The Effect of Presenting Long Documents with Large High-Resolution Displays on Comprehension of Content and User Experience

Seungwon Yang, Haeyong Chung, Chris North, and Edward A. Fox
Department of Computer Science, Virginia Tech, Blacksburg, VA 24061 USA
{seungwon, chungh, north, fox}@vt.edu

Processing information by reading a long scholarly document such as an electronic thesis or dissertation (ETD) requires a massive amount of a reader's cognitive resources. Also, reading a long digital document from conventional screens often is difficult. In this study, we investigated the effects of presenting a long document with large high-resolution displays (LHRDs); we focused on comprehension of the content and on user experience.

Three different methods of ETD presentations were compared: (1) Presenting an ETD's pages on an array of 50 tiled LCD monitors, organized by chapters. Users read, move, and reorganize pages and sections of the ETD on the large display. (2) Providing an ETD by rendering it to paper. Users are free to reorganize the document on the surface of a large desk. (3) Presenting an ETD on a single LCD monitor. Users navigate the pages using a traditional mouse-and-keyboard interface.

Twelve graduate students in the Human-Computer Interaction (HCI) area from the Computer Science Department were recruited. Four participants were randomly assigned to each presentation method. To motivate participants, a 64-page HCI Master's thesis, which contained multiple figures, was used after its abstract and appendix sections were removed. The tasks were related to comprehension of the content: to write a summary, and to answer a list of questions that require navigating pages. Completion time and accuracy were measured. User experiences were collected using a questionnaire and a semi-structured interview. These were indicative of the user's satisfaction and level of comprehension of the document.

To allow detailed analysis of how various characteristics of LHRD (e.g., high-resolution, wide field of view, and physical navigation) affect users' subjective understanding of the document, all the sessions were video and audio-recorded. Design implications were discussed based on findings from this study.

Introduction

Reading a long scholarly document such as a thesis or dissertation to understand its overall ideas or to find specific information from its multiple hundreds of pages requires a massive amount of the reader's cognitive resources. Although an electronic thesis or dissertation (ETD) can be viewed on a computer screen, and search results, annotations, and thumbnails are provided to help readers, understanding the overall contents and structure of a long research document is still a demanding task. These difficulties motivated us to seek more efficient and effective ways to comprehend ETDs. In this study, we defined 'comprehension' in two parts: (a) ability to understand the overall content (i.e., seeing the forest) and (b) ability to find/re-find/compare/contrast detailed information in the content (i.e., seeing the trees).

With an initial idea that more display space for textual information might aid comprehension, we decided to use a large high-resolution display (LHRD), i.e., the Gigapixel display (Figure 1 (a), (b)) that currently has 96 mega pixels with DPI=100. Despite a recent dramatic advance in size and resolution in display technologies, the scalability of single monitor displays is still limited by engineering and manufacturing constraints on DPI (Dot Per Inch) and large physical size. Therefore, tiled arrays of LCD monitors are typically used to provide more scalability in both the size and resolution. In this study, we refer to the large tiled display of LCD monitors as LHRD because the LCD based tiled display provided the highest DPI relative to physical size [3]. LHRD is an effective solution to significantly increase visual scalability through its large field of view and high resolution. LHRDs have been shown to be helpful in a variety of visual analytics and complex information work tasks [1, 2]. Hence we came up with three research questions:

(1) Does viewing all the pages of a long document on an LHRD improve users' overall understanding of the content?
(2) Does viewing all the pages of a long document on an LHRD improve users' information finding and comparisons?
(3) Can viewing the pages of a long document on an LHRD provide a better user experience?

To answer the research questions, we have developed four hypotheses and set up three different ways of displaying a thesis, for comparison: Gigapixel group, Paper on Table group, and Single Monitor group. The Gigapixel group was our main focus while the Single Monitor group was used as a control since it resembled one of the common ways of reading papers. To examine how people work on a large table with physical pages of a long document, we set up the Paper on Table group, too. The next section presents a list of the four hypotheses, which are based on the research questions above.

Hypotheses

The users' perception of the efficiency (i.e., how *quickly* they could perform the task) and effectiveness (i.e., how *accurately* they could perform the task) of the display medium, as well as objective task performance, were considered important. Based on our research questions, we developed four hypotheses, discussed below:

Hypothesis 1. The users of the Gigapixel display will summarize a long document with better quality compared to those in the Single Monitor and Paper on Table groups.

The Gigapixel setting provided a layout where all the pages of a thesis were displayed grouped by chapter. This layout gave additional 'spatial' information of the whole content to its readers, which potentially could enhance the accuracy of the content summary. In contrast, the Single Monitor setting displayed only a couple of pages on the screen at a time without a spatial layout of the thesis.

Hypothesis 2. The participants in the Gigapixel group will find/compare information in a long document faster than those in the Single Monitor and Paper on Table groups.

The Gigapixel setting provided a large display area for all pages of a thesis to be viewed, which might allow quick and direct access to the content of the thesis. But in the Single Monitor setting, users had to check pages in sequential order, which could be a bit slower compared to direct access.

Hypothesis 3. The Gigapixel group will answer more accurately in finding/ comparing information, when compared to either the Single Monitor or Paper on Table group.

The direct access to the ETD's content and spatial organization from the Gigapixel's large field of view might improve readers' ability to find information more accurately in the Gigapixel setting compared to the other two settings.

Hypothesis 4. Participants in the Gigapixel group and Paper on Table group will perceive a higher level of efficiency and effectiveness for using their display medium compared to the Single Monitor group.

The fact that the content of a thesis was directly accessible and that there was enough working space on the display to freely reorganize pages in a way that they felt comfortable in the Gigapixel and Paper on Table settings might affect users' perception of their performance positively.

Related Work

Many research results have been shown where user cognitive and performance tasks were improved by using LHRD [1, 4, 5]. These increases were generally attributed to its wide field of view, displaying a greater amount of information from much higher DPI (Dot Per Inch) and size, and facilitating physical navigation [5]. These advantages have shown significant performance increases in a variety of user tasks on large displays. Simmons et al. looked at how the slightly different display size and resolutions for typical display configurations (17 inch and 21 inch monitor) can affect user performance [6]. Their results showed there were user performance increases in slightly larger display settings. Czerwinski et al. showed a wider field of view supported by a multiple monitor configuration allows a woman to perform well in 3D navigation tasks with large displays [7]. Yost et al. showed that the effects of the increased amount of scaled up visual information on large displays make most tasks more efficient, beyond visual acuity limitation [5].

Physical navigation such as turning the head, leaning the torso, glancing, walking around, etc. was another important factor to make the user's cognitive ability and task performance more efficient on large displays. Ball et al. investigated performance and user behavior in a large display domain [2]. They looked at how the user performance for spatial search tasks was influenced by increasing the display size and resolution. Their results showed physical navigation significantly improved the performance. Shupp et al. also demonstrated some physical navigation characteristics of curved large displays. They observed that the curved display encouraged physical movement and leads to users moving more when interacting with the display [8]. However, they also observed that the use of a keyboard on a movable table appeared to lead to less physical navigation. This study was related to understanding and representing a document on a large high resolution display.

There were several studies related to reading documents on LHRD and comparing how LHRD changes use of paper in analyses of textual information. Visual separation and physical discontinuities when distributing textual information across the LHRD often occur. Tan el al. showed that visual discontinuities caused by bezels is not significant and do not appear to affect user performance on text based tasks such as proofreading and notification detection for documents, even though it leads to a small performance loss when coupled with an offset in depth [9].

Andrews et al. demonstrated how increased display space affects the way large displays are used within the context of the cognitively demanding task of sensemaking with textual information [10]. Specifically, their study also showed how incorporation of a large display system into an intelligence data analysis environment affects the use of paper artifacts for reading and notetaking. They observed that participants typically used paper in non-LHRD environments, but they didn't use paper in an LHRD environment, even though they brought a notepad with them, anticipating the need.

Experiment

Participants

A total of 12 graduate students (5 female, 7 male) participated in the experiment. Except for one participant, who was majoring in Industrial Systems Engineering, participants came from the Computer Science area, mostly with a Human-Computer Interaction background. Their age ranged from 22 to 40 years old. Web pages were the most familiar textual resources to them followed by conference proceedings and journal articles. Master's theses and doctoral dissertations were the least familiar resources, although everyone had read/viewed those resources in the form of either paper copies (33.3 %) or electronic documents on a computer screen (91.7 %).

They preferred reading textual information on a computer screen with an average preference rating of 4.25 (1: least – 5: most). For paper, the average rating was 3.17. They mentioned that digital documents are easier to manage, search, organize, and store. About 75% of the participants spent more than 8 hours reading textual information on their computer screen per week. Participants were more interested in finding specific information (75%), methodologies (75%), and literature reviews (83.3%), compared to understanding the overall topics (50%).

Experimental Setting

A Master's thesis, "The Design of Active Workspaces," was used for our experiment [11]. The paper was related to Human-Computer Interaction and contained several generalized design principles, theories, and two real applications for context-specific environments designed to assist people engaged in certain productive tasks. We thought that this paper does not require any specific expertise and could be understood by any general graduate student in the Computer Science area.

There were three different settings in the experiment. The first was to present all the pages on a Gigapixel display grouped by chapter as shown in Figure 1 (a). This roughly 70 page-long thesis was viewed on the Gigapixel display, which consists of 50 tiled LCD monitors (5 rows, 10 columns). Participants interacted with the display by using a handheld pointing interface, which allowed them to move digital pages with drag-and-drop (Figure 1 (b)). Another setting was to display a thesis rendered on paper on a large table. As shown in Figure 1 (c), a paper thesis was presented on a table grouped by chapter. Participants were allowed to freely move pages and annotate the thesis when they were doing the tasks. The third setting, which was used for our control group, was to display a thesis on a single monitor using Adobe's PDF viewer with searching feature disabled to be consistent with the other two settings. To help navigation, a document thumbnail view was provided on the left side of the screen. All the participants had access to a notepad and sticky notes throughout the experiments. A notebook computer was used for participants to write a summary (task 1). A Sony VX-2100 camcorder was used along with a 60 GB digital store to capture participants' behavior.

Figure 1. Experimental setting: (a) A thesis visualized on a Gigapixel display, (b) Interacting with the Gigapixel display using the handheld pointing device, (c) A paper thesis on a large table, and (d) A thesis on a single monitor.

Gigapixel ETD Viewer

Our Gigapixel ETD viewer (i.e., organized digital pages with a handheld device) allowed a user to view and manipulate a large number of pages (more than 600 pages at a time depending on the page size) without any pre-processing or modification of the pages. It enabled users to move page objects interactively. For example, to compare interesting figures and contents, users could drag-and-drop multiple pages by using a trigger, which acted like a left-click on a mouse, in the handheld interface device (Figure 2).

This tool was inspired by our real world skills and ways to view and organize pages on a large table. We considered the users' familiarity in reading a paper thesis and made the default size of each page in the viewer the same as a US letter size paper (8½ by 11 inches). Also, to encourage physical navigation and faciliate finding specific pages, we increased the font size of the page numbers. We plan to add zoom and pan features in this tool.

Figure 2. A user juxtaposes two pages to compare figures using handheld interface. Its red pointer is shown inside a circle.

Tasks and Procedure

Participants performed two kinds of tasks. The purpose of the first task, which was to write a 200-300 word summary of the thesis after reading it for 30 minutes, was to examine whether the participant had an overall understanding of the thesis. Participants wrote the summary using a word processor. The time to complete the task was recorded. The second task involved six questions: finding specific information (Q1 and Q2), elaborating on similarities and differences between two systems (Q3), finding information based on understanding of another information item (Q4), comparing two figures (Q5), and identifying a figure detail (Q6). Participants verbalized the question number before they worked on it to help record the time to complete each question. After completing the two tasks, post questionnaires were used to collect user experience data followed by a short semi-structured interview for more detailed user experience collection.

Results and Discussion

This study produced data in three different categories: 1) task completion time and scores, 2) users' feedback of their perception for efficiency/effectiveness of their display medium, and 3) behaviors from observation and interviews. Task completion time, scores and users' perceived efficiency/effectiveness of their display medium were analyzed using ANOVA and Tukey HSD.

User Performance

Task 1 and 2 average performance time is shown in Figure 3. No statistically significant differences among the groups were found in both of Figure 3 (a) and (b). Participants were allowed to take notes while they read the thesis for task 1. Participants from the Paper on Table (4 out of 4) and Single Monitor (3 out of 4) groups used the notepad often, whereas only one participant from the Gigapixel group wrote short outlines on a note. The other Gigapixel participants didn't use the notepad at all. We thought this was because Paper on Table and Single Monitor settings were configured on top of a desk, on which participants could write a note comfortably sitting on a chair. On the other hand, only a small rolling desk was provided for the Gigapixel setting and the discomfort of using it for writing while standing up and holding the handheld interface might have resulted in low frequency writing of notes.

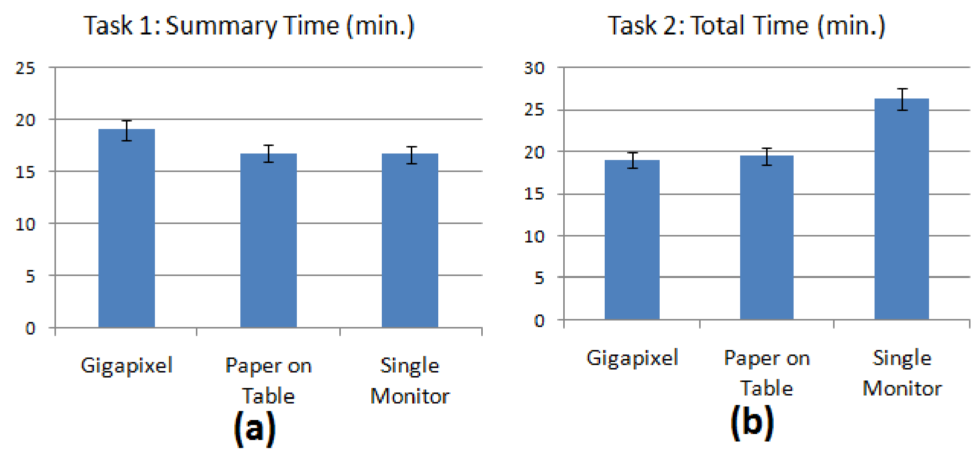

Figure 3. (a) Task 1 (summary) group average time and (b) Task 2 (info finding, comparison of info) time.

The participants who wrote the notes actively used them, and it reduced writing time for their task 1. The average writing time for three participants in the Gigapixel group, who did not use notes, is longer (18.3 min.) than that of either Paper on Table (16.75 min.) or Single Monitor (16.63 min.) groups in the performance data. Perhaps because Gigapixel participants (except for one) did not write a note, their average time for task 1 was more than that of the other groups, although the difference was not statistically significant (see Figure 3 (a)).

In Figure 3 (b), the average performance time of the Gigapixel group's task 2 was found to be lower than that of the Single Monitor group and slightly lower than that of the Paper on Table group. However, these differences were not statistically significant from ANOVA at the p = 0.05 level; thus we could not confirm *Hypothesis 2*. In the Single Monitor setting, pages were accessed sequentially; thus users had to use page down/up buttons or scrolling frequently to access information. But in the Gigapixel case, information on pages was distributed on the display surface with visual cues such as images, tables, or the structure of paragraphs; thus users had an opportunity to access information directly. The Paper on Table setting also resembled the Gigapixel setting with pages organized by chapter. But, pages in each chapter were piled up and accessed linearly by flipping through them. Compared to sequential access with a Single Monitor and semi-direct access with Paper on Table, the Gigapixel afforded benefits of utilizing direct access as well as visual cues on the pages to enhance performance in information finding tasks.

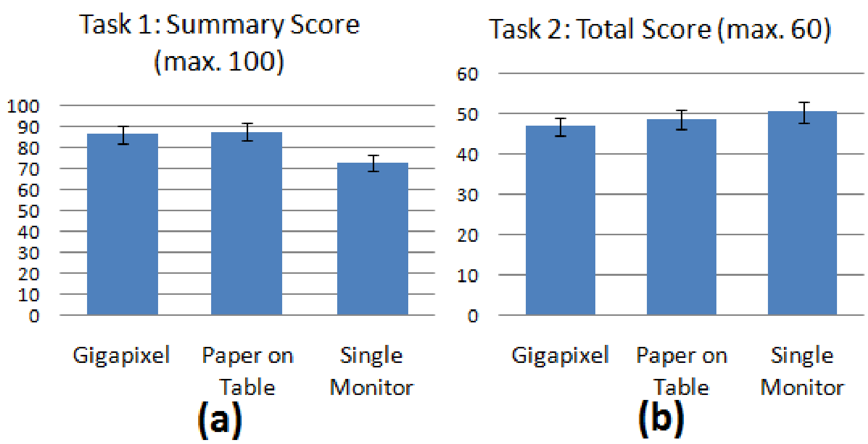

Figure 4. (a) Task 1 (summary) group average score; (b) Task 2 (Info finding, comparison) score.

To measure accuracy of task performance, thesis summaries (task 1) and six questions in task 2 were graded by two researchers. Those scores were averaged to reduce subjective factors in grading. In Figure 4 (a), the Gigapixel group's average score was higher than that of the Single Monitor group; however, we could not confirm *Hypothesis 1* since the differences were not statistically significant (p=0.196). The average scores of the Gigapixel and Paper on Table groups were similar in task 1. This might mean that added spatial information in the Gigapixel and Paper on Table settings might have contributed to the better quality of the summary. The average total scores of the three groups in performing task2 are shown in Figure 4 (b). We expected that the score of the Gigapixel group would surpass those of the other two groups, but it turned out that the average scores were not significantly different (p=0.816).

To see if we could find significant improvement of Gigapixel group's performance from sub-tasks in task 2, we compared average scores of each question for the three groups in Figure 5. The Gigapixel group's average performance for question 3, 'Find similarities and differences', showed a significant improvement in its accuracy with p=0.04 compared to that of the Single Monitor group (marked as a red box in Figure 5). Based on this, *Hypothesis 3* has been partially confirmed. For question 1, 'True/False info finding', and 4, 'Apply principle', Gigixel group's average performance score was lower than that of the other groups, but the differences were not statistically significant from Tukey-HSD analysis. For questions 2, 5 and 6, Gigapixel group performed better than or the same as the other groups.

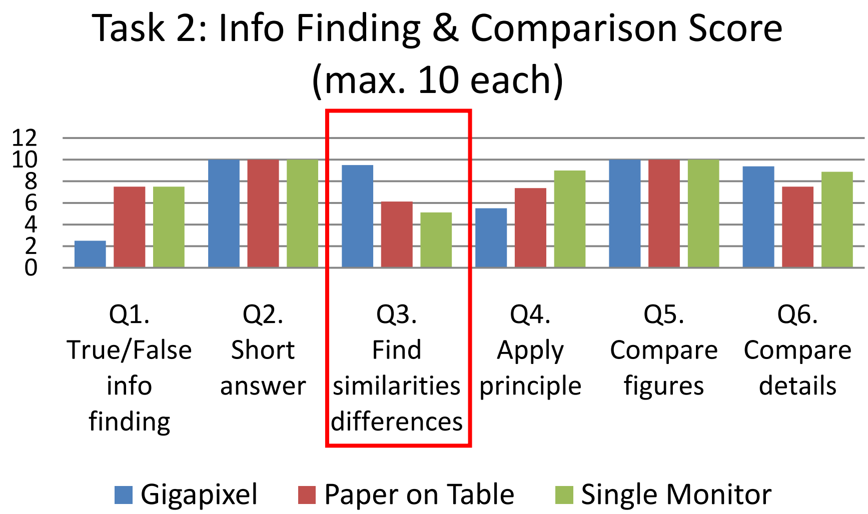

Figure 5. Average scores for questions in task 2. Questions are 1 to 6, starting from the left.

User's Perceived Efficiency and Effectiveness

Users' perceived efficiency and effectiveness, of the display medium that they used during the experiment, were collected using post-questionnaires. The group average ratings (1: not helpful at all – 5: very helpful) are displayed in Figure 6. In general, average user perceptions for efficiency and effectiveness of both the Gigapixel and Paper on Table groups were higher than that of the Single Monitor group. However, we could find a borderline significant difference (p = 0.061) only in the users' perception of effectiveness in performing task 2 between Paper on Table and Single Monitor groups (marked as a red box in Figure 6), which partially confirmed *Hypothesis 4*.

The meaning was that the users in Paper on Table group thought that their setting was helpful in performing the task 2, which was significantly higher than what the users of Single Monitor group had thought about their medium to perform the same task. However, the actual effectiveness in performing task 2 between the two groups were not statistically significant (Figure 4 (b)). We may conjecture that the wide working area of a large table as well as easy and familiar interaction with paper copies in Paper on Table setting provided this perception to the group members apart from the actual performance measures.

Although not significant with p=0.05 level, the Gigapixel group's perceptions of efficiency for task 2 (p = 0.151) and effectiveness for task 2 (p = 0.109) were higher than that of Single Monitor group. This could mean that there is a potential for these two cases to show significant differences with added participants since the rejection power of the hypothesis test will be less restricted.

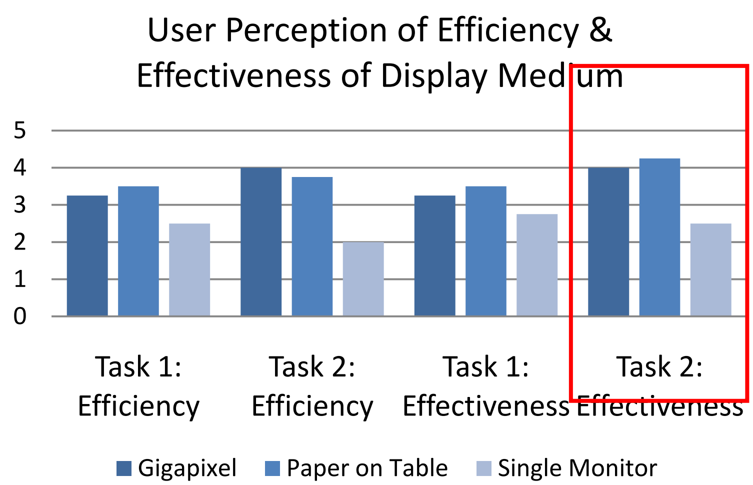

Figure 5. Average ratings of users' perceived efficiency and effectiveness of their display medium to perform tasks.

User Behaviors

Our observations and post intervews revealed the there were four different common behaviors. We present more holistic analyses of behaviors below. A summary of user behaviors for each task is given in Table 1.

Physical navigation. Participants of the Gigapixel group made use of physical navigation frequently to read the thesis and to find some information on the Gigapixel display. They stepped backward if they wanted to see the structure of the thesis and an overview of pages on the Gigiapixel display, and for more detailed view of an interesting one, they walked toward a certain page directly and started to read it. They also walked back and forth between pages frequently during the reading and whole task sessions. One participant commented:

"On Gigapixel, I could see the whole content with just one single view, so I can easily navigate and figure out where I should go without thinking that much. And, I could intuitively use physical navigation and see interested images and also view how it is related to the overall content of the thesis."

All participants in the Paper on Table group picked several pages in a chapter pile and brought them to their side to make it more comfortable for them to read. They used physical navigation partially, such as head rotation or eye gaze, but nobody stood up or walked to read the thesis actively while running the study. In the Single Monitor group, as we expected, there was no meaningful physical navigation.

Reading strategies and page switching strategies. Since the Gigapixel participants could switch between the pages very easily, they showed various ways to read and navigate the pages. Since the Gigapixel participants could access pages directly to look for specific information, they first looked at the table of contents, introductions, or conclusions, and then looked through the details in each page by moving back and forth among the pages frequently. Interestingly, some participants in the Gigapixel group first remembered approximate location of figures and snapshots to re-find information.

The Paper on Table group shared reading and page switching strategies used in both the Gigapixel and Single Monitor groups. Like the Gigapixel user, the participant moved to the related chapter directly after reading the problem, but in each chapter pile, all participants tried to maintain the page order and used sequencial ways to flip over each page until they found information on a certain page.

For the single screen group, participants had to use only a sequential approach to turn over and scroll up and down the pages until they found the page or information, with page up and down keys or the mouse wheel.

Arrangement of pages. Each Gigapixel participant used a different strategy for arranging the pages on the Gigapixel display. Two participants looked for free space available on the display, and dragged and dropped pages to those spaces. They used mostly the middle three rows of monitors. The Gigapixel participants often moved pages to a space where the participants could read more comfortably. Participants moved several pages because it was hard to read those pages on the top row of the screen due to light glare caused by the fluorescent light. Also, people moved pages off the bezels for better reading. We observed one participant tended to get groups of a section laid out horizontally, and split them into different sections in the left and right portions of the screen.

Like the Gigapixel group, the Paper on Table participants didn't group the pages specifically based on some information and just used the original grouping as given in the beginning. However, they divided the chapters into two or three in horizontal/vertical/diagonal ways to utilize space on the upper/lower desk without disrupting the original layout too much.

Comparing the pages or information. All Gigapixel and Paper participants juxtaposed the two relevant pages together to compare figures in question 5 of task 2. However, as we expected, comparing more than two figures on different pages was not easy for the Single Monitor environment. One Single Monitor participant reported:

"It was really hard to compare if related description and figures are placed in separate pages. In this case, I needed to go back and forth often. It is very inconvenient and sometimes hindered me from understanding the contents. I often met this situation."

Some participants in the Single Monitor group switched back and forth among the related pages and tried to memorize some information on the first one and then check in the other page based on their memory, but some students failed to remember everything and went back to the first page again. Those participants ended up taking notes on the information on the first page and compared it with the other page.

Table 1. Identified user behaviors from three different settings for each task.

	Gigapixel	**Paper on Table**	**Single Monitor**
Task 1	• Physical navigation • Reading from the table of contents (strategy) • Reading introduction and conclusion (strategy)	• No walking or standing • Reading the table of contents and re-reading it from time to time	• No walking or standing
	• Moving pages to middle three rows to avoid light glare on the monitor • Dragging pages to the central area	• Dividing the chapters into two or three in horizontal/vertical/diagonal ways • Not changing the original	• Using "Page Up/Down" keys to switch pages • Using the mouse wheel to go to more than one page at a time

	• Aligning the page with bezels to facilitate reading	layout much	• Highlighting the text
	• Not much note-taking • Sitting down to read the pages on the bottom	• A lot of note-taking • Sitting down on a chair all the time	• A lot of note-taking • Sitting down on a chair all the time
Task 2	• Direct access to each page using physical navigation	• Direct access to each chapter, sequential access of the pages in that chapter	• Mostly sequential access to the pages to go to the next and previous pages
	• Using the figures as visual cues to re-find information • Using middle three rows of monitors on Gigapixel (out of a total of 5 rows)	• Reading the table of contents to locate chapters/page numbers • Flipping over the single sided pages keeping the page order	• Using page thumbnails to jump into the page • Switching between the mouse wheel and scrollbar
	• Juxtaposing pages to compare figures	• Juxtaposing the pages to compare figures	• Visiting two different pages back and forth for comparison of figures

Design Implications

Based on our analysis of behaviors and feedback from the participants, we identified seven additional features to help reading ETDs on the large, high-resolution displays (LHRD).

- **Annotation, searching, and highlighting:** Most participants wanted to use these features while they were reading an ETD using LHRD. Touchscreen interface or touch-enabled interface devices such as smart phones or iPads might be used to enter or draw annotations instead of using conventional interfaces such as mice or keyboards. Users may use their fingers to highlight text directly or draw circles for important information on the display.
- **Connecting related pages visually:** While reading an ETD, users may need to link between related pages using persistent lines or color codes. It will enable users to access related information on the current page and help understand information by visualizing the connections.

- **Changing the page size:** Changing the page size may allow users to have more space and hide less relevant pages by making them smaller. Magnifying figures and graphics would be useful. For example, for the collaborative usage, if many people want to talk about something together, it will be hard for them to see small images on the same page at the same time. By magnifying the image, collaborators can see it and have a discussion comfortably.
- **Multiple document or reference supports:** Participants wanted to make use of LHRD's large space and resolution to open multiple references. It will be helpful if we see several theses or related references to compare methodologies.
- **Supporting various page layouts:** Depending on users' preferences, forcing a single page organization makes it inefficient to read papers. Providing different initial layouts might help users understand and navigate the paper better.
- **Aligning pages with bezels:** Several pages crossing the bezels made it hard for participants to read the paper on the Gigapixel. It affected user interaction and navigation behaviors during the exepriment. So, pages should be aligned with the bezels, rather than across them.
- **Temporary move:** LHRD users need drag-and-drop interactions of pages frequently. To preserve page layout of the thesis and keep the page's original location, we can design a `temporary move' interaction. A user can move more than one page to some specific locations by drag-and-drop, in order to compare them, but after a specified time or an action, the pages automatically go back to their original place.

Conclusion and Future Works

In this study, we examined the effect of presenting a long document on a large high-resolution display (LHRD). In general, Gigapixel visualization and applications were used to see the large coherent scene or overview combined across multiple tiled screens. We focused both on detail information of each tile of the screens and the overall view of the LHRD.

Although the average performances of Gigapixel group showed improvements in general, we found that only some of them were statistically significant. This led to a partial confirmation of *Hypotheses 3* and *4, but Hypotheses 1* and *2* could not be confirmed. One of the reasons for this result might be explained that the small number of participants (e.g., 4 people for each group, for a total of 12) in this pilot study restricted the power of our analysis test. In addition, variance was likely high (e.g., mean differences were approximately 2 among groups when the standard deviation was higher than 8 in Gigapixel and Paper on Table group) on these types of comprehension tasks, which involved reading a long thesis and writing answers and summaries. This remained as a limitation of the study. Further, the pre-grouped chapters given to the Gigapixel and Paper on Table participants affected the arrangement of pages. Participants from both settings tried not to change the original layout of the thesis.

We found that the Gigapixel group exhibited similar strategies and behaviors as did the Paper on Table group when reading a thesis. The Gigapixel's large field of view and physical navigation helped people recognize the structure of the thesis and quickly navigate it to re-find information. The physical navigating to nearby pages is almost instantaneous (eye glance, head rotation, walking), scanning multiple pages or comparing 2 pages faster. These characteristics resulted in higher user perceived efficiency and effectiveness as well as overall understanding of a thesis than that of reading it on a singe monitor in general.

As future work, we plan to incorporate one or multiple features mentioned in the Design Implications section. It will naturally be connected to our next study, which will involve many more participants. Another venue for extending this study is to apply the Gigapixel display in collaborative work. The Gigapixel display inherently supports collaborative work from its large field of view with high resolution. It might also offer benefits to group collaboration in reviewing scholarly publications. For example, multiple c ollaborators can view and read different sections of a thesis at the same time and discuss their findings to share opinions.

It is our expectation that the results of this exploratory study and design implications would lead to a more effective and efficient way of understanding ETDs as well as to a deeper understanding of user interactions with LHRD.

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