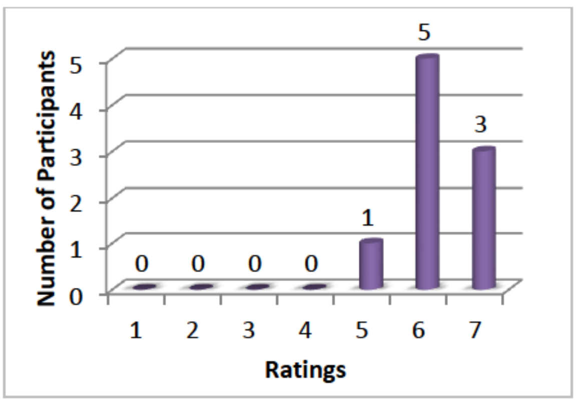
Table 6.6: Questions related to System Terminologies and System Information



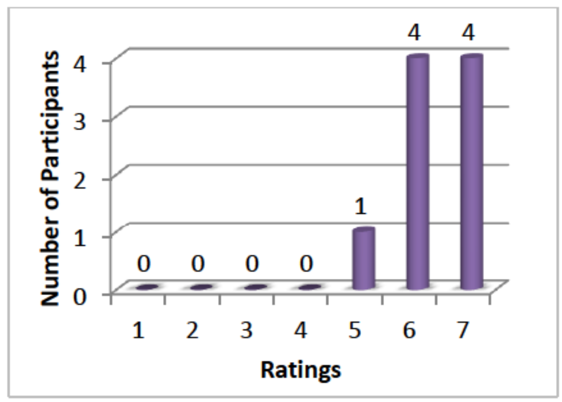
(a) Use of terms throughout the system (1=Inconsistent, 7=Consistent).



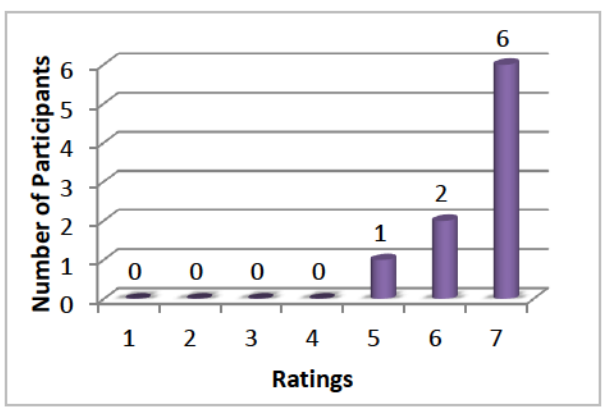
(b) Does the terminology relate well to the work you are doing? (1=Unrelated, 7=Related)



(c) Messages which appear on the screen (1=Inconsistent, 7=Consistent)



(d) Messages which appear on the screen (1=Confusing, 7=Clear)



(e) Does the system keep you informed about what it is doing? (1=Never, 7=Always)

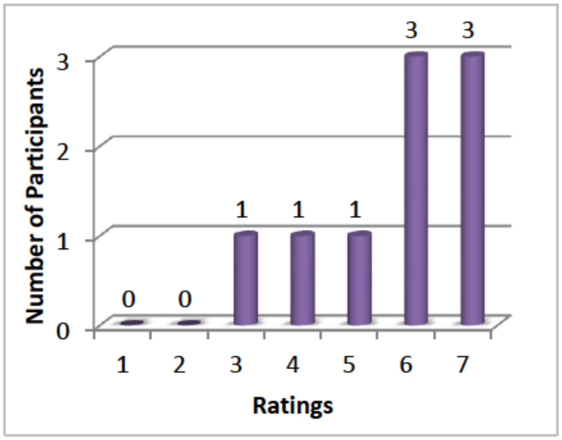
Figure 6.6: Participants' responses to the questions related to system terminologies and system information

4. System Capabilities

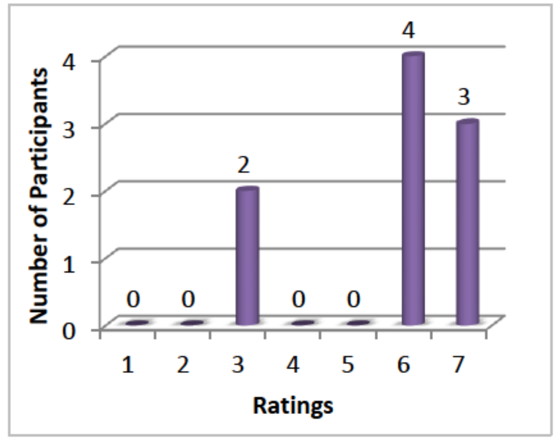
Few participants felt that the application should respond faster in some operations as it is indicated from the median 6 and mean 5.67 of first two questions in Table 6.7. However, the results suggest that, the reliability of the system was good enough. The ability to undo was missing in this application, as it is evident from the median 5 of sixth question. Although, the application allows the user to delete any annotation, but it does not provide a way to undo, which was suggested by almost every participant. The graphical representation of participants' responses to these questions is shown in Figure 6.7.

#	Question	Median	Mean
1.	System speed (1=Too Slow, 7=Fast Enough)	6	5.67
2.	Response time for most operations (1=Too Slow, 7=Fast Enough)	6	5.67
3.	Rate of information display (1=Too Slow, 7=Fast Enough)	6	5.89
4.	How reliable is the system (1=Unreliable, 7=Reliable)	6	6.11
5.	System failures occur (1=Frequently, 7=Seldom)	6	6.33
6.	Ability to Correcting your mistakes/Undo	5	5.00

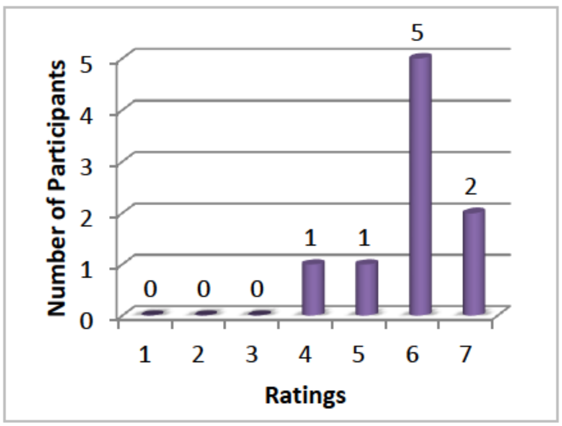
Table 6.7: Questions related to system capabilities



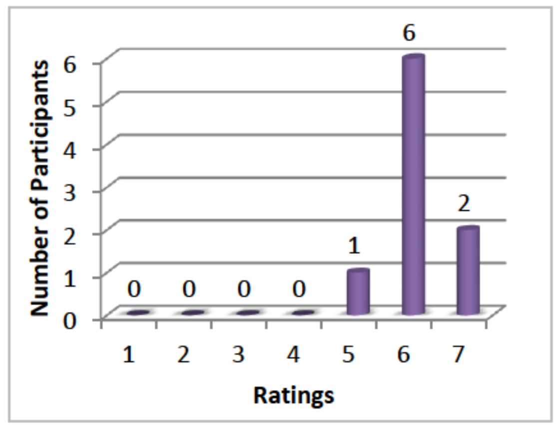
(a) System Speed (1=Too Slow, 7=Fast Enough).



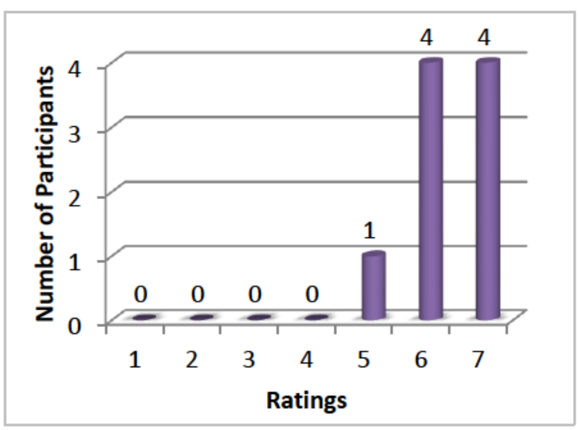
(b) Response time for most operations (1=Too Slow, 7=Fast Enough



(c) Rate of information display (1=Too Slow, 7=Fast Enough)



(d) How reliable is the system (1=Unreliable, 7=Reliable)



(e) System failures occur (1=Frequently, 7=Seldom)

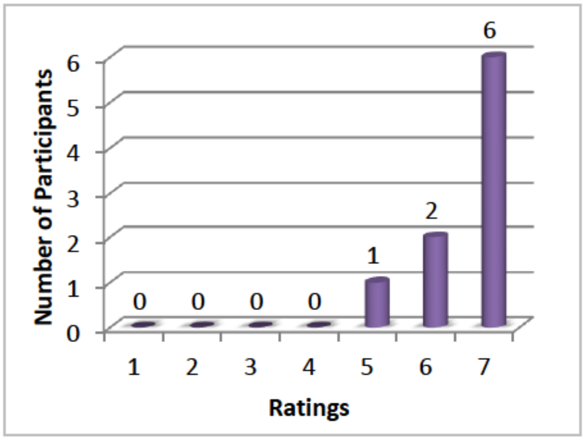
Figure 6.7: Participants' responses to the questions related to system capabilities

5. Screen Elements

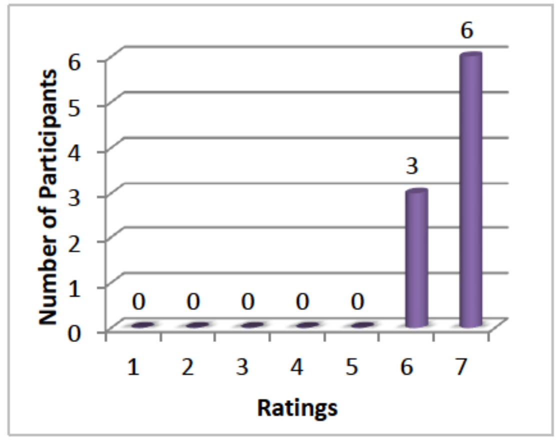
From the results shown in Table 6.8, it is suggested that the layout of the GestAnnot was helpful, and the other screen elements such as icons, text, etc. were easy to understand. The distribution of the participants' responses is shown in Figure 6.8.

#	Question	Median	Mean
1.	Characters on the screen (1=Hard to Read, 7=Easy to Read).	7	6.56
2.	Was the highlighting on screen helpful? (1=Not at all, 7=Very much)	7	6.67
3.	Were the screen layouts helpful? (1=Never, 7=Always)	7	6.44
4.	Amount of information that can be displayed on screen. (1=Inadequate, 7=Adequate)	7	6.67
5.	Arrangement of information. (1=Illogical, 7=Logical)	7	6.56
6.	Sequence of screens. (1=Confusing, 7=Clear)	6	6.11

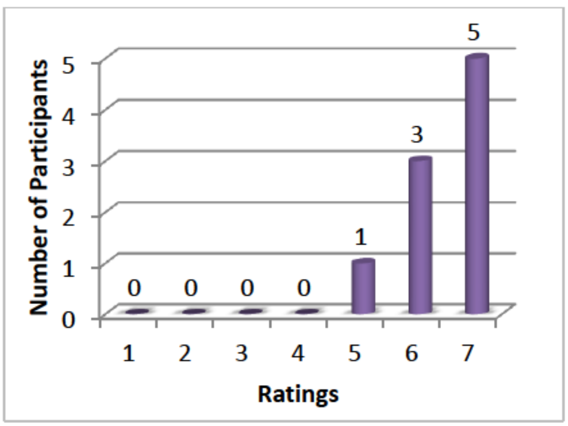
Table 6.8: Questions related to screen elements



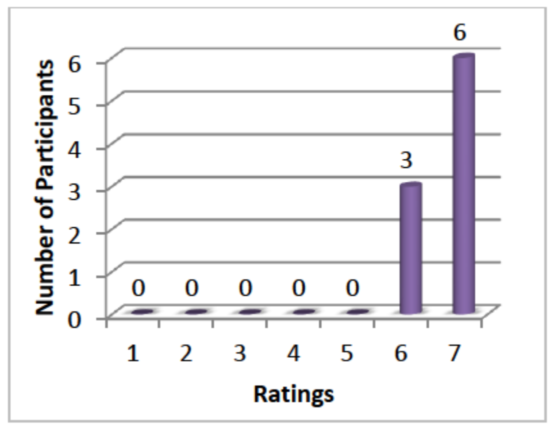
(a) Characters on the screen (1=Hard to Read, 7=Easy to Read).



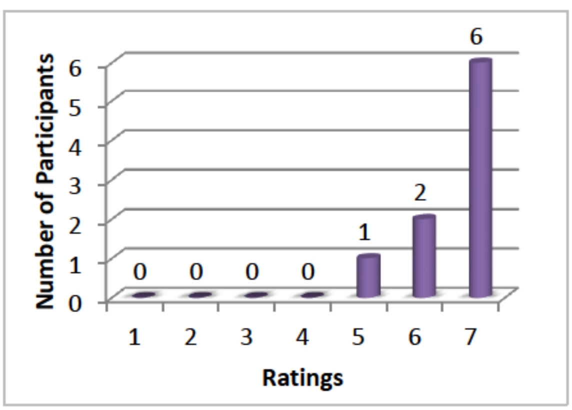
(b) Was the highlighting on screen helpful? (1=Not at all, 7=Very much)



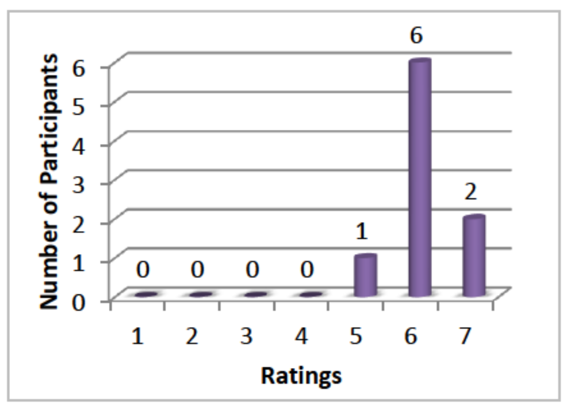
(c) Were the screen layouts helpful? (1=Never, 7=Always)



(d) Amount of information that can be displayed on screen. (1=Inadequate, 7=Adequate)



(e) Arrangement of information. (1=Illogical, 7=Logical)



(f) Sequence of screens. (1=Confusing, 7=Clear)

Figure 6.8: Participants' responses to the questions related to screen elements

6.6 PARTICIPANTS' COMMENTS

During the follow-up session, participants provided their feedback through semi-structured interviews and open-ended questions asked in the questionnaire. Both interview and questionnaire's questions were related to their experiences with the application. In this section, we discuss the participants' responses to these questions, which will eventually reflect the necessary changes that can be made to enhance the usability of GestAnnot.

6.6.1 Gestures

All participants mentioned that gestures have increased their efficiency in using annotations while reading articles, academic papers, etc. P6 said, "The highlighting is easy and it is easy to post comments…the application is overall interactive to use." P1 stated, "It was very easy and comfortable to use gesture based approach to change the selected operation." In both interview and questionnaire, we asked participants whether gestures used in the system were easy to use, and 8 participants responded that all gestures were quite easy to use, but one participant (P2) said that he has some difficulty using the three-finger swipe gestures for switching between the anchor annotation tools. He suggested that it would be better if he can use two-finger swipe for this operation. We have already considered two-finger swipe gestures before making improvements in the design, but we did not use it because it might conflict with the pinch and two- finger tap gestures that are used for zooming and creating arrow in GestAnnot. Moreover, it is evident from Table 6.1 that P2 used this system for less than an hour and only created 33 annotations, which was least among all other participants. As shown in Figure 6.9, P2 performed three-finger swipe gesture only six times during field trial. This might be the reason why P2 found three-finger swipe difficult that he used the system for a very short period and did not use much of the annotation features of GestAnnot.

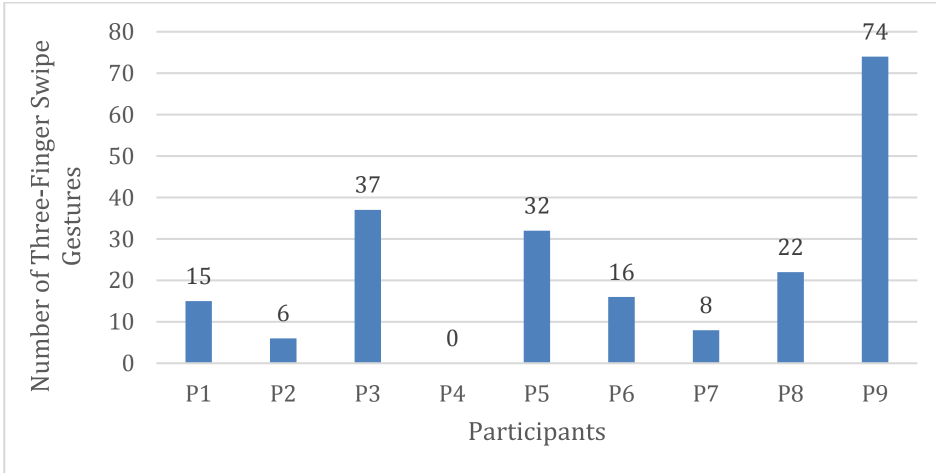


Figure 6.9: Number of Three-Finger Swipe Gestures by participants during field trial

P6 mentioned, when he was scrolling the page very rapidly, sometimes the application was responding to double tap gesture. It happens when the time duration between the two taps is lesser than the threshold time between the taps of double-tap gesture. In this case, P6 was tapping on the screen rapidly to scroll the page; therefore, the system was translating two consecutive taps into double tap gesture thereby opening a comment dialog. However, decreasing the threshold time between the taps of double tap gesture, and making the system ignore double tap gesture while the user scrolls the page might resolve this issue.

6.6.2 Highlight and Comment

Participants mentioned that the selection of the text by tap and drag gesture is easy in this application. One participant (P5) said that the selection accuracy should be increased. He said that sometimes the word does not become selected when he taps on it. It happens when the touch point does not lie on any word; instead, it occurs in between the text lines or words. This issue might be resolved by making the system select the closest word to the touch point, when the point of touch lies between the text lines. He also suggested when the user lifts the finger after dragging the selection widget; the application should automatically include the last word in that selection even if the user has selected a portion of that word. Few participants in the lab study also suggested this feature. Furthermore, P9 said that she liked that the application allows the user to extend or contract the existing highlight, which was useful during her reading tasks.

Three participants (P1, P6, and P9) suggested that the comments should automatically adjust it size and font to fit within the margins and available space so that it does not spread outside the page limit or overlap the text or other comment annotation. Many participants in the lab study also suggested this feature.

One participant (P6) suggested that there should be a feature to link a comment with a highlight annotation. In the future versions, this feature can be incorporated and some gesture can be assigned to do this. For example, if the user taps on a highlight and a comment simultaneously, it should generate a visual link between these annotations. However, an arrow annotation can act as a visual link between a comment and a highlight. Two participants (P1, P2) suggested a similar feature of having a composite annotation. They said when the user creates an arrow; it should automatically create a comment at the pointed end of that arrow. We propose that these two suggestions can be combined in a way, when user taps with two fingers having one finger on a highlight annotation, it should create an arrow and a comment at its pointed end and also the arrow should act like a link between these highlight and comment annotations. This approach will not require using any other gesture; therefore, this technique will not be difficult to learn.

6.6.3 Arrow and Freehand

All participants mentioned that the arrow was very easy to use with two-finger tap. P6 said, “Instead of tick-marking I thought I could use the arrow also.” This suggests that, if the application provides different tools that can be used easily, users might use them for different purposes. P3 suggested that they should be able to draw curved arrow also, along with the straight ones. Although, users can do this using freehand tool, but P3 suggested that the straight arrow should have some pivot point, which can be used to transform it to the curved arrow. Two participants (P7, P8) mentioned that the system does not allow them to rotate the arrow once it is created, which is required in some cases. Furthermore, two participants (P6, P9) said, when they started using this application, they were using two-finger tap to generate the arrow but the direction of arrow was not clear to them. Later, they realized that the first finger that touches the screen specifies the starting point and the second finger specifies the pointed end of the arrow. Although, this technique was described in the help pop-up but the image used for describing the gesture was indicating two-finger tap. P9 suggested that instead of an image of the gesture in the help dialog, if it shows animated hand performing this gesture, then it would make the direction of an arrow more intuitive to understand. Furthermore, three participants (P1, P5, and P9) reported that they had a difficulty in selecting the arrow annotation when it overlaps the original text. Many participants mentioned this issue in the lab study as well and the potential solution to this problem was proposed in the Section 4.5.6.

Participants mentioned that the freehand tool was very helpful for drawing shapes and symbols while few of them said that they do not usually use shapes or symbols in their annotations. P6 said,” I liked making shapes with freehand” while P8 stated, “Freehand tool is not mainly useful." Moreover, three participants (P3, P7, and P8) mentioned that the freehand drawing lags behind the finger movement; therefore, its sensitivity should be increased. However, this might have happened because of the less touch sensitivity of the device that participants used for their readings. We realized this problem later and it can be resolved by using tablets with faster graphics processor, and optimizing the code that renders the freehand digital ink.

6.6.4 Document Viewing and Browsing

GestAnnot was designed for opening and viewing one PDF document at time, but two participants (P1, P3) said that it should allow them to open multiple documents in different tabs, which can be navigated easily by using some gesture. In addition, it should allow them to copy the annotations from one document to another. However, it is not difficult to implement but it requires more hardware resources, which are usually limited in tablets.

GestAnnot has a feature to view and annotate a file from a URL. P1 said when he did not copy the "http://" part of a URL of an online article; the application could not open that online file. Therefore, it should automatically append this prefix when user does not provide it in the URL. He also suggested that it should automatically save the online file to the local drive before creating annotations on it.

In GestAnnot, the user can browse a list of all PDF files present on the local drive of the tablet. P1 suggested that instead of a simple list, it should allow users to group these files into folders. In addition, recently opened files should be grouped into a separate list to access them quickly. Furthermore, P1 noticed that GestAnnot does not play the embedded video files in PDF documents, which can be an additional useful feature in this application if it can support it.

6.6.5 Miscellaneous

Two participants (P1, P3) suggested that GestAnnot should include some built-in symbols such as star, asterisk, smileys, etc., which can be used by simple drag and drop technique. One participant (P9) said that she would like to have inbuilt shapes such as rectangle, ellipse, etc. in the application.

All participants mentioned that the undo option is required in the system especially for the freehand drawing. All participants in the lab study unanimously demanded this feature too. In the current PDFTron SDK, the undo feature is not present, therefore; we could not include it in our design, but it should be considered in the future versions.

Two participants (P1, P9) mentioned that changing color was very easy. P1 stated, "When I was reading the article, I have highlighted everything into some green portion or yellow portion…Later on I was reading the conclusion…I wanted to highlight it into different color because it was the conclusion…It was very easy to mark it as red color…and it was giving me a different feeling that this is a kind of some special selection…and it was very easy to perform".

P1 reported that he could not turn the page when the freehand tool was activated. This was one of the most common issues identified by participants in the lab study. As discussed in Section 4.5.1, this issue might be resolved by providing buttons for turning the pages when freehand tool is activated.

Most importantly, the major goal of this application was to integrate the annotation task with the reading activity smoothly and provide a better user experience. P5 said, "It added to my reading and I found it easy to use." P6 stated, "The application is overall interactive and easy to use." P4 said, "The system is really useful for the researchers especially for reading articles. It reduces efforts and makes it easy to annotate." P5 also stated, "The application provides more than required amount of tools. I think it is the best tool I have come across for active reading by far…I like the system for the type and variety of annotation tool it provides. It really helps in reading and making notes simultaneously." P9 mentioned in the questionnaire, "In general, this app is more versatile and easy to use than the current PDF annotation applications available in the market."

6.7 Important Findings from this Study

We have conducted this user study to assess if the application performs effectively as required by the users during the real-world reading tasks. The results of this study has helped us to understand what features of GestAnnot are more or less appealing to the participants, and what features are required to be added in the application to support the annotation requirements of the participants. From the careful analysis of the study data presented in the Sections 6.5 and 6.6, we were able to identify some interesting findings, which are described in following subsections:

6.7.1 Change in Annotation Behavior

From the analysis of the participants' comments, we came across a very interesting finding. A participant mentioned that he usually uses checkmark annotation, when he reads from paper. However, he used arrow in place of checkmark while he read few articles using GestAnnot. He mentioned that he knew that he could draw checkmark using freehand tool which was a two-step process (1) Mode Switching to Freehand Mode, 2) Drawing

Checkmark), but he preferred to use arrow through “Two-Finger Tap” gesture because it required only one step and it was easier than drawing with freehand (see Section 6.6.3). This observation suggests that some users might be willing to change their annotation behavior if they come across an easier annotation type to use. It would form an interesting research subject for some future research to validate this kind of annotation behavior modification.

This observation also indicates that if users are accustomed to use some special symbols, which have some particular meaning to them, the application should be flexible enough to accommodate this need as conveniently as it does for other annotation types. For example, if the user uses “#” symbol in his annotations quite often, he should not have to switch the mode to freehand drawing and then draw this symbol. As a possible solution, the application could provide some built-in gestures that could be associated with a symbol of the user’s choice, wherein this symbol could come from a list of available symbols or be drawn by the user if it is absent from that list.

6.7.2 Composite Annotation

Participants mentioned that they generally used arrow and comment together, therefore, the application should have a composite annotation tool along with an associated gesture, which create arrow and comment in one step instead of creating each of them separately (see Section 6.6.2).

Participants also suggested that there could be some visual link connecting two different annotation types, e.g., a highlight and a comment, to indicate a relationship between them. A possible solution could be a gesture like “Two-Finger Tap” tap with one finger on highlight and the other on the comment to create the said visual link. This visual link could be a simple arrow or a line.

6.7.3 Miscellaneous

- One of the most common issues that were raised by the participants was that the comment should automatically adjust itself within the available marginal space. They mentioned that after typing the comment, it took much effort to resize the comment box so that it did not overlap the text or other annotations. As a possible solution, the application should automatically adjust the font size and the line spacing of the text in the comment to accommodate the comment in the space available (see Section 6.6.2).
- Few participants mentioned that the application should allow them to open multiple documents in different tabs of the same window so that it is easier for them to navigate between documents. They also suggested that they should be able to copy and paste some annotations particularly a note or a comment from one document to the other (see Section 6.6.5).
- Many participants mentioned that they often missed selecting the whole last word while performing highlight or some other anchor annotations. As a result, the annotation thus created included the selected portion of the word. Although, they liked that they could extend the anchor annotations from its boundary points, they still wanted that the application should automatically include the remaining portion of the word, where the anchor annotation ended (see Section 6.6.2).
- As suggested by many participants, instead of showing a picture of a gesture and its description in the help pop-up, which appeared when they tapped on gesture icons, they would prefer an animated clip that demonstrates how to use a particular gesture.

- Participants also mentioned that the application should allow them to make curved arrows. As a possible solution, the straight arrow should have a pivot point form where it could be bent.
- An undo feature was demanded by almost every participant especially for reverting the freehand strokes.

6.7.4 Repetitive Arrows

We collected time stamped participants' interaction during the field trial, as described in section 6.5.2. In the collected log data, we observed that participants created more than one arrow in a continuous sequence and the time interval between the consecutive occurrences of arrows usually lied between 2-6 seconds. Table 6.9 shows the number of times such sequences occurred in participants' task along with the size (number of arrows) of each sequence.

The occurrence of these sequences might suggest two perspectives. First, the participants might have created multiple arrows for practicing the corresponding gesture. However, log data suggests that these sequences occurred throughout their reading task; therefore, it is unlikely that participants were just practicing the gesture. Second, P6 suggested that he used arrow for marking interesting points in the text instead of checkmark, which he generally used on paper (see Section 6.6.3). It is a possibility that other participants have used the arrow annotations in a similar way.

However, we cannot explain this behavior with confidence because we did not collect the documents, which were annotated by the participants during the field trial. Therefore, future research could try to uncover the reason behind this behavior.

Participant	# Sequence	Size of Sequences
P1	7	3, 3, 4, 2, 4, 2, 2
P2	4	4, 4, 5, 4
P3	5	2, 3, 3, 4, 5
P4	5	3, 2, 5, 3, 3
P5	4	3, 4, 3, 2
P6	3	2, 4, 2
P7	4	4, 2, 2, 3
P8	8	4, 2, 7, 2, 3, 2, 2, 3
P9	13	4, 2, 2, 7, 4, 2, 3, 3, 7, 9, 13, 3, 2

Table 6.9: Sequences of arrow annotation

6.7.5 Switching by Swipe vs. Switching by Selection

As discussed in section 5.2, the improved design incorporated three-finger swipe gestures, to switch between anchor annotations tools (i.e., highlight, underline, squiggle, and strike-through). Alternatively, users could switch between these tools by simply selecting the tool from the tool menu. From the collected log data, it is evident that four participants (P3, P5, P8, and P9) used other anchor annotation tools in addition to the highlight tool (see Table 6.3). Other participants (P1, P2, P4, P6, P7, and P10) have not created more than two annotations (see Table 6.3) using other anchor tools (underline, squiggly, and strike-through), which suggests that they might have created these annotations while trying the interface but not while actual reading tasks. Therefore, we ignored these six participants for the purpose of our analysis described in this section. We observed the log data and calculated the number of times a participants used three-finger swipe to switch, and number of times they performed switching by selecting the tool from the menu. While doing this, we ignored those cases where participants performed three-finger swipe gesture but did not use the switched anchor annotation tool after switching. This is because they might have performed these gestures while trying the interface but not while performing the task. As shown in Table 6.10, all four participants (P3, P5, P8, and P9) who used multiple anchor annotation tools have used three-finger swipe technique more number of times than simple selection technique. This indicates that participants preferred to use three-finger swipe gesture than menu-based interaction to select the desired anchor annotation tools. This finding suggests that the design feature of incorporating a gesture for selecting the current anchor annotation tool was liked by the participants.

Participant	# Switching by Swipe	# Switching by Selection
P3	9	5
P5	17	2
P8	3	1
P9	11	0

Table 6.10: Switching by Swipe vs. Switching by Selection

6.8 Proposed Guidelines for an Active Reading Application on Tablet

1. *The swipe gestures are appropriate for switching between anchor annotation tools*. As a possible solution, three-finger left and right swipe gestures are suitable for this task and they are easy to learn and use (refer to Section 6.6.1).

2. *The two-finger tap gesture is appropriate for creating arrow annotation* (refer to Section 6.6.3).

3. *The anchor annotations should include the entire word if users miss to include the whole word and select only a portion of this word.* This guideline was also formulated by the

results of the lab study. Therefore, our both studies confirm that participants require this feature in the application (refer to Section 6.6.2).

4. *The comment should adjust itself within the available marginal space without the need to resize and reposition it explicitly.* This guideline was also formulated by the results of the lab study. Therefore, our both studies confirm that participants require this feature in the application (refer to Section 6.6.2).

5. *There should be a "link" tool in the application, which can be used to join a comment with a highlight annotation (or any other anchor annotation)* (refer to Section 6.6.2).

6. *There should be a composite annotation tool, which creates an arrow and a comment (at the pointed end of arrow) in one-step without having to create them separately* (refer to Section 6.6.3).

7. *The user should be able to bend the arrow annotation to make a curved arrow* (refer to Section 6.6.3).

8. *The animated clips for demonstrating the gestures should be provided in the application.* This guideline was also formulated by the results of the lab study. Therefore, our both studies confirm that participants require this feature in the application (refer to Section 6.6.3).

9. *The users should be able to open multiple-documents in different tabs and in same window, and should be able to copy and paste comments or sticky notes annotation from one document to another* (refer to Section 6.6.4).

10. *Few built-in symbols (e.g., asterisk and star) should be provided in a menu, which can*

be used through simple drag and drop interaction or through gestures. This guideline was also formulated by the results of the lab study. Therefore, our both studies confirm that participants require this feature in the application (refer to Sections 6.6.5 and 6.7.1).

11. *The application must allow users to undo any number of previous steps.* This guideline was also formulated by the results of the lab study. Therefore, our both studies confirm that participants require this feature in the application (refer to Section 6.6.5).

12. *During the freehand drawing mode, users should be able to turn and scroll the page and to perform zoom in or zoom out.* A possible solution could be providing dedicated buttons for these operations, which should appear while the freehand mode is active. This guideline was also formulated by the results of the lab study. Therefore, our both studies confirm that participants require this feature in the application (refer to Section 6.6.5).

6.9 Reflections on Methodology

The major objective behind this study was to understand how effective GestAnnot was in providing an Active Reading environment in the real world scenario. We based most of our results on the user reported data collected through questionnaires and interviews. Although, we collected software logs during the field trial, we could not derive results from it with enough confidence due to three reasons. First, in the application logs, we did not record some important interactions such as, how many time participants had to delete an annotation or how many times they used the help for gestures. This could have provided us with additional data to understand how accurately participants performed their tasks using GestAnnot, rather than just relying on user reported data. Second, we could not determine what interactions in the log data accounted for practicing with the application and what interactions occurred during the actual reading task. Third, we did not collect the documents on which participants made annotations during the field trial; therefore, we could not determine how participants used different annotation in their reading tasks.

To address the above-mentioned limitations of our methodology, we could have done it differently in two aspects. First, we could record the screen co-ordinates of participants' interactions, which might have helped us in getting better picture of what participants did during the field trial. Second, more importantly, we could modify the ethics application to collect the documents on which participants annotated during the field trial. This could give us a more accurate understanding of what, why and how participants used GestAnnot in their Active Reading tasks. Additionally, it could help us in determining what interactions were performed for practicing with the application and what were performed during the actual reading tasks.

6.10 Summary

In this chapter, we presented the quantitative and qualitative results of the field study, which was conducted to evaluate the GestAnnot in a real-world scenario. The results showed that the participants liked the improved design and would like to use this system for their future reading activities, as well. The results also indicate that the GestAnnot performs mostly as required by the participants. The suggestions made by the participants will further improve the usability of this application and provide a better reading environment. This study validated some guidelines which were formulated in the lab study and also provides more design guidelines, which can be followed in the future designs of annotation applications.

CHAPTER 7 CONCLUSION AND FUTURE WORK

In this chapter, we discuss the features, which should be incorporated in the future design of annotation applications.

7.1 Future Work

We developed a gesture-based annotation system for providing better reading experience and annotation facility. To evaluate GestAnnot application, we conducted a lab study and field study with graduate students from different fields and departments. Since the population included mainly students, population that is more diverse will be required to further evaluate and validate the application. In the subsequent sections, we will discuss various features that can be considered in the future development of an annotation application. These features are based upon the participants' suggestions provided in the user studies and the personal experience gained during the research.

7.1.1 Customizing Gestures

We have observed that few participants performed four and five-finger tap very easily while other have difficulties in doing so. Therefore, we have changed these gestures to three-finger swipe gestures, which were well acknowledged by the participants in the field study. In the future designs, few presets of gestures may be provided so that the users can have freedom to choose the appropriate gestures' set for them. For example, one preset might have four and five-finger tap gestures and other have three-finger swipe gestures for switching between the anchor tools. However, the choice of gestures in different presets will require some evaluation studies to provide the presets that can suit a wide range of users' preferences.

7.1.2 Pop-Up Menu

We provided four common colors for quick access in the pop-up menu, which appears upon tapping on an annotation. The future designs should allow users to select the number and choice of these quick access colors in the pop-up menu. Also, if the user selects any other color from the 'color dialog picker' as shown in Figure 3.6, the recently selected color should be shown in the pop-up menu so that the user can easily access these colors without going to color-dialog picker again. However, only one or two of such colors should be present in the pop-up; otherwise, it will increase the size of the pop-up and may confuse the user.

In the current design, users can select one of the five text sizes for comment annotation but it does not allow them to input customize text sizes. This feature should also be considered in future development also.

7.1.3 Accuracy and Sensitivity

The selection accuracy of text can be enhanced in further development of GestAnnot. As discussed in Section 6.6.2, when users try to select a word by tapping on it and the touch point of their finger lies in between the words or between the lines of text, it should automatically select the closest word to the touch point. In addition, it should automatically selects the last word of the selection, when user selects only a portion of that word.

The sensitivity of the device in recognizing gestures is a crucial requirement for this application, which depends upon various parameters. For example, changing the threshold distance and speed of swipe motion can vary the sensitivity of swipe gestures. Similarly, the sensitivity of double-tap can be adjusted by varying the duration threshold between its two taps. In future developments, an option to adjust the sensitivity of these gestures can be provided so that users can select the suitable settings according to their preferences and their device capabilities.

7.1.4 Help and Tutorials

In the current design, we provided static help for all gestures used in the system. However, the animated clips that can demonstrate the gestures' operations will provide more lucid help to users. Moreover, similar tutorials that ask the user to try various operations of the application at the startup of the application can assist in learning about the interface.

7.1.5 Exporting Annotations

In the current design, we did not implement this feature of exporting annotations to a document but it should be considered in future developments. In addition, if the exported annotations have the name and the page number of the original document on which it was created, it will make it easier to refer to the original document, whenever necessary.

7.1.6 Shape Detection and Inbuilt Symbols

From the participants' feedback, it is clear that they preferred to draw shapes such as rectangle, ellipse, etc. with freehand to the inbuilt shapes (see Section 4.4.2). This is because inbuilt shapes require resizing and repositioning to include the desired content in it. However, the participants also mentioned that the freehand shapes are not "clean" as the inbuilt shapes. Therefore, the future designers should consider shape detection techniques, which will automatically transform the user's drawn shapes to "perfect" and "clean" shapes. For instance, when the user draws a rectangle, the application should straighten out its lines and align them at 90 degrees to each other to form a geometrically perfect rectangle.

In future versions of this application, few symbolic annotations can be included such as asterisk, star, smilies, etc., which the user would be able to use by simple drag and drop interactions.

7.1.7 Audio Annotations and Voice Recognition

As suggested by few participants, the future design of annotation application should consider audio annotations. It may also use some gesture to initiate the audio annotation such as two finger double tap or any other simpler gesture. In future designs, the voice-to-text feature might be incorporated to create comment annotation from speech if the user does not prefer typing on touch screen.

7.1.8 Deleting and Undo

In the current version, the user needs to tap on the annotation and then select the delete option from the pop-up menu to remove an annotation. If the user can simply drag the annotation to a recycle bin icon to delete it then, it might saves the user's effort. In addition, the undo operation should be considered in the future versions, and if possible, a gesture to perform undo would be another interesting feature.

7.1.9 System Feedback

In the current version, the help messages appear at the top-center of the screen upon activation of any annotation tool. Few participants mentioned that sometimes they could not read the message properly because they were not looking at the top of the screen (see Section 4.4.4). Therefore, different positions of these messages should be evaluated in the future studies to choose the best one including at center of the screen and near the point where user performs the gesture. In addition, the haptic and audio feedback can be considered, as it does not require any visual attention unlike message feedback.

7.1.10 Cloud Storage

The future versions of GestAnnot could be integrated with the cloud-based storage on which users can store their files along with their annotations, and can access it anywhere without storing it on local memory.

7.1.11 Multiple Document View

The user should have an option to view and annotate multiple documents and the navigation between these tabs should be easy (see Section 6.6.3). This can be achieved by incorporating multi-tab interface in which, each tab corresponds to one opened document and can be viewed by simply tapping on that tab.

7.1.12 Bimanual Gestures

In a recent work by Wagner et al. [68], researchers introduced and evaluated bimanual interaction techniques for handheld tablet devices. In their study, they argued that participants preferred to use bimanual gesture with the thumb of non-dominant hand (e.g., left hand for a right-handed user) at the side of the device. In the future research, it would be interesting to know how such bimanual techniques could be incorporated in GestAnnot's design to provide a better way of annotating on handheld devices. For example, it could be used to switch between freehand mode and annotation tool mode as opposed to three-finger tap gesture in the current version of GestAnnot.

7.1.13 Miscellaneous

The dictionary is a useful feature that can be added in this application. An option to use a dictionary can be provided in the pop-menu that appears when users press and hold their finger on the word. In the current version, this pop-up includes only "copy" option and the dictionary option can be added to this pop-up.

It would be an interesting feature to rotate the comment so that the user could align it along graphs or figures. In addition, the automatic adjustment of comment within the available marginal space would be a significant improvement in the design.

7.2 Contributions

In this section, we recapitulate the contributions presented in the beginning of this thesis and summarize how our research makes these contributions.

By aggregating the literature about the previous annotation systems, we provided a concrete understanding of what is required to smoothly integrate the annotation activity with the reading process. Our analysis of the existing applications suggested that they required a lot of work on the part of the user to use annotation features, which added to the cognitive load thus hindering the active reading process. From this analysis, we developed the insight that an effective application would need to address the shortcoming of these applications so that the annotation task can successfully be integrated into reading activity.

We identified various annotation tools that can be provided in the application to support wide range of users' annotation needs. The techniques of multi-touch gestures were deployed in the system to use various annotation tools without having to choose a tool every time the user wishes to use it, as opposed to existing menu-based applications.

We then developed this application and conducted a lab evaluation study to compare its functionality and usability with the existing menu-based application. The quantitative and qualitative results from this study showed that the GestAnnot was significantly superior in terms of the usability and performance than one of the best menu-based application. The participants' feedback from this study then contributed to the improved design of this application.

To better understand if the application supports the wide range of annotation needs of prospective users in the real world; we conducted a field study in which the participants used this application for their reading tasks over a period of 2-5 days. It is evident from the results of this study that the participants liked the improved design, and would like to use it in the future reading tasks.

As a whole, the findings from these two evaluations enabled us to provide the concrete guidelines for how to support annotation features in active reading tasks. Finally, these findings confirmed that GestAnnot application provides an effective, superior and an efficient alternative to existing annotation applications.

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APPENDIX A: Post Activity Questionnaire for Lab Study

Participant ID: ___________________

Application: ___________________

Part 1

For the following questions, please circle the numbers, which most appropriately reflect your impression about using this system. NA=Not Applicable

1. Overall reactions to the system

1.1	Overall reactions to the system	Terrible						Wonderful	
		1	2	3	4	5	6	7	
		Frustrating						Satisfying	
		1	2	3	4	5	6	7	
		Dull						Stimulating	
		1	2	3	4	5	6	7	
		Difficult						Easy	
		1	2	3	4	5	6	7	
		Rigid						Flexible	
		1	2	3	4	5	6	7	

2. Screen

2.1	Characters on the screen	Hard to read						Easy to read	
		1	2	3	4	5	6	7	
2.2	Was the highlighting on the screen helpful?	Not at all						Very much	NA
		1	2	3	4	5	6	7	
2.3	Were the screen layouts helpful?	Never						Always	
		1	2	3	4	5	6	7	

2.3.1	Amount of information that can be displayed on screen	Inadequate	Adequate	
		1 2 3 4	5 6 7	
2.3.2	Arrangement of information on screen	Illogical	Logical	
		1 2 3 4	5 6 7	
2.4	Sequence of screens	Confusing	Clear	
		1 2 3 4	5 6 7	

3. Terminologies and System Information

3.1	Use of terms throughout the system	Inconsistent	Consistent	
		1 2 3 4	5 6 7	
3.2	Does the terminology relate well to the work you are doing?	Unrelated	Well related	
		1 2 3 4	5 6 7	
3.3	Messages which appear on the screen	Inconsistent	Consistent	NA
		1 2 3 4	5 6 7	
3.4	Messages which appear on the screen	Confusing	Clear	NA
		1 2 3 4	5 6 7	
3.5	Does the system keep you informed about what it is doing?	Never	Always	NA
		1 2 3 4	5 6 7	
3.6	Error messages	Unhelpful	Helpful	NA
		1 2 3 4	5 6 7	

4. Learning

4.1	Learning to operate the system	Difficult	Easy	
		1 2 3 4	5 6 7	
4.2	Exploration of the features by trial and error	Discouraging	Encouraging	
		1 2 3 4	5 6 7	
4.3	Can tasks be performed in a straightforward manner?	Never	Always	
		1 2 3 4	5 6 7	
4.3.1	Number of steps per task (i.e. steps to create a particular type of annotation)	Too many	Just right	
		1 2 3 4	5 6 7	
4.4	Help messages on the screen	Confusing	Clear	NA
		1 2 3 4	5 6 7	
4.5	Tutorials for beginners	Confusing	Clear	NA
		1 2 3 4	5 6 7	

5. System Capabilities

5.1	System speed	Too slow	Fast enough	
		1 2 3 4	5 6 7	
5.1.1	Response time for most operations	Too slow	Fast enough	
		1 2 3 4	5 6 7	
5.1.2	Rate of information display	Too slow	Fast enough	
		1 2 3 4	5 6 7	
5.2	How reliable is the system	Unreliable	Reliable	

		1 2 3 4	5 6 7	
5.2.1	System failures occur	Frequently	Seldom	
		1 2 3 4	5 6 7	
5.3	Correcting your mistakes/Ability to undo	Difficult	Easy	NA
		1 2 3 4	5 6 7	

Part 2

1. How often do you perform Active Reading?
   a. Very Frequently (many times a week)
   b. Frequently (few times a week)
   c. Occasionally (few times a month)
   d. Very rarely

2. Do you use any other application for active reading? If yes, please specify.

   ____

   ____

   ____

   ____

3. Does the system perform the tasks as required/expected?

   ___ Yes

   ___No

   If no, what functionality do you think what lacking in the system?

   ____

   ____

   ____

4. What features of the system did you like the most?

5. What features of the system did you not like?

6. What other features would you like to be added to the system?

7. Any other comments you have about the system.

APPENDIX B: Post Activity Questionnaire for Field Study

Participant ID: ___________________

Part 1

1. Overall reactions to the system

1.1	Overall reactions to the system	Terrible	Wonderful	
		1 2 3 4	5 6 7	
		Frustrating	Satisfying	
		1 2 3 4	5 6 7	
		Dull	Stimulating	
		1 2 3 4	5 6 7	
		Difficult	Easy	
		1 2 3 4	5 6 7	
		Rigid	Flexible	
		1 2 3 4	5 6 7	

2. Screen

2.1	Characters on the screen	Hard to read	Easy to read	
		1 2 3 4	5 6 7	
2.2	Was the highlighting on the screen helpful?	Not at all	Very much	
		1 2 3 4	5 6 7	
2.3	Were the screen layouts helpful?	Never	Always	
		1 2 3 4	5 6 7	
2.3.1	Amount of information that can be displayed on screen	Inadequate	Adequate	NA
		1 2 3 4	5 6 7	
2.3.2	Arrangement of information	Illogical	Logical	

	on screen			
		1 2 3 4	5 6 7	
2.4	Sequence of screens	Confusing	Clear	NA
		1 2 3 4	5 6 7	

3. Terminologies and System Information

3.1	Use of terms throughout the system	Inconsistent	Consistent	
		1 2 3 4	5 6 7	
3.2	Does the terminology relate well to the work you are doing?	Unrelated	Well related	
		1 2 3 4	5 6 7	
3.3	Messages which appear on the screen	Inconsistent	Consistent	
		1 2 3 4	5 6 7	
3.4	Messages which appear on the screen	Confusing	Clear	
		1 2 3 4	5 6 7	
3.5	Does the system keep you informed about what it is doing?	Never	Always	
		1 2 3 4	5 6 7	
3.6	Error messages	Unhelpful	Helpful	NA
		1 2 3 4	5 6 7	

4. Learning

4.1	Learning to operate the system	Difficult	Easy	
		1 2 3 4	5 6 7	

4.2	Exploration of the features by trial and error	Discouraging	Encouraging	
		1 2 3 4	5 6 7	
4.3	Can tasks be performed in a straightforward manner?	Never	Always	
		1 2 3 4	5 6 7	
4.3.1	Number of steps per task (i.e. steps to create a particular type of annotation)	Too many	Just right	
		1 2 3 4	5 6 7	
4.4	Help messages on the screen	Confusing	Clear	NA
		1 2 3 4	5 6 7	
4.5	Tutorials for beginners	Confusing	Clear	NA
		1 2 3 4	5 6 7	

5. System Capabilities

5.1	System speed	Too slow	Fast enough	
		1 2 3 4	5 6 7	
5.1.1	Response time for most operations	Too slow	Fast enough	
		1 2 3 4	5 6 7	
5.1.2	Rate of information display	Too slow	Fast enough	
		1 2 3 4	5 6 7	
5.2	How reliable is the system	Unreliable	Reliable	
		1 2 3 4	5 6 7	
5.2.1	System failures occur	Frequently	Seldom	
		1 2 3 4	5 6 7	
5.3	Correcting your	Difficult	Easy	NA

	mistakes/Ability to undo			
		1 2 3 4	5 6 7	

Part 2

1. How often do you perform Active Reading?
   e. Very Frequently (many times a week)
   f. Frequently (few times a week)
   g. Occasionally (few times a month)
   h. Very rarely

2. How long did you work with this application?
   a. Less than an hour
   b. 1 hour to less than 3 hours
   c. 3 hours to less than 5 hours
   d. More than 5 hours

3. What kind of Active Reading Task did you perform with this application?
   a. Article Review
   b. Grading or Marking Assignments (or tests)
   c. Reading Comprehension
   d. Other, Please specify ____________________

4. How often do you use Multi-Touch Gestures on a touch screen device?
   a. Very Frequently (many times a week)
   b. Frequently (few times a week)
   c. Occasionally (few times a month)
   d. Very rarely
   e. Never Used

5. Do you use any other application for active reading? If yes, please specify.

____

____

6. Does the system perform the tasks as required/expected?
___ Yes

___No

If no, what functionality do you think what lacking in the system?

7. What features of the system did you like the most?

8. What features of the system did you not like?

9. What other features would you like to be added to the system?

10. Are the gestures provided in the application easy to use? If not, please specify.

11. Does the application allow you to mark all types of annotation, as you require? If not, what other types of annotation would you like to include in the application?

12. Any other comments you have about the system.

APPENDIX C: Ethics Board Approval for Lab Study

DALHOUSIE UNIVERSITY
Inspiring Minds

Social Sciences & Humanities Research Ethics Board
Letter of Approval

June 12, 2013

Mr Varinder Singh
Computer Science\Computer Science

Dear Varinder,

REB #: 2013-3008
Project Title: A Paper Annotation Tool for Tablet (Phase I)

Effective Date: June 11, 2013
Expiry Date: June 11, 2014

The Social Sciences & Humanities Research Ethics Board has reviewed your application for research involving humans and found the proposed research to be in accordance with the Tri-Council Policy Statement on *Ethical Conduct for Research Involving Humans.* This approval will be in effect for 12 months as indicated above. This approval is subject to the conditions listed below which constitute your on-going responsibilities with respect to the ethical conduct of this research.

Sincerely,

Dr. Sophie Jacques, Chair

APPENDIX D: Ethics Board Approval for Field Study

DALHOUSIE UNIVERSITY
Inspiring Minds

Social Sciences & Humanities Research Ethics Board
Letter of Approval

June 20, 2013

Mr Varinder Singh
Computer Science\Computer Science

Dear Varinder,

REB #: 2013-3033
Project Title: A Paper Annotation Tool for Tablet (Phase 2)

Effective Date: June 20, 2013
Expiry Date: June 20, 2014

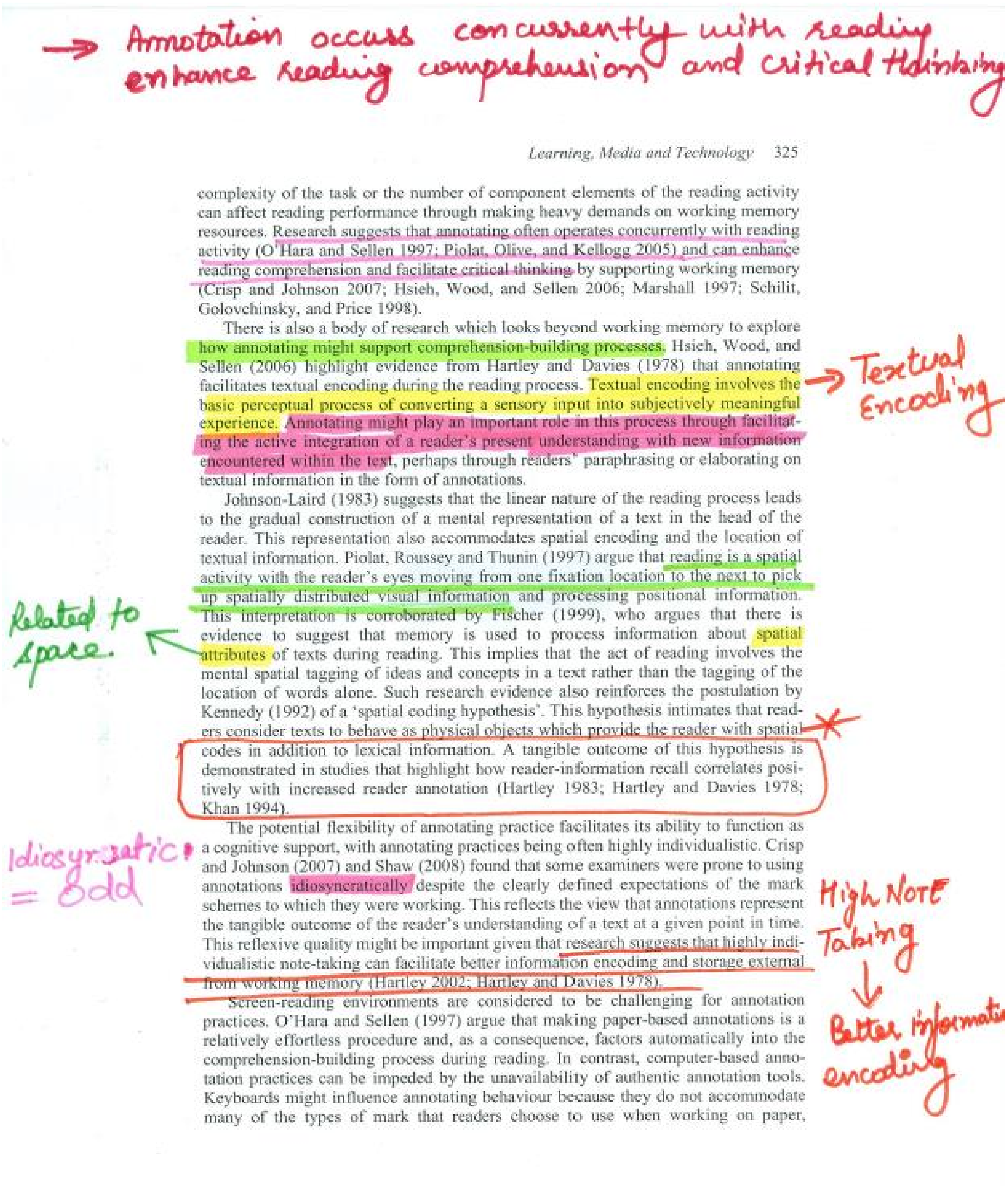
The Social Sciences & Humanities Research Ethics Board has reviewed your application for research involving humans and found the proposed research to be in accordance with the Tri-Council Policy Statement on *Ethical Conduct for Research Involving Humans.* This approval will be in effect for 12 months as indicated above. This approval is subject to the conditions listed below which constitute your on-going responsibilities with respect to the ethical conduct of this research.

Sincerely,

Dr. Sophie Jacques, Chair

APPENDIX E: Task Documents

<u>Preview of the First Document</u> (There were five other similar pages)



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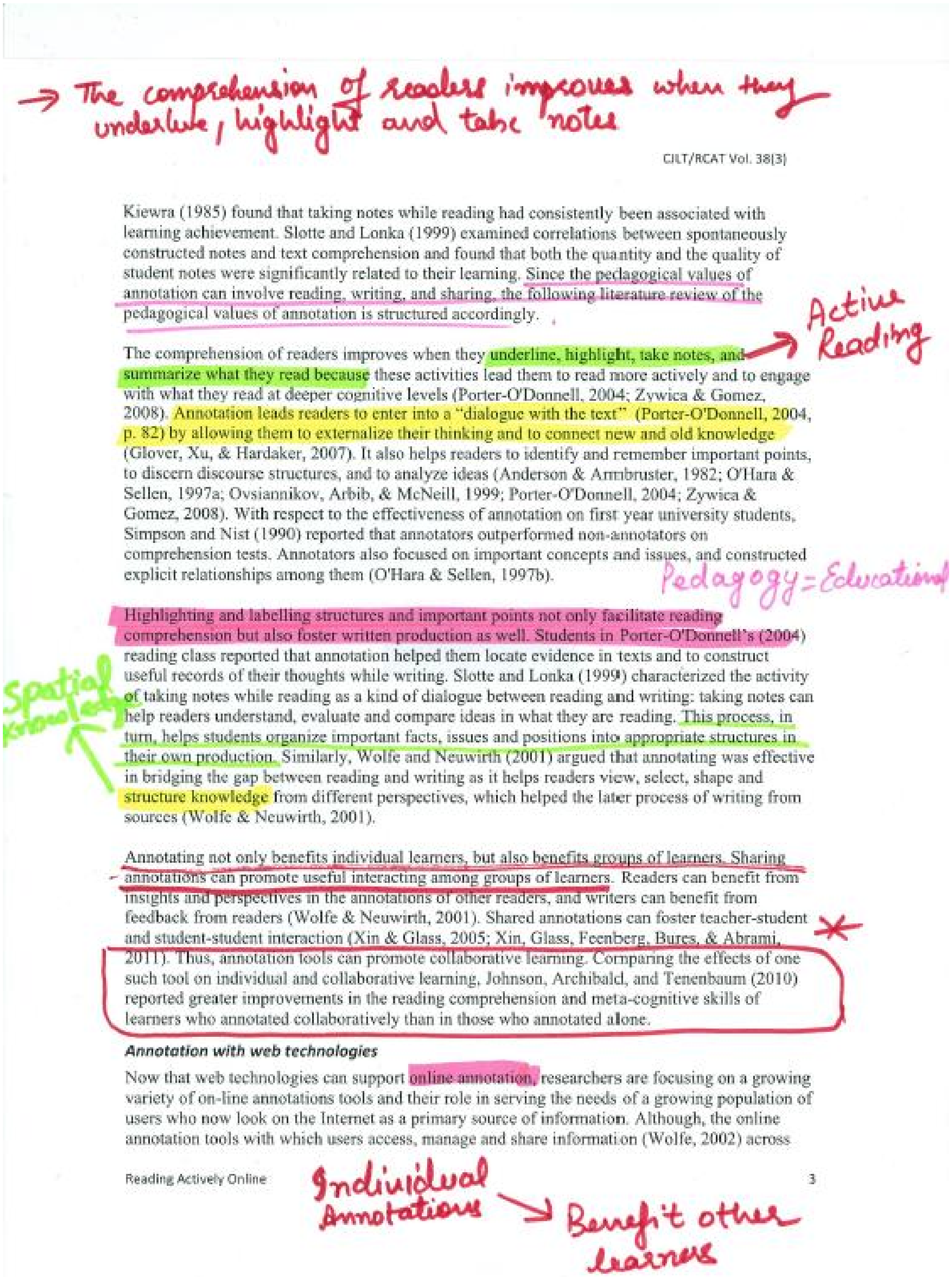
complexity of the task or the number of component elements of the reading activity can affect reading performance through making heavy demands on working memory resources. Research suggests that annotating often operates concurrently with reading activity (O'Hara and Sellen 1997; Piolat, Olive, and Kellogg 2005) and can enhance reading comprehension and facilitate critical thinking by supporting working memory (Crisp and Johnson 2007; Hsieh, Wood, and Sellen 2006; Marshall 1997; Schilit, Golovchinsky, and Price 1998).

There is also a body of research which looks beyond working memory to explore how annotating might support comprehension-building processes. Hsieh, Wood, and Sellen (2006) highlight evidence from Hartley and Davies (1978) that annotating facilitates textual encoding during the reading process. Textual encoding involves the basic perceptual process of converting a sensory input into subjectively meaningful experience. Annotating might play an important role in this process through facilitating the active integration of a reader's present understanding with new information encountered within the text, perhaps through readers' paraphrasing or elaborating on textual information in the form of annotations.

Johnson-Laird (1983) suggests that the linear nature of the reading process leads to the gradual construction of a mental representation of a text in the head of the reader. This representation also accommodates spatial encoding and the location of textual information. Piolat, Roussey and Thunin (1997) argue that reading is a spatial activity with the reader's eyes moving from one fixation location to the next to pick up spatially distributed visual information and processing positional information. This interpretation is corroborated by Fischer (1999), who argues that there is evidence to suggest that memory is used to process information about spatial attributes of texts during reading. This implies that the act of reading involves the mental spatial tagging of ideas and concepts in a text rather than the tagging of the location of words alone. Such research evidence also reinforces the postulation by Kennedy (1992) of a 'spatial coding hypothesis'. This hypothesis intimates that readers consider texts to behave as physical objects which provide the reader with spatial codes in addition to lexical information. A tangible outcome of this hypothesis is demonstrated in studies that highlight how reader-information recall correlates positively with increased reader annotation (Hartley 1983; Hartley and Davies 1978; Khan 1994).

The potential flexibility of annotating practice facilitates its ability to function as a cognitive support, with annotating practices being often highly individualistic. Crisp and Johnson (2007) and Shaw (2008) found that some examiners were prone to using annotations idiosyncratically despite the clearly defined expectations of the mark schemes to which they were working. This reflects the view that annotations represent the tangible outcome of the reader's understanding of a text at a given point in time. This reflexive quality might be important given that research suggests that highly individualistic note-taking can facilitate better information encoding and storage external from working memory (Hartley 2002; Hartley and Davies 1978).

Screen-reading environments are considered to be challenging for annotation practices. O'Hara and Sellen (1997) argue that making paper-based annotations is a relatively effortless procedure and, as a consequence, factors automatically into the comprehension-building process during reading. In contrast, computer-based annotation practices can be impeded by the unavailability of authentic annotation tools. Keyboards might influence annotating behaviour because they do not accommodate many of the types of mark that readers choose to use when working on paper, Preview of the Second Document (There were five other similar pages)



Kiewra (1985) found that taking notes while reading had consistently been associated with learning achievement. Slotte and Lonka (1999) examined correlations between spontaneously constructed notes and text comprehension and found that both the quantity and the quality of student notes were significantly related to their learning. Since the pedagogical values of annotation can involve reading, writing, and sharing, the following literature review of the pedagogical values of annotation is structured accordingly.

The comprehension of readers improves when they underline, highlight, take notes, and summarize what they read because these activities lead them to read more actively and to engage with what they read at deeper cognitive levels (Porter-O'Donnell, 2004; Zywica & Gomez, 2008). Annotation leads readers to enter into a "dialogue with the text" (Porter-O'Donnell, 2004, p. 82) by allowing them to externalize their thinking and to connect new and old knowledge (Glover, Xu, & Hardaker, 2007). It also helps readers to identify and remember important points, to discern discourse structures, and to analyze ideas (Anderson & Armbruster, 1982; O'Hara & Sellen, 1997a; Ovsiannikov, Arbib, & McNeill, 1999; Porter-O'Donnell, 2004; Zywica & Gomez, 2008). With respect to the effectiveness of annotation on first year university students, Simpson and Nist (1990) reported that annotators outperformed non-annotators on comprehension tests. Annotators also focused on important concepts and issues, and constructed explicit relationships among them (O'Hara & Sellen, 1997b).

Highlighting and labelling structures and important points not only facilitate reading comprehension but also foster written production as well. Students in Porter-O'Donnell's (2004) reading class reported that annotation helped them locate evidence in texts and to construct useful records of their thoughts while writing. Slotte and Lonka (1999) characterized the activity of taking notes while reading as a kind of dialogue between reading and writing: taking notes can help readers understand, evaluate and compare ideas in what they are reading. This process, in turn, helps students organize important facts, issues and positions into appropriate structures in their own production. Similarly, Wolfe and Neuwirth (2001) argued that annotating was effective in bridging the gap between reading and writing as it helps readers view, select, shape and structure knowledge from different perspectives, which helped the later process of writing from sources (Wolfe & Neuwirth, 2001).

Annotating not only benefits individual learners, but also benefits groups of learners. Sharing annotations can promote useful interacting among groups of learners. Readers can benefit from insights and perspectives in the annotations of other readers, and writers can benefit from feedback from readers (Wolfe & Neuwirth, 2001). Shared annotations can foster teacher-student and student-student interaction (Xin & Glass, 2005; Xin, Glass, Feenberg, Bures, & Abrami, 2011). Thus, annotation tools can promote collaborative learning. Comparing the effects of one such tool on individual and collaborative learning, Johnson, Archibald, and Tenenbaum (2010) reported greater improvements in the reading comprehension and meta-cognitive skills of learners who annotated collaboratively than in those who annotated alone.

Annotation with web technologies

Now that web technologies can support online annotation, researchers are focusing on a growing variety of on-line annotations tools and their role in serving the needs of a growing population of users who now look on the Internet as a primary source of information. Although, the online annotation tools with which users access, manage and share information (Wolfe, 2002) across

APPENDIX F: Questions of Semi-Structured Interviews

1. How was your experience using the application?
2. What features of the system did you like the most?
3. What features of the system did you not like?
4. What other features would you like to be added to the system?
5. Did you face any problem performing any task?
6. Do you have more comments or suggestions for the system?

Questions specific to GestAnnot

1. Did you have any problem executing a particular gesture?
2. Which gestures did you find easy to learn and use?
3. Which gestures did you find difficult to learn and use?