Designing a Physical Aid to Support Active Reading on Tablets

Andrea Bianchi
Sungkyunkwan University
Suwon, Korea
andrea.whites@gmail.com

So-Ryang Ban
Sungkyunkwan University
Suwon, Korea
thdid48@gmail.com

Ian Oakley
Dept of Human & Systems Eng.
UNIST, Ulsan, Korea
ian.r.oakley@gmail.com

ABSTRACT
Tablet computers and portable eReaders are gradually becoming the preferred platform for the consumption of textual materials. However, although these technologies are powerful, it is widely acknowledged that print documents better support the advanced *active reading* tasks necessary to gain a deep understanding of a text. While prior work to address this issue has aimed improve digital eReaders by either leveraging familiar physical affordances or by extending paper's capabilities with digital tools, in this paper we propose a juncture of these two approaches. We first present a formative study that captures the needs and requirements of users during active reading tasks with tablets. We instantiate the findings in the design of a simple physical aid to support active reading: a smart bookmark. We then define an interaction space for this device, describe a set of interfaces designed to facilitate active reading and close with a user study that assesses the potential of the bookmark device and interaction techniques.

Author Keywords
eReader; active reading; tangible; tablet; bookmark; eTab.

ACM Classification Keywords
H.5.2 Information Interfaces and Presentation: Input.

INTRODUCTION
Reading is becoming digital. In today's information dense world, absorbing, processing and understanding increasing amounts of written content is a core skill for knowledge workers. Digital technologies such as eReaders and tablets are facilitating reading activities by making this wealth of material available to users in convenient, lightweight, connected and readily accessible form factors. However, while powerful, these devices are not well suited to Active Reading [19] tasks, a term referring to a broad set of cognitive skills and activities, such as thinking, learning, note taking, annotations, searching and skimming, that enable an individual to achieve a deep level of comprehension of a document. For example, it is the process that academics engage in when performing a close reading of a research article.

CHI 2015, April 18 – 23, 2015, Seoul, Republic of Korea.

http://dx.doi.org/10.1145/2702123.2702303

In fact, it has long been reported that people prefer to perform active reading with physical paper rather than on personal computers [24] and recent updates to this literature indicate the same holds true for tablet computers [19, 27]. Recognizing these problems as a design opportunity, many authors have investigated how technology can be improved to better support active reading. In early work on the topic, O'Hara and Sellen [21] suggest that design efforts should be directed towards aiding three key tasks: annotation, effortless navigation, and flexible spatial layout. Instantiating such recommendations, pioneering work such as XLibris [25], an active reading system based on a pen tablet and paper-like user interface, attempted to surpass the traditional reading experience by pushing its design in two ways. On one hand it augmented reading by integrating novel digital tools and functions such as search and indexing. On the other, it enabled users to transfer their normal reading practices from the physical world to the digital by its reliance on a pen and slate format device.

Most subsequent work can be broadly categorized as developing these two themes, creating either advanced software interfaces to improve tasks such as page navigation [28], copy/paste [29], annotations [14] and information gathering [12], or sophisticated hardware systems that mimic the properties of structure of physical paper books (e.g., dual screen readers [13] and foldable [7] or flexible [3] displays). While both approaches have value, purely software based solutions lack the vaunted (and valued) physicality of books while, practically, current hardware based approaches suffer from the complexity of the prototypes produced. These often require additional fixed hardware infrastructure such as cameras and projectors [8, 10], multitouch-tables [12, 14], or propose substantial alternations and modifications to the slate style tablet computer [3, 7, 11]. As such, while these approaches are novel, its unclear they are well matched to real eReading scenarios for tablets which place value on qualities such as portability, mobility, reliability, convenience and robustness [6, 7, 27].

The work in this article seeks to define a space at the juncture of these two approaches. It aims to combine the benefits of a physical user interface with the power and flexibility of digital representations in a lightweight and unobtrusive design for currently available eReading platforms. It does this by proposing a novel active reading system for tablet computers based on augmenting a familiar physical tool: a bookmark. The paper presents a formative study that captures user needs and requirements for such a tool. Using the insights gained from this process we designed and developed a functional prototype on a tablet computer and performed a study to capture user reactions. The contributions of this work are 1) extending the literature on understanding user needs in active reading tasks on tablets, 2) explicitly considering the role that a physical tool could play in mediating the digital reading experience, and 3) instantiating this knowledge in the design of a functioning prototype.

RELATED WORK

Active Reading combines activities such as thinking, learning, note taking, annotations, searching or skimming to gain a deep understanding of a written text [21, 25, 27]. Prior work in HCI has comprehensively contrasted how individuals perform active reading on paper versus on personal computers [19, 21] or tablets [6]. Accordingly, the review in this article focuses on two specific and relevant topics: readers that use physical interfaces to mimic the affordances of paper and those that use software interfaces to provide novel features and functions.

Physical interfaces leveraging on book affordances

Numerous authors have, through the construction of elaborate hardware, mimicked specific qualities of paper books in custom digital devices, typically with the goal of transferring the affordances of paper to the digital domain. For example, Chen et al. [7] presented a hinged dual-display system that creates a pair of display surfaces that can be opened and closed like a traditional book. They explored interactions such as content navigation or marking pages. Codex [13], a broadly similar system, extended these ideas by adding a stylus and investigating how coupled screens could aid tasks such as reading and note-taking. Other authors have explored squeezable or flexible systems that mirror aspects of the deformability of paper. Both gBook [3] and BendFlip [33], for example, sense forces and deformations to their surfaces to control navigation – simulating actions such as flipping rapidly through the pages of a book by bending it between finger and thumb. This work provides compelling design exemplars and motivates our research in that it convincingly demonstrates that physical aspects of the reading experience – the multiple surfaces available and the hand manipulations that can be performed – are important, valuable and worth conserving in the digital domain.

New features for digital content

Researchers have also explored new ways of working with text enabled by digitization. Hinckley et al. [12], for example, extended the vocabulary of actions that can be performed during an active reading task by introducing "pockets", virtual locations where users can temporarily stow notes, reminders or bookmarks and the idea of two-way cross-referenced notes that are dynamically linked to the text. Building on these ideas, LiquidText [28] further explored mechanisms for linking and referring to notes. The system allows users to create notes and excerpts of text, displayed in a separate area, that are flexibly linked to the source material and can be dynamically manipulated.

Indeed, note taking has been the focus of much research. The importance of physical paper in such processes is well acknowledged [24] and reflected in HCI projects. For example, Mackay et al. [18] presented prototypes to support note-taking scenarios among scientists based on the combination of a physical notebook, a graphics tablet, pens that can write on these surfaces and a magic lens [2, 26] that mediates between the physical and digital representations. Similarly, PapierCraft [17] and S-Notebook [22] use the Anoto pen system to issue commands or establish links between paper-based and digital contents. Hinchley et al. [14] extend these ideas by exploring rich bimanual input combining a digital stylus and multi-touch. Proposed interactions such as using a touch to mark a location in a book, then flipping to another page and writing a note with a pen before returning to the marked page highlight the power and potential of rich physical interactions coupled with digital annotations. Physical metaphors for bookmarks and eReaders have also been explored. NoteDrop [29], for instance, uses a special wearable bracelet to allow users to physically "pick up" words from a document by placing a physical object on a multi-touch screen. These words can then be physically dropped into zones on the side of the device to trigger actions such as copying or searching.

This literature presents a compelling case for the benefits that digital tools bring to the reading experience. The research in this paper aims to combine these advantages with the power and familiarity of a physical, tangible reading aid to provide readers with seamless, direct interaction with digital tools and content.

Tools and techniques for interacting with digital content

This work also builds on a set of well known techniques for tangible interaction with digital content and for sensing, visualizing and interacting on and with transparent devices such as magic lenses [e.g., 2, 10, 11]. In particular our work is inspired by the idea of manipulating physical widgets and tiles to seamlessly interact with digital content – concepts that originate with metaDesk [30] and have been extended in influential systems such as DataTiles [23], Tangible Tiles [31], paper GUI palettes [8], and explored commercially in products such as Adobe's Ink & Slide [1], a device designed to aid sketching on tablets. Our work also builds on prior systems that have presented transparent physical widgets that enable interaction with content displayed directly beneath their surface. Prominent work in this area includes SLAP widgets [32], the tPad [11] and cAR [10].

While SLAP widgets are tracked using visual markers in a tabletop system, tPad and cAR rely on a custom semi-transparent capacitive screen tracked by an external camera or situated over a tabletop. cAR is particularly relevant to our work as it explores how transparent physical widgets could be applied to reading tasks. However, cAR differs from the current paper in its focus on the technical realization of sensing solutions and its reliance on a large-scale computing platform. Indeed, cAR presents interaction techniques for Active Reading (based on actions such as moving or drawing on the display) only briefly and there is little discussion of the motivations underpinning their design. Finally, specific magic lens techniques that influenced our work include those that sense and react to touch input and gestures over their surface [2, 16, 26].

In sum, the goal of this paper is to combine these powerful interface and interaction ideas from literature into a novel, concrete and practically feasible (e.g. unpowered and compatible with current tablet platforms) design-led prototype that can support active reading tasks.

FORMATIVE STUDY

To inform the design of a tangible interface for active reading, we conducted a formative study using the speed-dating technique [9] to capture user needs and requirements. Speed-dating is a concept validation technique in which users are presented with storyboards depicting a range of possible usage scenarios describing tasks and activities, with the goal of conveying a rich set of possibilities and stimulating a detailed discussion about a targeted design space. It is expressly intended to help designers choose to *make the right thing* during the early stages of project conceptualization. The comments, reactions and opinions of participants are captured. Designers then synthesize this information with the aim of expressing user needs and the validity and value of specific design directions and concepts.

Participants and method

We recruited 10 users (age 25-27, four female, all engaged in, or recently completed, graduate studies) who regularly perform active reading of academic papers. They were compensated with 10 USD. All participants owned an eReader device, tablet or smartphone that they used for reading books and articles (40% academic material, 10% fiction, 50% non-fiction) from various locations (70% home or workplace, 30% traveling and commuting). Half of participants preferred physical books over eReaders for affective reasons such as feeling genuine ownership of print material or enjoying the material texture of paper. Those who preferred eReaders reported appreciating the portability benefits of storing multiple articles on a single device.

Method and material

The user study was carried out in a quiet lab area and took approximately 1 hour and 20 minutes per participant. On

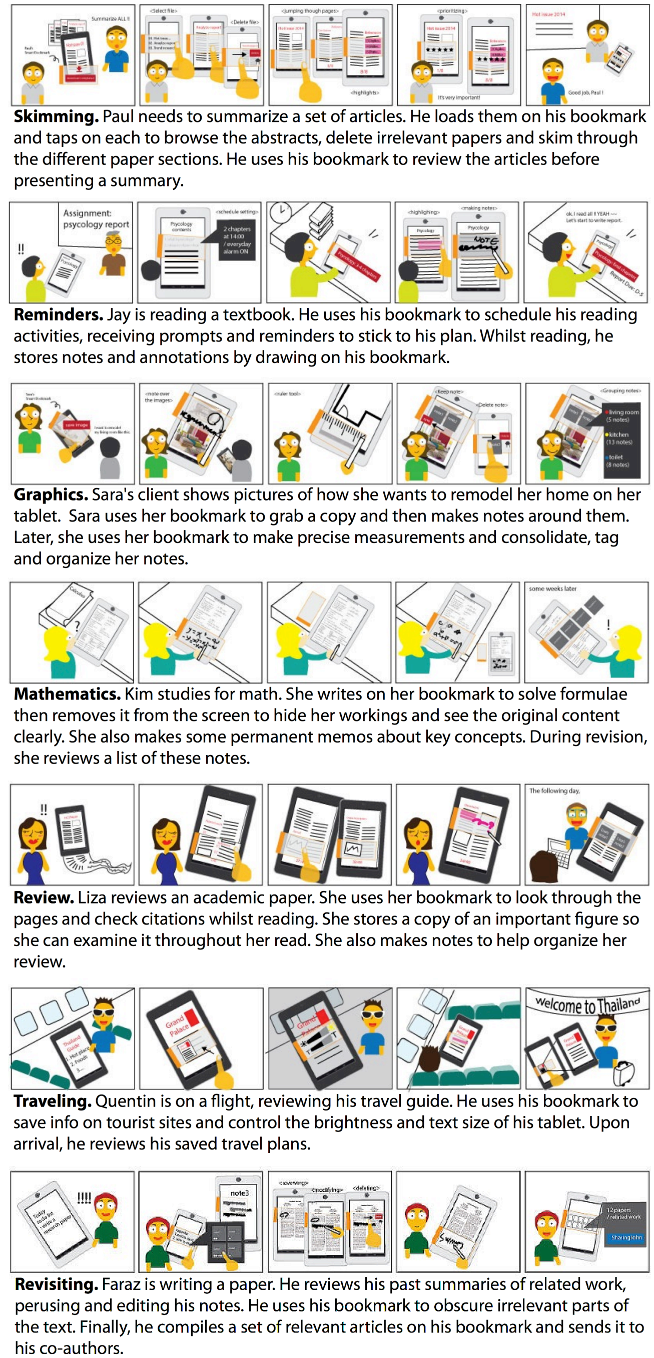

Figure 1. The storyboard/scenarios used in the formative study. The captions shown are translated summaries.

arrival, participants were briefed about the experiment and their demographics were collected. The interviewer presented seven scenarios/storyboards (see next section) and, after clarifications, collected user opinions, elaborations and reflection on each one for ten minutes. The session closed with time for open comments, reflections and suggestions from participants.

One prominent theme in the storyboards was examining academic research – a complex, challenging activity that requires training, skill and practice [15]. The storyboards were also inspired by prior research on active reading [12, 27] and Keshav's [15] three-pass model of reading which highlights key processes of skimming, in depth reading and reviewing. Ultimately, we produced seven storyboards (Figure 1), redundantly depicting a broad set of tasks, features and situations in the following scenarios.

Skimming. A student is asked by his supervisor to perform a literature review of several articles. This scenario explores page-to-page navigation, paper management and the saving and review of collections of articles.

Reminders. A user tasked with reading a book in a set period of time defines a reading schedule. The scenario explores notifications, highlighting text and taking notes.

Graphics. A user reviews a paper with rich and detailed graphics. This scenario covers pen annotations, note management and physically measuring angle and length.

Mathematics. A user reads a textbook containing many mathematical equations. This scenario explores annotations in the form of processing material (e.g. working out an equation) and making comments for later reference.

Review. A user reviews an article for a journal or conference. This scenario explores techniques for comparing and cross-referencing among parts of a document and reviewing notes and annotations.

Traveling. This scenario explores reading during travel. It explores managing content for future reference and tools to increase the legibility of text in distracting environments.

Revisiting. A user returns to a paper, reviewing their previous annotations and saved contents and uses tools to focus their attention of specific parts of the text.

Results

We processed the outcomes of the study by conducting an affinity process on user feedback. This focused on identifying the subset of tasks and activities presented in the scenarios that users reported to be valuable, interesting and useful, then clustering these together into meaningful groups. Ultimately, we arrived at two-dimensional structure that showed how three common readings tasks were supported by three different classes of activity. We termed the three tasks *skimming*, or rapid scanning with the goal of gaining an overview of a document, *understanding*, with the goal of achieving comprehension of a text, and *discussing*, or the deep reading required to be able to analyze or criticize an article. In formulating this structure, we drew on Keshav's [15] three-pass reading approach as a mechanism for understanding and interpreting user comments; the three tasks we propose reflect those he describes. The three kinds of activities are *managing*, *annotating & extracting*, and *exploring*, activities similar to those suggested by O'Hara and Sellen [21]. These activities were derived by synthesizing the features and abilities our participants reported to be of most interest and value. Managing activities correspond to navigating around, adding, deleting or re-ordering sets of pages, documents, notes or other material. Annotating and extracting activities relate to creating and linking notes to content and capturing or retrieving content for subsequent (potentially external) sharing or use. Finally, exploring activities entail visualizing, searching or comparing different parts the document in order to better understand particular points or extract key information. We discuss these activities in more detail below and they are summarized in Table 1.

In terms of the management activity, *navigation* came across strongly as a core reading activity. This has featured prominently in prior work [12, 28] and our participants once again highlighted its importance. Efficiency and flexibility were particularly valued properties. Beyond easy sequential navigation, users also favored rapid access to document overviews that would enable them to quickly jump to specific pages to support skimming style reading. They also reported a desire to mark or store particular pages for later reference, such as during subsequent viewing for clarifying or discussing content. When considering both sets of documents and their own comments or annotations they made similar observations relating to the importance of ordering, highlighting or otherwise prioritizing particular elements or articles. Marking (for subsequent viewing) the perceived relevance and importance of particular content was viewed as a vital task for achieving deep comprehension.

The *annotating and extracting* activity relates closely to note taking features that appear in prior work [e.g., 13, 14, 18]. Users valued annotations for all three of the reading processes we identified. During skimming, notes serve as quick reminders. During understanding readings, notes link to and are used to clarify contents. In discussion readings, notes are collated, sorted, categorized and potentially shared with others. Users also identified two broadly different classes of notes – those that refer to particular content specifically (and typically are written directly over that content) and over-arching comments that refer to a document in a general sense, rather than any specific point, region or section (a distinction previously characterized as inter-page versus intra-page annotations [27]). Users also raised concerns about clutter. There were two main issues. Firstly, users were concerned that notes might obscure the original content, making it hard to view or access. Secondly, revision of notes was viewed as essential to their effective use – editing, sorting, deleting and reordering were important in ensuring notes were useful as opposed to simply overwhelming and profligate. Finally, users were very positive about using styli to create hand written (rather than typed) notes, as this would allow integration of content such as drawings, expressions (e.g. exclamation marks, emoticons) and spatial information (e.g. arrows).

	Managing content	Annotations & Extractions	Exploring
Skimming	1 Quick navigation among pages. View document overviews.	2 Add/delete memo-style notes. Notes that link to source material.	3 Rapid access to content on other document pages.
Understanding	4 Organize content by priority. Store and manage content.	5 Capture excerpts for reference. Writing annotations on original file and control its visibility.	6 Highlighting text. Tools to analyze content (e.g. measure, isolate or increase prominence).
Discussing	7 Categorize annotations automatically (e.g. time) & manually (e.g. tagging). Easy sharing of notes.	8 Show and hide notes. Manage captured excerpts and notes.	9 Flexibly make, show and hide highlights and text.

Table 1. Results of the formative study. Three common reading tasks (skimming, understanding and discussing) supported by three activity types (content management, annotation & extraction, and exploring). Table cells show specific examples in each area. The results are derived from an affinity process conducted over user feedback received during the study.

Regarding the *exploring* activity, users commented very positively on ideas about displaying and manipulating alternative content on a reading aid, describing these kinds of feature as "like a small dual screen". They saw value in using this kind of capability to rapidly examine or contrast text or image excerpts from other pages or documents with currently displayed content. These results match previous authors' focus on supporting text extraction for quick cross-comparison [10, 14, 28]. However, moving beyond the approaches proposed in these prior systems, users also emphasized the importance of accessing captured material while remaining in the context of the current document and without disrupting the flow of reading. Different participants also stressed that different forms of content might be useful – their notes, content from other pages in a document, particularly important charts or images and even material from an entirely different, but related, documents. They also indicated that, typically, cross-referencing tasks involve viewing multiple pieces of information from a range of sources and that tools should support a variety of display, navigation, access, search and view options.

Users also made comments about the use of a physical aid as a practical tool to support examining a document. They saw value in using the tool physically – to highlight particular parts of text, or to establish the relationships of particular elements in complex figures. They were negative on its use to control or deal what were perceived as digital aspects of the system: font sizes, screen brightness, alarms and reminders. This kind of functionality was viewed as redundant with the basic tablet UI or, in the case of reminders, "annoying" and superfluous.

Finally, users also advanced opinions and comments about viable form factors for a physical bookmark object. The idea of a rectangular window with a handle at one end was prominent. Opinions as to an optimal size of the object varied considerably. One group of users indicated a large bookmark, capable of covering the width of the tablet would best support annotation and visualization activities. Others were more concerned about portability and suggested much smaller, easier to carry, sizes. Some suggested the idea of integrating the bookmark into a pocket in a tablet cover or case, an already common type of accessory. A final practical concern is that users almost universally and strongly disliked the idea of having to charge an additional device – any reading aid should either be unpowered or capable of operating without recharge for substantial periods of times, ideally in the order of several weeks or longer.

Selection of features for design

Extending the affinity process that led to Table 1, we isolated a subset of the activities in the study scenarios that users found valuable (e.g. those relating to content management, annotation and visualization) and discarded those that received negative comments or a lack of interest (e.g. reminders, or controlling display settings). These activities appear as the examples in Table 1 (shown in cells one through nine). To move towards designing applications based on these findings, we further reduced the examples to a set of five cross-cutting interface features termed: *page navigation*; *content capture*; *annotation*; *magic lens* and; *visual aids*. The *navigation* feature drew on activities shown in Table 1 such as moving between pages, storing content and providing overviews (shown in cells 1 and 4). Similarly, *content capture* reflected ideas about storing and managing images extracted from on-screen contents (cells 5 and 8). The *annotation* feature consisted of techniques to make, save, edit and organize inter-page and intra-page annotations [27] (cells 2, 5, 7 and 8) while the *magic lens* collected issues relating to exploring and cross-checking other document contents whilst reading a page (cell 3). Finally, the *visual aid* feature related to processing the physical qualities of documents – obscuring or highlighting specific content areas and measuring qualities such as length or angle (cells 6 and 9). These interface features became the targets for our subsequent interaction design process.

In conclusion, the formative study clearly shows that the tasks performed during active reading vary considerably depending on the desired level of understanding of the text. Moreover, the activities to support these tasks are not necessarily similar (e.g., annotation versus bookmarking), suggesting that designers should strive for a diversification of approaches (e.g., developing multiple distinct tools) instead of proposing single unified solutions. Finally, the study emphasized that users involved in a reading task see considerable value in the simplicity and directness of a physical tool and physical interaction over an elaborate graphical user interface.

INTERACTION SPACE

Reflecting the conclusions from the formative study, this paper proposes an active reading aid in the form of a smart bookmark: the eTab. It takes the form of a transparent physical object that requires no batteries and that can be placed on the surface of a tablet computer [10, 32] and its presence sensed by the device's capacitive screen [5]. With this setup it is possible to use it as a display surface for alternative or augmented content. The bookmark is also sufficiently thin that touches and gestures on its surface are detected by the tablet multi-touch screen underneath it. The design space enabled by this setup results in a novel combination of both display and interaction possibilities. We isolate the most important features in Figure 2:

Looking. Similar to a magic lens [2, 16, 26], the bookmark allows users to simultaneously view two separate information spaces, one on the main tablet screen and one through the bookmark. These spaces can be adjusted as the tool can be freely moved around the surface and the content can be updated to reflect its location.

Interacting. As with SLAP widgets [32], touches and gestures (single tap, double tap, swipe, pinch, drag) on and off the bookmark can be discriminated and mapped to different interface actions (a vocabulary of gestures comparable or larger than that of similar systems [10, 11]). For example, swiping on the bookmark can be used to navigate between documents, while swiping on the tablet could be used to navigate within the current document.

Transitions. The presence of two separate information spaces also inherently supports interaction between these zones. Touch or strokes can be used to move, or otherwise associate, content from one interaction space to the other. This functionality can provide the advantages of dual-screen setups such as Codex [13] and the rich two-way linking present in LiquidText [28].

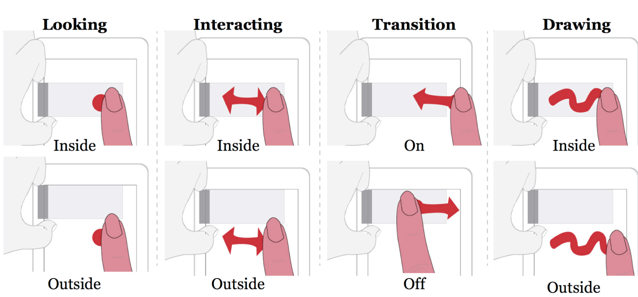

Figure 2. The two interaction spaces available with the eTab. Interaction can be separated based on whether it takes place on or off the transparent region of the bookmark. Interactions include looking at different content, interacting with gestures or taps, dragging from one space to the other, and drawing or writing using either or both the spaces.

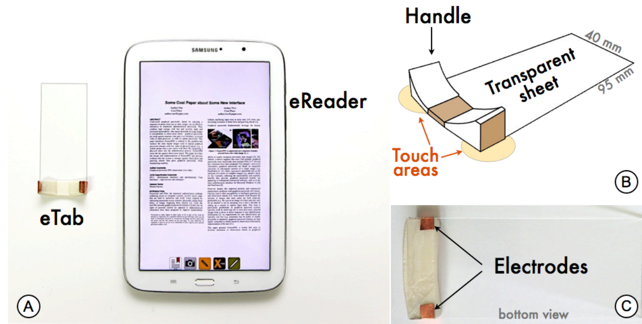

Figure 3. System overview (A); a sketch of the eTab highlighting the touch areas and transparent sheet (B); bottom view of the eTab prototype (C).

Drawing. Similarly, annotations, sketches and other drawn content can be entered both on and off the bookmark surface, allowing user entered content to be treated differently. For example, each space could be used to store different types of annotation, or one space could be used for annotations and the other for gestural input, potentially enabling a rich set of bimanual interactions [8, 14].

PROTOTYPE

The prototype (Figure 3) consists of a physical bookmark-like object and an eReader application developed for Android, running on a Samsung Galaxy Note 8.0 tablet. The physical bookmark (Figure 3.B) is composed of a 40 mm wide x 95 mm long x 0.5 mm thick transparent plastic body with a low-profile 3D printed handle. Similar to DataTiles [23] and SLAP widgets [32], the use of a thin transparent sheet allows the tablet touchscreen to precisely register input to bookmark's surface. Moreover, it serves to clearly and physically depict the size of the virtual bookmark region. The upper surface of the bookmark's handle is covered with a thin copper sheet which is connected to a pair of 0.5 cm square copper coated regions on its base (Figure 3.C). Due to the conductivity of the metal sheet, placing the bookmark on a multi-touch capacitive screen and touching the handle causes a recognizable pair of touch points to appear, a well documented technique for tracking physical objects on a tablet computer [1].

The eReader application is based on a standard portrait format viewer that allows users to navigate to different pages of a document by tapping on the sides of the screen, to zoom with pinch gestures and to pan with single finger movements. When the bookmark is placed on the screen its presence is registered based on the two capacitive points it produces. However, it remains inactive until a user taps on its transparent body. When this occurs, the currently selected bookmark view is activated and remains on until the bookmark is removed from the tablet screen. Whilst on-screen users can view and interact with the bookmark using the interaction space we define above: by repositioning it, looking at the contents displayed on its body and tapping, drawing or gesturing on, around or between this region and the surrounding screen area (Figure 2). Using this setup and

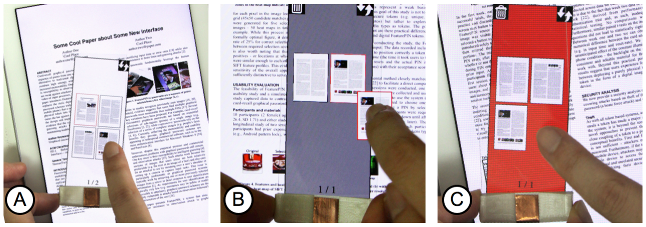

Figure 4. Navigation to pages by tapping on thumbnails (A), bookmarking custom pages by dragging them on to the eTab (B), and deleting pages by selecting them (C).

the features for design previously selected, we instantiated the results of the formative study into five different tools. The individual modes are selected from a row of five icons docked at the bottom of the tablet, each corresponding to a specific bookmark mode. The icons appear only before the eTab is activated (e.g. before placing it on the screen). This switching mechanism was inspired by common GUI designs (e.g. OSX dock).

Page Navigation

Navigation and marking pages for reference is a core feature for active reading. As such we developed page navigation functions (Figure 4) that enable users to quickly select and move to any page in a document. This is achieved by placing the eTab on the screen. Underneath its transparent body, thumbnails of all the document pages in groups of four are displayed, with the current page shown on the main display highlighted. Users can tap on a page to navigate to it and move to previous or subsequent sets of page thumbnails by swiping across the eTab.

A button located at the tip of the eTab toggles to a mode in which users can view and manage thumbnails of a set of saved pages. Pages are added to the set by tapping on the main tablet screen and dragging onto the eTab (a feature that resembles the pockets in Hinckley et al's GatherReader system [12]) and removed by tapping on the thumbnail and dragging off the eTab (Figure 4.B). Saved pages can be viewed by tapping on the thumbnail. Finally, there is also an explicit delete button for fast deletion of bookmarked pages (Figure 4.C).

Screen Capture

Taking advantage of the ease with which the eTab can be moved around, we designed a screen capture tool (Figure 5) to support saving, comparing and cross-referencing content. In this mode, once the eTab is positioned on the page, it acts as a camera. Tapping on the eTab takes and stores a screenshot of the content underneath its transparent body (a feature similar to one proposed in cAR [10]). Multiple screenshots can be taken and a user can tap a button to review the captured contents. These are displayed on the eTab body and are stored permanently on the tablet, making them available as a reader moves to other pages and, indeed, other documents. Swiping across the body of the eTab navigates through the set of stored screenshots and they can be deleted in the same way as the page thumbnails described above. The images are also stored in public folders on the tablet (and potentially on the clipboard), making them easily available to other applications, a feature explicitly requested by users.

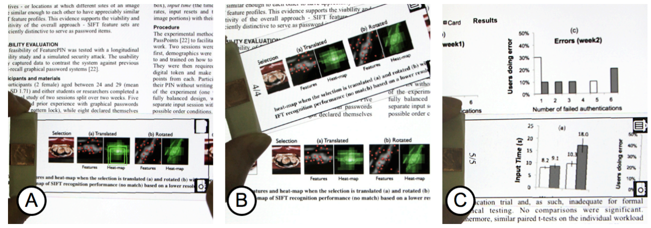

Figure 5. Screen-capture portions of the screen by tapping on the eTab (A, B). Screen-captures are saved and can be viewed (and navigated among) by swiping on the eTab surface (C).

Notes and Annotations

The ability for users to take notes and otherwise annotate material is a critical to active reading [27]. Accordingly, this issue has received considerable attention in the research community [e.g. 8, 14, 18, 28]. Similarly, the participants of our formative study repeatedly highlighted the importance of different kinds of notes. Specifically they strongly valued the ability to write notes that summarize comments referring or relating to the document as a whole, as well as notes directly linked to (and typically written over) specific portions of text in the document.

In line with these comments, we developed two different note formats. In the first (Figure 6.A), users write notes directly on the transparent body of the eTab, as they would write a post-it note in a real document. As with the screen capture application they can navigate through a set of notes by swiping across the eTab, delete notes via a trashcan icon, or modify the current note by simply writing or drawing additional content. These notes can be accessed from any page or document in the reader and can also be saved and copied for use and integration with external applications. In the second annotation format (Figure 6.B and C), users write and draw on the page around the eTab, directly on the displayed contents. These annotations are displayed only in the document locations in which they were original made, scaled in accordance with the main text, and are shown only when the eTab is placed on the screen. This ensures the marks do not permanently clutter or obscure the original contents. Whilst in this mode, the eTab displays a palette of colors and brush options (similar to [8]) that users can tap to select and control the format and style of their annotations (Figure 6.B).

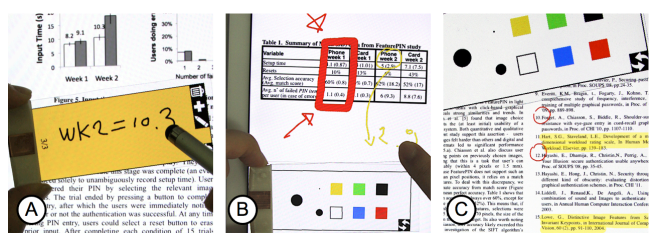

Figure 6. Two note styles are implemented. Post-it notes (A) and in-text annotations (B and C). With annotations, the eTab serves as a palette for colors and pen sizes (B).

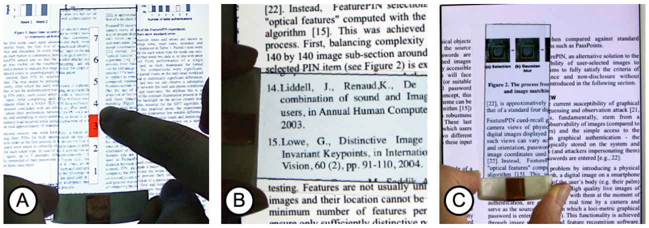

Figure 7. The X-Ray magic lens allows users to select a different document page (A) that will be visualized inside the eTab for reference or comparison with current contents (B, C).

X-Ray magic lens

Inspired by the work on magic lenses and contextual information displays [2, 16, 26], we designed an X-Ray tool that allows users to view the content on any page in a document in a window delimited by the eTab's transparent body (Figure 7). This system allows a user to quickly glance through the document to retrieve information present in another location. For example, a user could review or clarify a passage on a previous page (Figure 7.C), cross-reference a figure or check a citation (Figure 7.B) by looking through the X-Ray tool instead of flipping to the relevant page. In this way, the X-Ray tool offers ready access to other pages (scaled and panned with the current page) in order to support comparison and cross-referencing tasks.

Visual helpers

In the formative study, users reported challenges in following prose in dense writing on screen. To address these issues, we developed simple visual aids that allow users to underline an area of text (Figure 8.A), or to selectively obscure the content of lines above and below one of particular interest (Figure 8.B). These tools are designed to help users focus on a specific portion of text or minimize peripheral distractors. Extending these ideas we also created a ruler tool (Figure 8.C) that can be used to measure the length and angle between on-screen objects. This function is particularly intended for tasks such as examining maps, floor plans and images with scales. Users can rely on an accurate physical ruler integrated with the digital system and not have to physically print off articles in order to take measurements with traditional off-line tools.

USABILITY STUDY

We conducted an informal usability evaluation using the 10 participants who completed the formative study. They were first introduced to the eTab features and then given the opportunity to try them out. Comments and opinions were solicited throughout and the study took about 20 minutes per participant. Overall, users reported the bookmarking, annotations, screen-capture and the X-Ray magic lens functions to be both useful and usable. Comments included P5's appreciation of the ease with which pages could be added or removed from custom sets of bookmarks. P4 was positive about hiding all in-text annotations when the eTab is off the screen as it enabled him to "quickly see the original paper" while P10 appreciated the X-Ray tool as it was "more convenient than page jumping" when checking material in other pages. Finally, P2 regarded the screen-capture tool as very "familiar".

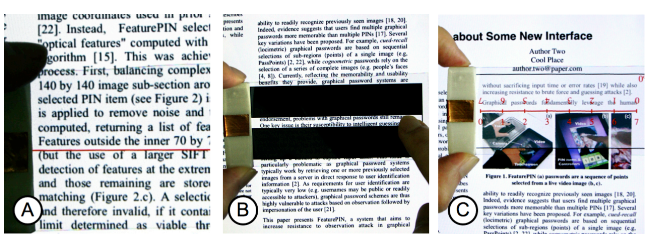

Figure 8. Visualization tools: an underline (A) and a visual band (B) to help users read dense text. A ruler tool (C) to measure length and angles of on-screen content.

Other tools received mixed comments. For example, P3 and P9 indicating that the line and the band tools are simple to use, but have limited applicability. P6 saw value in combining the navigation tool with the post-it notes, but P7 and P8 remarked that the eTab is small and would limit the usefulness and depth of the notes they could make. The small size of the eTab was also mentioned for the screen-capture (P2). These comments highlight a key recurring trade-off between the need for a portable physical tool and a large surface for rich interaction. One way to alleviate this concern would be to allow users to virtually expand the bookmark in specific circumstances – for example, during note taking, they could use a magnifying widget to expand the available drawing canvas. Finally, while some participants appreciated the consistency between the different applications (P10: "all eTab interaction methods are similar, so it is easy"), others commented that some of the interactions, such as dragging a page of the surface of the eTab to delete it, have poor affordances – there are few cues to indicate what can be done. We note this is a common problem with gestural style UIs [20].

DISCUSSION

Exploring multiple diverse ideas is a powerful way to gain insights into new input modalities and technologies [14]. For this reason we designed the eTab to cover a range of topics and to function not as a single monolithic system, but as a set of five different applications with complementary features designed to work together rapidly and seamlessly – users can simply lift and replace the eTab to switch modes. We argue this perspective is well suited to complex and varied tasks involved in active reading. For example, as illustrated in Figure 9, a typical active reading scenario with the eTab might involve a user studying a paper and quickly looking up a reference using the X-Ray functionality, then switching to annotate, comment on or highlight some text directly on the screen using a stylus. As reading continues, they navigate around the page by zooming or panning and then make a post-it note comment for later reference. This complex sequence of actions can occur rapidly and fluidly based on the rich bi-manual input [14] enabled by combining the physical tools of the eTab and a standard stylus with finger touches. As in previous work [14] and, as

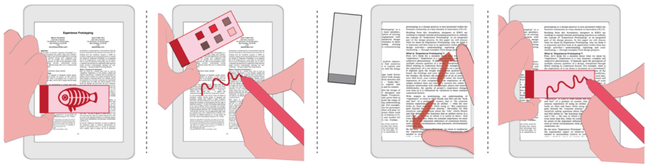

Figure 9. The flow of interactions across a series of interrelated subtasks using hands, stylus and the eTab.

exemplified in Figure 9, the real value of the eTab system lies in the way it supports a rapid flow between the different interaction styles required for a series of closely interrelated subtasks. It serves as a mechanism to mediate between activities without disrupting focus and the flow of work.

Ultimately, the novel aspects of this work, compared to previous systems with similar design intentions [10, 14], is that it further expands the vocabulary of actions and the set of tools involved in the interactions that support active reading tasks. It also specifically focuses on the design of tools that operate with current available portable eReader devices (such as tablet computers). While Hinckley et al. [13, 14] made a case for the benefits of simultaneous use of touch and pen input, in this paper we extend this argument to explore the value that the eTab, a physical tool with very different physical properties and affordances, can bring to the active reading task. We design, present and discuss the novel interactions enabled by this tool, and show how they can co-exist in the ecosystem of interactions based on the more standard input techniques of pen and touch. Ultimately we believe that physical tools have much to offer to the digital reading experience and that the eTab represents a novel interactive design that showcases key aspects of this potential.

LIMITATIONS, FUTURE WORK AND CONCLUSION

This paper has presented the eTab, a simple physical aid for active reading on a tablet computer that works with currently available tablet devices and without batteries. The design of the system was motivated by prior literature and a formative study in which we exposed participants to scenarios depicting the potential of such a tool. We instantiated their feedback in the design of the eTab software in order to support activities such as rapid navigation, flexible note-taking and easy capture, manipulation and comparison of content. Finally, we validated our designs in a qualitative user study.

There are also limitations to this work. Perhaps the most serious is that the qualitative study, whilst informative, was brief and lab-based. As such, it does not allow us to comment on how the system would be used during real reading experiences – whether positive commentary on novel features such as the screen capture or X-Ray would actually lead to integration into real world reading practices. Given the simplicity, portability and robustness of our hardware, a more naturalistic field study is an obvious next step for this work.

There are also many further opportunities for future work. In terms of developing the prototype, we plan to explore different physical form factors. The formative study showed users had diverse preferences regarding the size of a prospective digital reading aid – either small and portable or large and with a substantial viewing/interaction space – and we are interested in exploring the potential of such variations. It is also clear that users manipulate the eTab (and devices in closely related systems [10, 11]) in a typical bimanual way: the device is fixed in place with non-dominant hand and interaction occurs with the dominant hand. This provides some guidance as to effective minimum sizes for the eTab – it must be sufficiently large to comfortably support this bimanual interaction style. To deal with the range of size recommendations, we are also interested in developing software or hardware prototypes than might expand and contract (virtually via an on-screen widget or physical via a mechanical mechanism) to provide users with differently sized eTab devices that can best cater to their preferences and needs.

Future versions of the eTab software should also improve the integration between the eTab modes – currently switching modes requires removing and replacing the eTab on the screen, an action that might become overly laborious if frequently performed. We are also interested in designing interfaces based on text-extraction functionality to support search, translation and text mining. Finally, in terms of the empirical work, a more substantial and longer-term usability study would improve the scope and validity of the findings from the second experiment in this article.

Ultimately, despite the advantages of paper, we believe that the convenience of digital reading platforms (such as tablet computers and eBook readers) will make them the dominant format for consumption of textual material. The eTab, by merging key aspects of the physical experience with the process of digital reading, represents a feasible and practical step towards combining the best of both these worlds – the expressiveness and rich affordances of physical objects with the flexibility and power of digital contents.

ACKNOWLEDGMENTS

This paper was supported by Samsung Research Fund, Sungkyunkwan University, 2014, and by Basic Science Research Program through the National Research Foundation of Korea (NRF) funded by the Ministry of Science, ICT and Future Planning (2014R1A1A1002223).

REFERENCES

1. Adobe Ink & Slide: http://www.adobe.com/products/ink-and-slide.html [Last access: January 2015].
2. Bier, E.A., Stone, M.C., Pier, K., Buxton, W., DeRose, T.D.: Toolglass and magic lenses: the see-through interface. In SIGGRAPH'93, 73-80.

3. Burstyn, J., Herriotts, M.A.: gBook: an e-book reader with physical document navigation techniques. In CHI EA'10, 4369-4374.
4. Büschel, W., Kister, U., Frisch, M., Dachselt, R.: T4 - transparent and translucent tangibles on tabletops. In AVI '14, 81-88.
5. Chan, L., Müller, S., Roudaut, A., Baudisch, P.: CapStones and ZebraWidgets: sensing stacks of building blocks, dials and sliders on capacitive touch screens. In CHI'12, 2189-2192.
6. Chen, G., Cheng, W., Chang, T., Zheng, X., Huang, R.: A comparison of reading comprehension across paper, computer screens, and tablets: Does tablet familiarity matter? In Journal of Computers in Education, 1-13.
7. Chen, N., Guimbretiere, F., Dixon, M., Lewis, C., Agrawala, M.: Navigation techniques for dual-display e-book readers. In CHI'08, 1779-1788.
8. Dachselt, R. and Al-Saiegh,S.: Interacting with Printed Books Using Digital Pens and Smart Mobile Projection. In CHI EA’11, 21-23.
9. Davidoff, S., Lee, M.K., Dey, A.K., Zimmerman, J.: Rapidly Exploring Application Design Through Speed Dating. In UbiComp'07, 429-446.
10. Hincapié-Ramos, J.D, Roscher, S., Büschel, W., Kister, U., Dachselt, R., Irani, P.: cAR: Contact Augmented Reality with Transparent-Display Mobile Devices.In PerDis '14, 80-85.
11. Hincapié-Ramos, J.D, Roscher, S., Büschel, W., Kister, U., Dachselt, R., Irani, P.: tPad: designing transparent-display mobile interactions. In DIS '14, 161-170.
12. Hinckley, K., Bi, X., Pahud, M., Buxton, B.: Informal information gathering techniques for active reading. In CHI'12, 1893-1896.
13. Hinckley, K., Dixon, M., Sarin, R., Guimbretiere, F., Balakrishnan, R.: Codex: a dual screen tablet computer. In CHI'09, 1933-1942.
14. Hinckley, K., Yatani, K., Pahud, M., Coddington, N., Rodenhouse, J., Wilson, A., Benko, H., Buxton, B.: Pen + touch = new tools. In UIST'10, 27-36.
15. Keshav, S.: How to read a paper. SIGCOMM Comput. Commun. Rev. 37, 3 (July 2007), 83-84.
16. Kim, K.T. and Elmqvist, N.: Embodied Lenses for Collaborative Visual Queries on Tabletop Displays. In Information Visualization, 11(4): 336-355, 2012.
17. Liao, C., Guimbretière, F., Hinckley, K., Hollan, J.: Papiercraft: A gesture-based command system for interactive paper. In TOCHI. 14, 4, Article 18, 27 pp.
18. Mackay, W.E., Pothier, G., Letondal, C., Bøegh, K., Sørensen, H.E.: The missing link: augmenting biology laboratory notebooks. In UIST'02, 41-50.
19. Morris, M.R., Bernheim Brush, A.J., Meyers, B.R.: Reading Revisited: Evaluating the Usability of Digital Display Surfaces for Active Reading Tasks. In TABLETOP'07, 79-86.
20. Norman, D.A.: Natural user interfaces are not natural. In Interactions 17, 3 (May 2010), 6-10.
21. O'Hara, K. and Sellen, A.: A comparison of reading paper and on-line documents. In CHI'97, 335-342.
22. Pietrzak, T., Malacria, S., Lecolinet, E.: S-Notebook: augmenting mobile devices with interactive paper for data management. In AVI'12, 733-736.
23. Rekimoto, J., Ullmer, B., Oba, H., DataTiles: a modular platform for mixed physical and graphical interactions. In CHI'01, 269-276.
24. Sellen, A. J. and R. H. R. Harper, The Myth of the Paperless Office, 2003, pp. 242.
25. Schilit, B.N., Golovchinsky, G., Price, M.N.: Beyond paper: supporting active reading with free form digital ink annotations. In CHI'98, 249-256.
26. Spindler, M., Tominski, C., Schumann, H., Dachselt, R.: Tangible views for information visualization. In ITS'10.
27. Tashman, C.S. and Edwards, W.K.: Active reading and its discontents: the situations, problems and ideas of readers. In CHI'11, 2927-2936.
28. Tashman, C.S. and Edwards, W.K.: LiquidText: a flexible, multitouch environment to support active reading. In CHI'11, 3285-3294.
29. Thom, E. and Jones, M.: Holding onto the magic: lightweight augmentation of digital reading devices. In DIS'12, 510-513.
30. Ullmer, B. and Ishii, H.: The metaDESK: models and prototypes for tangible user interfaces. In UIST'97.
31. Waldner, M., Hauber, J., Zauner, J., Haller, M., Billinghurst, M.: Tangible tiles: design and evaluation of a tangible user interface in a collaborative tabletop setup. In OZCHI'06, 151-158.
32. Weiss, M., Wagner, J., Jansen, Y., Jennings, R., Khoshabeh, R., Hollan, J.D., Borchers, J.: SLAP widgets: bridging the gap between virtual and physical controls on tabletops. In CHI'09, 481-490.
33. Wightman, D., Ginn, T., Vertegaal, R.: BendFlip: Examining Input Techniques for Electronic Book Readers with Flexible Form Factors. In INTERACT'11, 117-133.
34. Zeleznik, R., Bragdon, A., Adeputra,F., Ko, K.: Hands-on math: a page-based multi-touch and pen desktop for technical work and problem solving. In UIST'10, 17-26.