Graduate Student Use of a Multi-Slate Reading System

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ABSTRACT

In laboratory studies, multi-surface slate-based reading systems have shown great promise as platforms for active reading. However, the true utility of such a system can only be ascertained through the rigors of real world use. We conducted month-long deployments of a multi-slate reading system to support the active reading activities of graduate students in the humanities. During these deployments we documented how the added display area and increased micro-mobility of multiple devices enhanced navigation and reading comfort. We also noted the essential role of writing and annotation. Finally, we observed how electronic affordances like synchronization across devices helped provide functionality that would not have been possible with paper documents. This paper contributes new information about how electronic reading solutions fit into real world reading workflows.

Author Keywords

reading; e-book; e-reading; multi-slate; tablet; multi-screen computing; deployment; graduate students; academia

ACM Classification Keywords

H.5.m. [Information interfaces and presentation]: Miscellaneous.

INTRODUCTION

How we might replace paper-based reading and writing with digital systems has been a recurring theme in HCI research. While many transforming technologies have emerged (e.g., e-paper displays, tablet devices, direct pen input), it is clear that we have still not met the challenge of developing effective digital systems to support intensive work-related reading activities (often called "active reading"). Case in point, even commercially successful e-book readers like the Amazon Kindle have only had limited success in this space [27, 28]. For many active reading tasks, paper continues to be preferred over electronic alternatives for reasons of increased display area, tangibility, reliability and navigability [29]. Researchers studying the affordances of paper and how they compare to digital systems [1, 19, 20] have argued that that a reading environment with several independent screens may be the best way forward.

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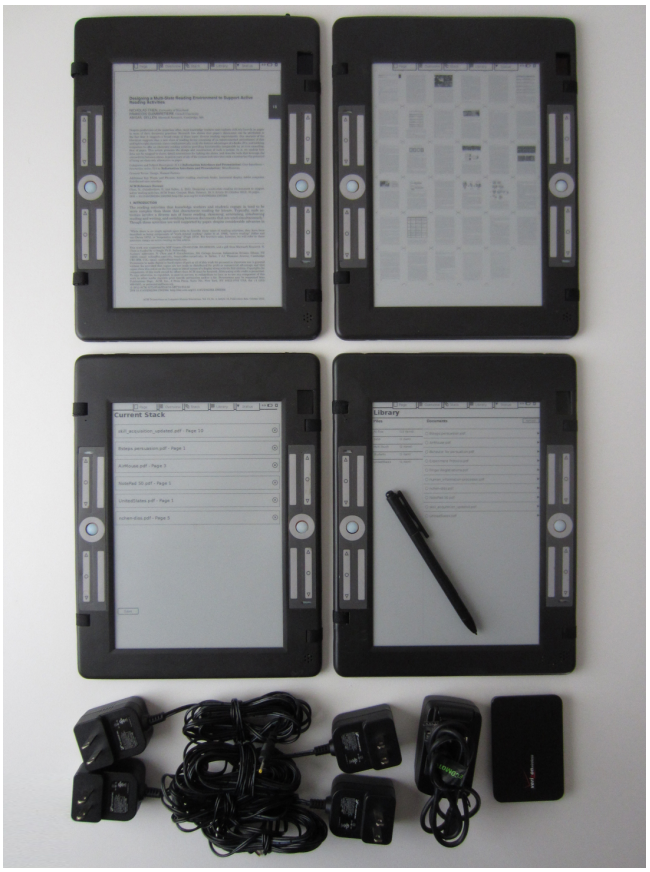

Figure 1 - Full set of equipment (consisting of slates, stylus, Wi-Fi hotspot and power adapters) provided to participants. Slates above are showing the four UI views in the system (clockwise from top left: Page, Thumbnail, Library, Stack).

The United Slates multi-slate reading system [5] was created to test this conjecture. In the system, a set of bespoke slates with e-paper screens and pen digitizers work in concert to support a diverse range of active reading requirements. Although preliminary results from laboratory evaluations suggested that such an approach was promising, such explorations always beg the question of how this kind of system might fare in real-world use.

Conducting a real world deployment of the United Slates provides the opportunity to evaluate the system against

more complex reading tasks consonant with what we know active reading tasks entail. It also allows us to see how the system fits into the existing ecosystem of reading tools and workflows—an aspect that is crucial to understand for any new technology. Finally, extended real-world use gives users a chance to evolve their practices in response to the affordances of the reading system.

In this paper, we present an evaluation of United Slates, which, as far as we know, is the first systematic deployment of a multi-screen e-reading system. Seven PhD students in the humanities were given a version of the system consisting of four slates (Figure 1). Participants used the system for about a month for common academic tasks that included research, teaching, participating in discussions, and grading.

While there was much to be learned about how to improve the system, the findings broadly confirm various design recommendations that call for writing and annotation capabilities and multiple screens in order to support active reading [1, 21, 29, 30]. Beyond confirming past conjectures, we show that the tight connectivity across devices in the United Slates results in some important improvements in the reading experience versus previous systems. We also show how paper practice can be both attended to and surpassed using digital systems. We believe that the ideas embodied in United Slates can be extended to domains beyond academic reading since these areas would likely benefit from the extra display area and high device mobility characteristic of United Slates.

RELATED WORK

Requirements of Active Reading

The style of reading frequently encountered during academic activities has been collectively referred to in the literature as "active reading" [2, 19, 26]. Drawing on the literature, Chen et al. [5] provide a survey of the full range of requirements for active reading. Some of these requirements concern the low level capabilities of the reading medium, such as being thin and lightweight [16, 32] and providing facilities for freeform ink annotation [14, 30]. However, ethnographers have noted that some fundamental requirements, like reading across multiple documents [1, 22], reading while writing [21], and information extraction [1], benefit from having multiple reading surfaces. These studies indicate that active reading may be better supported with a setup with multiple screens for reading and writing.

Previous E-Reading Deployments

Although there are many electronic systems that have been designed to support reading activities, only a handful have been deployed in the wild. In general, deployments have occurred in academic environments. HP Jornada PDAs, provided to students at the University of Virginia, were found to be highly portable and thus more convenient, but had trouble with texts that were format-sensitive [16]. Deployment of the Sony Reader e-book device into the classroom [3, 33] revealed deficiencies in navigation for classroom reading. The Kindle DX, another reading device, has recently been tested in several universities. Thayer et al. found that the device lacked support for the diverse navigation needs of student readers. Also, the absence of freeform ink annotation capabilities severely limited students' abilities to read responsively [30]. A report detailing the deployment of Kindle DX devices at Princeton University mirrored many of the sentiments regarding the difficulty of navigating and the lack of annotation facilities [31].

The problems previous devices have had in supporting academic reading highlight the importance of providing full support for the reading requirements outlined above. United Slates, being a purpose-built system for active reading, resolves many of the problems that have afflicted past e-reading systems. Participants were therefore able to use United Slates for a greater range of reading activities than in past systems. Consequently, we are able to report on usages that have so far not been described in the literature.

THE UNITED SLATES SYSTEM

The United Slates system implements researchers' recommendations [1, 21, 22] for a reading environment with multiple reading and writing surfaces via an extensible set of lightweight, highly mobile slate devices that support freeform ink input. The design of United Slates is based on the idea that slates need to be independent to retain their desirable physical qualities, but electronically linked to minimize operation overhead. Further, the system integrates tightly with a user's PC since many reading activities occur in conjunction with, or in support of tasks on the computer.

Slate Hardware

In order to have the desired combination of thinness, low weight, and support for writing, we use custom slates for our design. Each slate (Figure 1) uses E-Ink electronic paper displays to maximize readability and to minimize weight and thickness. A Wacom inductive pen digitizer enables high-resolution ink input via stylus. The slates communicate over a Wi-Fi connection. We also provided participants with a 3G Hotspot to allow use in locations without Wi-Fi.

User Interface

Users view the content on a slate using one of four UI views (Figure 1). The page view presents one page of the document in its entirety without the need to pan or scroll. Buttons on the edges of each slate turn the pages while in this view. Written annotations can also be added using the stylus. The Space-filling thumbnail [7] view displays every page in the document as a thumbnail. Tapping on a thumbnail navigates to the corresponding page. The Stack view presents a list of recently used documents and provides a faster way to switch between them. Finally, the Library lists the documents available on the slate. The list of documents can be sorted and filtered using attribute tags.

Slates can work in standalone fashion. However, an inter-slate command system additionally lets users (1) perform

stitching operations [11] that transfer a page or thumbnail being displayed on one slate onto another, (2) create *hyperlinks* from the document on one slate to another, and (3) copy text to a shared distributed clipboard [18].

The version of United Slates used in the deployment provided a mechanism to simplify transfer of PDF documents from a PC to the slates. All devices share access to a special Dropbox[1] folder in the cloud. Annotations applied to a document are embedded into the PDF and synchronized with the shared folder. This meant that the most up-to-date version of a document was always accessible to all devices. Full details about the implementation can be found in [6].

Further integration of the slates with the user's Mac or Windows PC consisted of an application that connected the computer's clipboard with the distributed clipboard. The application also let users turn the pages on the slate remotely from the PC and to open a copy of a document being displayed on a slate in the computer's default PDF viewer with a single click.

Finally, we included a tool for users to easily track their usage of the system. A journaling feature inspired by Sohn et al. [28] allowed participants to write short usage notes on the slate. These notes were sent to a web-based journal where detailed information could be supplied at a later time.

METHOD

The goal of our study was to document our participants' use of United Slates in the context of real academic work. We wished to make observations of how features of United Slates helped or hindered its use as an alternative to our participants' existing reading strategies and technologies.

Participants

Seven people participated in our study. We specifically recruited for senior graduate students who were engaged in research. Participants were paid $750, which was computed based on a rate of $15/hour for the approximately 50 hours of total time commitment that was expected for the study.

Procedure

The study involved the following phases, which culminated in the deployment of the United Slates system with users.

Photo-Diary

At the beginning of the study, we asked users to maintain a photo diary [4] documenting their reading activities over a seven-day period. The use of photo diaries was attractive since it allowed the rapid capture of activities and their surrounding context in detail with minimal interruption to the participant. We met with all participants at least three times: once to start, once halfway through the week, and once at the end of the week. During the meetings photos were used to elicit conversations about the reading activity depicted. We probed what the goal was, where it occurred, the materials and tools used, and the participant encountered any problems or frustrations.

Training Sessions

Participants underwent a training session to minimize the chance that users' unfamiliarity would discourage their use of the system. Training consisted of four 30-45 minute sessions spaced over a week. During these sessions we explained where we thought various features, particularly the more advanced ones, would be useful. For instance, we suggested that hyperlinks could be used to support cross-referencing, and that stitching content across devices might be a good way to setup the reading environment to view different parts of a document.

At the end of training, we recapped the features and conducted a short interview asking about the expected applicability of each feature to their reading activities in the upcoming weeks. This discussion enabled comparisons of intended use to actual use but also served to motivate participants to use the system during the deployment proper.

Deployment

Participants received four slates for the deployment. We explained that they were not expected to use all of the slates at the same time; giving them four was to ensure they would have the option to use additional slates should the need arise (Figure 1).

Deployments lasted until participants performed between 30-40 hours of work using the United Slates. We kept the definition of "work" loose to encourage use of the system for a variety of activities. Activities where participants used slates alongside other materials were counted as slate use. Slate usage was tracked via three mechanisms. First, low-level usage data (e.g., power on/off, page turns, UI view change, inter-slate operations) was logged. Second, the students documented their usage in the web journal. Finally, participants were asked to take photos of system use whenever they used it for an activity they had not previously photographed. Our first group of users had trouble remembering to take photos and enter their usage into the journal. Therefore, for later users we sent twice-a-week emails reminding them to track and photograph their usage.

A final wrap-up meeting and debriefing session occurred at the end of the study. For this meeting we prepared personalized questions based on the specific participant's usage of the United Slates along with general questions about the slate functionality and overall impressions that were shared among participants. This interview lasted 2-3 hours.

Analysis

Our analysis involved the first author going through interview notes to extract descriptions of how each participant used United Slates. From these descriptions, behaviors resulting from the unique aspects of the system were highlighted. Examples of these include multi-slate use, new ways of working due to digital functionality, and differences participants noted between reading with United Slates

[1] http://www.dropbox.com

and with paper documents. Finally, to double-check the accuracy of notes, and to obtain exact quotations, we transcribed relevant sections from the audio recordings of the interviews.

The automatically collected log data was inspected to confirm participants' reported usage. However, given the considerable variance in how participants used United Slates, we felt that comparing quantitative measures of usage across participants would be inappropriate.

FINDINGS

Participants tended to perform work related reading tasks in sporadic bursts due to personal travel, holidays, and other commitments in their schedules. Consequently, participants took between 3 to 8 weeks to reach the requisite amount of use (5.3 weeks average). In what follows, we first describe how each participant used United Slates to supply some context. We then elaborate on features of United Slates that shaped its use. We close by discussing the limitations of the current prototype. A more comprehensive report of all of our results can be found in [6].

Participant Thumbnails

As the descriptions below illustrate, the highly specialized work of our graduate student participants meant they were engaged in many different kinds of tasks. For instance, many of our participants had teaching and grading responsibilities in addition to conducting research. All participant names have been changed.

Hannah – Hannah was a Ph.D. student in History writing her dissertation. Hannah's work consisted largely of revisiting documents that she had collected on past research trips, which were archived electronically on her computer. With these documents, Hannah marked up important sections and then either made notes about the documents, or referred to them for details as she was writing.

Prior to receiving the slates, Hannah tended to print these documents out to read and mark up. The marked up printouts were then scanned back into her computer so that they were more easily accessed. When reading electronically using her laptop, Hannah often placed a second laptop next to it to simplify the process of reading while taking notes; one laptop was dedicated to viewing the document while the other was for writing. Hannah preferred to use two devices rather than flipping between windows (Figure 2a).

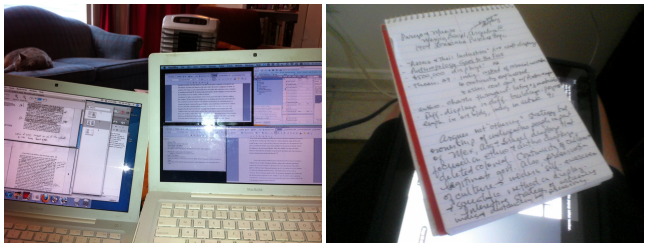

Figure 2 – a) (Left) Hannah's dual laptop reading environment; one laptop was for reading and the other for taking notes. Hannah preferred this arrangement to flipping between windows. b) (Right) Jane would keep notes on paper when reading with an iPad since the iPad did not support writing.

After receiving the United Slates system, Hannah continued working on her dissertation but used the slates in lieu of printouts or her second laptop. She mainly used one or two slates alongside her computer while she was writing. Hannah also used the slates to take notes and annotate papers for History department colloquia, during which students and professors read and then discussed each other's papers. Finally, Hannah used the slates for grading student papers and for completing job applications. Hannah was the most avid of our participants, finding the system particularly well suited for her dissertation writing activities. In fact, Hannah asked to borrow a slate following the study in order to continue using the system.

Justin - Justin was a student in English who was finalizing his dissertation and also teaching two writing seminars. Normally, Justin relied on paper printouts for these tasks.

For his dissertation, Justin's activities skewed towards editing and polishing the text. With the slates, Justin would create PDF versions of his dissertation and use the slates to review, proofread, and edit sections of his dissertation in lieu of printing them out. For his teaching responsibilities, Justin placed reading materials that he assigned to students on the slates and brought the slates to the classroom for his lectures. Justin also graded student papers using the slates.

Beyond these two core responsibilities, Justin regularly followed a handful of academic journals. As new issues appeared, Justin would log on and download articles of interest onto the slates. Normally, his standard practice would be to read the journal articles on the PC, and occasionally read the ones that arrived in the mail in print form. Over the course of the deployment Justin made several trips to academic conferences with the slates. Justin provided vivid descriptions of his use of United Slates while travelling between the university and the conference venue.

Barry – Barry, a student in English, mostly used the system for readings related to his dissertation. These materials included: a book central to his dissertation that he had been primarily reading on the iPad, and segments of a historical manuscript. He also used the slates for note taking alongside a large book that was only available to read on his Kindle (due to Amazon's proprietary e-book file format). Since these readings were for his dissertation, Barry made extensive annotations on these materials.

Barry also read journal articles on the slates. Normally, Barry would travel to the library, obtain a stack of recent journals and peruse the bound paper versions of the journal. Lastly, Barry sat in on several lectures while he had the slate and took notes on the slates during those lectures.

Barry was the least enthusiastic of our participants. We think this can be attributed to Barry's reading being heavily

rooted in books and linear in nature. Barry's other devices adequately supported this style of reading. Moreover, the iPad tended to be more responsive than the slate devices. Nevertheless, Barry was quite positive about features in United Slates like writing and synchronized annotations.

Cathy – Cathy, a Ph.D. student in History, was simultaneously preparing a research prospectus, completing a paper for a class, and completing her Ph.D. reading list.

For the research prospectus, Cathy used the slates for one long book and several historical manuscripts. When reading with the slates, Cathy mixed note taking in the paper notebook with direct annotations on the slate. Cathy only placed one item from her reading list on the slate, owing to the difficulty of finding electronic editions of the items on the list. For this particular title, Cathy also had a copy of the paper book and alternated between using the paper book and slates to read. Slates were also used beside the PC for writing the paper for the class. For paper writing, the slates were used for an initial read-through, as well as for reference as Cathy was writing. Slates were also used to read and participate in a History colloquium and to read and comment on a student paper.

Jane - Jane was a student in Architectural History. Jane's reading activities centered on readings from the course she was teaching. The majority of these readings were chapters of books and journal articles. Jane read and made notes on the documents she planned to use in class. Jane's normal practice was to print out these documents so that she could write on them. For these teaching tasks Jane preferred paper documents, but Jane mentioned she had transitioned to using an iPad to read most electronic documents. However, the fact the iPad lacked a stylus meant she often had to take notes in a separate notebook (Figure 2b).

Jane used the slates in class to teach and to lead discussions. Jane also used the slates to assemble a comprehensive end-of-semester review document for her students summarizing the topics and documents covered in the class. For the review, Jane used all four slates together, taking turns using each slate to view materials that had been covered over the course of the semester. Jane's simultaneous use of four slates was notable and unique among our users. Outside of teaching, Jane used the slates for multiple History colloquia, employing anywhere from 1-3 slates. Finally, Jane employed the slates while making changes to a journal article that she was preparing for final submission.

Anne - Anne was a student in History who had recently advanced to candidacy. Anne was at a stage where she was gathering documents for her dissertation, reading the documents, and placing notes about these documents into the software tools she used for notes management and writing. Anne emphasized that her goal was to extract out all of the relevant information from the documents she was reading so that she would not need to return to the original document. The materials Anne used ranged from digitized books to shorter article-length documents. Normally, Anne's work process would be to read on paper, annotate the documents, and then copy handwritten marks and excerpts from the documents into the software tools on her computer. After being provided with the slates, Anne no longer relied as heavily on manually transferring annotations.

During the deployment, Anne additionally needed to prepare a syllabus for a course she was scheduled to teach. For that task, she went through many iterations of the document, each time making small changes. Anne would use slates and paper interchangeably; some versions were edited using paper printouts others using slates.

Gina – Gina, a student in the English department, had completed her dissertation but not yet defended. Gina closely followed about 10 journals, from which she would download and read articles. Gina would read these journal articles on her Kindle. Gina's reading activities also included sections of 19th Century books that Gina intended to use for future writing projects and for group discussion. Since these book sections were only available in electronic form, Gina would normally print these out on paper so that she could read and mark them up. Gina would also print out readings for discussion groups for similar reasons.

Gina used United Slates for all of the above activities. The system was used predominantly for reading the journal articles. Gina annotated the most heavily out of our participants. The slates proved particularly helpful for marking up readings without printing them out.

From the detailed descriptions participants supplied about the activities summarized above, it was apparent that there were certain aspects of United Slates that participants found to be particularly relevant to their reading activities. Three of the most salient were: the availability of multiple screens, support for writing and annotation, and always-available synchronization across devices.

The Utility of Multiple Slates

The use of multiple slates conferred important benefits. The reasons for this were twofold: First, with additional slates more information could be viewed at any given time. Second, the physical properties of the slates—increased micro-mobility (i.e., ease of making small adjustments to the positioning of the devices) [12] , in particular—made the added space more useful.

Extra Display Area

The added display area was most commonly used to support non-linear navigation tasks like viewing two parts of the same document simultaneously, as was the case in following up on endnotes. Users found United Slates especially useful for this type of navigation since it was difficult to perform using conventional electronic document viewers. For instance, Justin mentioned that he would often disregard the endnotes when reading on his computer owing to the difficulty of scrolling back and forth. The extra space also supported the use of several documents at once. Jane,

Figure 3 - A sampling of how participants used the United Slates system. From left to right: a) superior screen positioning next to laptop (Hannah), b) Superimposed annotations (Gina), c) reading across multiple documents (Jane), d) using multiple slates to read and take notes at the same time (Hannah).

who used all 4 slates when assembling a review document for the course she was teaching, found that seeing several documents simultaneously helped her better "see" the connections between content (Figure 3c). Another way multiple documents were used was when one slate was used for writing and another for reading (Figure 3d).

An added advantage was that the display real estate associated with each slate was readily accessible without having to perform traditional window management tasks like minimizing or resizing windows. In general, this resulted in a less distracting reading experience as is evident in Hannah's remarks:

"*I didn't have to go back and forth; having two [slates] meant that all the information was there…I would have normally read on the computer and it's a real pain to read across two windows. I can never layout things the way I want.*"

Lastly, a particularly interesting use of extra slates was when Jane opened documents in advance on the additional slates and put them aside as reminders of things she still needed to read. This echoes Malone's [13] finding that paper documents in the workspace serve as reminders of tasks that still needed to be completed.

Micro-Mobility

Benefits arising from the portability and lightness of the slates comprise the second advantage of the multi-slate configuration, making it easier to operate the system in a variety of environments and postures. Hannah, for instance, sometimes used the slates on her lap, nestled between her body and the laptop and alongside the laptop on a desk (Figure 3a). Hannah had previously employed two laptops for her research work. Comparing the experience of using a slate against the extra laptop, Hannah said *"[a slate] is more comfortable than two laptops, it's so light on my lap."*

Justin used the slates successfully while a passenger during a road trip:

"At one point, I had two slates in the car to revise my introduction. I had one showing the Intro and the other with Chapter 2 to check what I wrote in the Intro matched what I said in Chapter 2. I would hold the slates one on top of the other most of the time. When I needed to check something, I would fan the two out to see both at the same time."

Justin's description illustrates how the form factor of the slates meant they remained usable in situations quite different from conventional flat surfaces like a desk. This result corroborates similar findings that a key strength of tablet devices is that they are conducive for use in a variety of locations [20]. Furthermore, the stacking and fanning interactions that Justin discussed can be directly attributed to the slates' unique affordances.

The micro-mobility of each slate also helped the reading environment smoothly adapt to changing reading requirements. Jane discussed how she could set up a slate in the periphery to casually consult related information. However, when she occasionally needed to go over the information in detail, the slate could be easily picked up (Figure 4).

These findings confirm that multiple displays do much more than provide more screen area. Importantly, they provided a more tailored use of space, which offers flexibility over a variety of settings and for many different tasks. For that reason, a single large screen probably cannot fully replicate the experience of using multiple lightweight devices. It bears mentioning that one of the advantages (and ironies) of the multi-slate configuration is that it also gave participants the freedom to use only a single slate. For many activities this was sufficient and often more desirable since it eliminated superfluous hardware and increased portability.

Writing and Annotation Capabilities

In light of the strong evidence prior studies have presented

Figure 4 - Mobility of the slates enabled Jane to quickly adapt to changing reading needs. A slate could change from providing peripheral information (left) to supporting reading in detail (right).

concerning the importance of writing and annotation in academic reading, it is perhaps not surprising that these capabilities had a strong, positive effect.

The importance of superimposed annotation (writing on top of pre-existing text, Figure 3b) was a big reason our participants decided to take part in the study in the first place. Hannah explained that the ability to write on digital documents was a feature she had *"been waiting for my entire life."* Jane also said that the writing and annotation features of United Slates were *"the best thing about the slate"* and *"a game changer"*. All of the other participants expressed similar sentiments.

Superimposed annotations served a number of critical roles in participants' reading activities, often supporting requirements identified in previous studies of reading [14,30]. For example, Jane explained *"With an iPad I would use a notebook on the side to take notes. With the slates the notes were not split between two different locations."* Annotating also helped participants stay engaged with the material [14]. Justin recounts how he *"enjoyed having the increased engagement of reading on paper back."* That participants annotated with words as well as symbols supports Marshall's recommendations that reading devices provide support for both notes and non-interpretive markings [12]. Several participants further took advantage of the presence and unique appearance of markings in the thumbnail overview to help identify locations in the document they had not yet visited.

Connectivity and Synchronization between Devices

The ubiquitous availability and automatic synchronization of documents and annotations on all devices in the United Slates system (e.g., slates and PC) provided the capabilities that most clearly surpassed the affordances of paper. The degree to which users benefitted from this was surprising, since synchronization across devices was originally intended to simplify the process of moving content onto the slates and maintaining consistency across slates. Synchronization, as it turns out, plays an essential role in conveying peace of mind, portability, and ease of retrieval—qualities that are traditionally associated with paper [27].

Automatic mirroring of written annotations across devices was the most compelling function. This capability amplified the usefulness of the writing capabilities described above by increasing the reliability and availability of annotations. Since marks were stored in the cloud and readily accessible almost immediately after creation, participants could call up annotated documents almost anywhere with either a slate or a PC. In fact, Barry found this aspect of the system so useful he made plans to scan in his paper documents following the deployment so that he could reproduce the workflow he enjoyed with United Slates.

Participants particularly valued the fact that annotations made on any slate became instantly available on the PC. There were several reasons for this. For one, no additional effort was required to get a copy of a marked up document onto the computer. In contrast, working with paper usually meant a laborious process of scanning a paper document back into the PC. The ease with which annotations were captured using United Slates meant that participants were able to build a more comprehensive archive of their work. Justin was pleased that the notes he made for teaching would automatically be available in the future. Jane was also very keen on how the slates preserved her work, saying, *"An immediate archive of the work you've done is something I'll miss about the slates."*

Synchronized annotations also solved a related problem of managing multiple versions of documents. Hannah, when describing the experience of reading on paper, said, *"sometimes I had two copies printed out but couldn't store one or find one—it was a pain."* Hannah explained how she would eventually need to find and re-integrate notes made across several different printouts of a document. With United Slates, there was a single "master" copy of a document. This behavior sidestepped the problem of having to recombine annotations spread across different copies of a document. Synchronized annotations also minimized the chance annotations got lost, as indicated when Cathy noted:

"I still prefer to write on paper, but I also lose paper. I'm less likely to lose stuff on [the slates] – that surprised me. It's more secure knowing my writing is on the computer. Or in a weird way it's all in one place instead of 5 different notebooks and random pieces of papers and folders."

Synchronization across devices also added an extra degree of portability beyond the ability to store many documents on an electronic device. Justin, for example, kept one slate device at his carrel in the library. Since documents added to the slates also propagated to the slate at the library, Justin reported that if he was going to read in the library, he could do so without carrying any slates at all. Given the importance of supporting reading in different venues [29], we believe this pattern of use was interesting as it highlights that factors beyond the device hardware can have an influence on macro mobility.

Finally, the synchronization across devices ensured that data was never stranded on a device. One way this property was useful was in allowing users the freedom to work with the device best suited for a given task. Jane, for instance, sometimes found it easier to browse through documents on her PC versus the slates. The ability to fluidly move between devices had the additional benefit of reassuring users that their work would not be lost if a slate ran out of power or malfunctioned, which gave users the confidence to shift more of their activities to the United Slates system. We believe that inspiring this kind of confidence, while not necessarily a reading requirement, *per se*, is key to the practical adoption of a reading system.

Inter-slate Interactions

We had expected that inter-slate interactions, which included the ability to shift documents from one slate to an-

other, and to create hyperlinks between documents, would play an important role in helping our participants work with content spread across multiple slates. Preliminary interviews indicated that participants thought these features would be useful, consistent with earlier work [5]. Justin mentioned that links could be useful for jumping back and forth between notes when only a single slate was available. Hannah thought that the ability to Stitch thumbnails from one slate to another would be useful for saving a location while flipping through other pages, much like using a finger to bookmark. As a result, we were surprised that these features were not used extensively during the deployment.

Several factors may have contributed to the lack of use. First, participants indicated that there were shortcomings in the interaction and graphic design of these features. Second, although the inter-slate interactions reduced the number of steps needed to open a document across multiple slates [5], this did not translate to substantial time savings because navigation time was dominated by page rendering speed rather than the number of interactions. As a result, there was less incentive for participants to use these shortcuts. It will be important to see if design refinements or better hardware might affect the uptake of these interactions.

Limitations

Annotation and Writing

A common complaint about the slates was that the space available for notes and annotations was overly constrained. The problem occurred frequently during grading activities. Suggested workarounds included features that allow typing out particularly long comments, appending blank pages, or attaching virtual Post-its, matching similar features proposed in the literature [24].

In addition, subtle bits of meta-information embedded in paper documents were not available on the slates. For example, with paper documents, different ink colors could be used to help distinguish marks made during different reading passes, Given participants' desire to have a comprehensive archive of their marked annotations, reintroducing this information and giving users the option to manipulate the document view based on it was said to be useful.

Navigation

The slow refresh rate of the electronic paper screens severely undermined navigation activities like preventing the quick skimming of documents, or finding of key parts of a document. As a result, participants found it difficult to keep pace or find parts of a document in an ad hoc way during teaching or discussion activities. Hannah worked around these issues by having different pages of the document open on multiple slates. Participants also noted that United Slates was unsuitable for information triage activities [17]. With alternative electronic displays, it should be possible to provide more responsive mechanisms and dynamic visualizations (e.g., animations, panning and zooming), which should provide much improved capabilities.

Portability

Our participants' reports gave insight to the quantity of hardware users could realistically transport. Users thought that carrying one slate was more portable than a printout, and two was equivalent to a standard book. No users carried around three or four slates. Relying on synchronization may mitigate some of the issues of transporting multiple slates (i.e., Justin's library carrel strategy). Also, Hannah remarked that remembering to pack and carry around the *accessories* for the slates, like their power adapters and the wireless hotspot, rather than the slates themselves, turned out to be the bigger nuisance that hindered portability.

DISCUSSION

Successfully Supporting Active Reading

The successes of the United Slates system validate several design recommendations that have already appeared in the literature. Researchers arguing for a reading system with multiple reading and writing surfaces cited expected gains in ergonomics [21], cross-referencing [1, 22], and writing while reading [1, 21]. The deployment confirmed ergonomic benefits from the added micro-mobility of the slates, navigation benefits from having more content visible, and important advantages from the ability to write in conjunction with reading. Also, United Slates' support for annotation and writing was regarded as a key reason for its utility. This reinforces the recommendation that e-readers support the creation of new content from the displayed text [30].

An unexpected new finding that comes out of this deployment was the importance of features providing added versatility. First, cloud-based synchronization allowed laptop and slates to be used interchangeably depending on which was most suitable for an activity. Second, stylus-based inking placed minimal restrictions on annotations. Third, micro-mobility of separate lightweight devices allowed for ergonomic and meaningful arrangements to suit different reading tasks and environments (e.g., laying out in the workspace as reminders, stacking and fanning in the car, holding up to read), increasing where and how the United Slates could be used. This versatility enabled participants' use of the United Slates for activities that we had not explicitly designed for. Matching paper's adaptability for many different tasks helped make the United Slates much more compelling as an alternative to paper.

Although our study population consisted of graduate students, academic activities like participating in discussions, document revision, and information gathering have workplace analogs [1]. Therefore, we believe the findings in this paper should be largely applicable to active reading in the workplace. However, one caveat is that our participants predominantly progressed linearly through their books and articles. The non-linear and hyperlink navigation functionality of the United Slates, used sparingly in this study, may prove to be more useful to users in other domains. For instance, engineers consulting technical documentation often perform quick jumps between non-sequential locations.

Improvements Over Existing Electronic Systems

One of the central improvements United Slates offered over previous systems for active reading [19, 26] was in the connectivity between devices in the environment. The improved connectivity produced a number of interesting and surprising shifts when compared to how users perceived previous e-reading technologies.

Unlike Morris et al.'s users [19], none of the students complained about the isolation of content across devices (both PC and slates). Also, in contrast to the legal scholars using XLibris [15] who were worried about duplicated functionality when using both an e-reader and a PC, United Slates users welcomed the symbiotic relationship between slates and the PC. Participants noted that connectivity made work alongside the PC more efficient. At the same time, connectivity also made it easier to work away from the PC and its associated distractions since there was relatively little switching cost to move work back to the PC.

It is also interesting to note that United Slates' users never expressed a desire to print out content, as many did when working with XLibris [15]. One likely explanation is that the desire for a paper hard copy stems from insecurities about whether a particular textual resource would be available when needed. By lowering the chance of information being stranded on a device, a major motivation for paper use was removed. Eliminating the problem of multiple paper versions of a document was an extra bonus.

Enabling New Reading Interactions

Although creating a system that matches the capabilities of paper is an important target, the potential of digital systems to surpass the functionality of paper is most exciting. New interactions by users of United Slates show how reading might go beyond the current status quo. One example of something paper is poor at, but that United Slates did well was the ability to maintain an accessible store of documents and annotations. The ability to access information rapidly from any location and without printing was a feature that many participants missed after returning the slates.

Another example is the blending of writing, proofreading, and revising the electronic system makes possible. Justin, for instance, streamlined his revision process by copying and pasting chunks of text he planned to alter into a scratch document (in case he wanted to reuse the text) as he was reading. This style of working allowed him to avoid having to repeatedly flip between windows while authoring the changes to the document. In this way, the United Slates supports editing activities similar to augmented paper [10], but without having to generate a hard copy of a document.

Lastly, electronic systems allow documents to bypass certain physical limitations that paper documents impose. A prime example was how users were able view the main text side-by-side with endnotes on the multi-slate system without having to turn any pages.

FUTURE WORK

As reading devices become more prevalent, enabling their use in collaborative activities is an area ripe for innovation. Recent research into collaborative reading [25] has shown that electronic devices can support these activities better than paper. The colloquia, teaching, and grading scenarios where United Slates was used all featured collaborative elements; participants were excited about the potential of extending United Slates so that it could be used collaboratively. A multi-slate environment, in addition to having much of the required communications infrastructure in place, offers some unique characteristics that could be useful for collaborative activities. For instance, physical separation of devices can allow for public and private display spaces and richer viewing options. This pattern of use also motivates new avenues of research into multi-device use such as coordinating turn-taking, and proxemics [9].

Also, this study demonstrated multi-device use was practical and useful for reading once barriers associated multi-device use like device setup and switch costs [23] were addressed. The same strategies may enable other domains to benefit from cooperative multi-device use in similar ways. For example, designers, who rely on the micro-mobile properties of paper [8], could likely take advantage of multiple interlinked mobile displays. Information visualization also seems to be a promising area given its use of multiple linked data views. We intend to explore the use of alternative combinations of devices (e.g., tablets, tabletops, phones) to support activities in these other domains.

CONCLUSION

Month-long deployments of a multi-slate reading system in the wild found that digital reading systems can be successfully used in real active reading contexts. Our participants—graduate students in the humanities—were particularly heavy readers in terms of the intensity, diversity and complexity with which they actively engaged with documents. If a reading system can serve their needs, then such a system will likely have wider applicability into other active reading domains.

In showing the importance of writing in reading activities, of micro-mobility for enhancing comfort and versatility, and the benefits from having multiple displays, the deployment confirmed long-held conjectures about how best to support active reading requirements. These claims had not been validated previously with a deployable system providing all of these capabilities. At the same time, the deployment brought to light other aspects of device design that have not been identified previously. A key finding was the transformative role of having annotations and documents simultaneously available through a low-overhead, closely connected system of devices including the PC.

Overall, this deployment of the United Slates system demonstrated that the use of a multi-slate reading system recaptures many of the beneficial affordances associated with paper documents. Although there were clearly aspects of

the system that can and should be improved, participant comments during the deployment indicated that there were many elements the system got right, providing functionality that not only equaled, but surpassed, paper.

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