Digital+Paper: Investigating Current Technology Preferences in Academic Reading

ABSTRACT

This paper examines responsive reading in an academic context while focusing on a particular demographic and investigates the factors that influence the choice of reading technology. We conducted a 3-week diary study followed by post-study interviews with 10 computer science graduate students. Participants reported on reading sessions they undertook as part of their academic life. We examined the workflow students use in the absence of technological bias or imposition. We found that preferences for reading technologies varied widely from student to student and within individuals based on document availability, the nature of the task, and economic and social factors. We observed digital technology was used in three quarters of reported reading sessions, sometimes alongside paper. Reading mostly occurred in multi-document scenarios, often concurrently with writing, and digital devices were favoured for certain tasks that had previously been performed on paper (e.g., notetaking, proofreading). We believe we have transcended the "paper vs digital" rhetoric and emerged into a space where digital technology is in fact preferred and exists alongside paper in a synergistic world we call "digital+paper".

Author Keywords

Academic reading practice; mixed-methods research; thematic analysis; technology selection.

ACM Classification Keywords

H.5.m. Information Interfaces and Presentation (I.7): Miscellaneous

INTRODUCTION

Knowledge workers and, by extension, academics, engage in a type of reading alternatively described as responsive [25], analytical and inspectional [2], active [23], or close [12]. It entails "developing new knowledge or modifying existing knowledge by engaging with the ideas presented in a text." [25]. We will refer to it as "responsive reading", acknowledging the bidirectional nature of information flow in the activity and its related tasks.

Successful responsive reading relies on a diverse set of requirements, ranging from low-level properties like portability and text readability, through broad considerations such as archiving, determining relevance, and multi-document workspaces, to the ability to perform essential companion activities which almost always accompany it [5]. Support for these activities (e.g., freeform annotation, non-linear navigation and multi-document spatial layout) is particularly important since they are repeatedly cited [4, 23, 24, 25] as the biggest barriers to adopting digital technologies in responsive reading.

Since the advent of digital technology, studies on responsive reading have largely favoured paper. This is unsurprising given that most professionals and academics have been educated in paper-based contexts. Paper has definite advantages: it is constant, flexible, configurable, and it unrestrictedly accepts a variety of markings. Navigating paper documents is simple, familiar and habitual for all literate humans. Of course, there are disadvantages to paper: it is cumbersome in large quantities, environmentally taxing and difficult to transport. Sharing, editing, or otherwise manipulating paper documents is also extremely limited.

In contrast, digital text is far less expensive to produce and store, and much faster to replicate and disseminate. Yet, in 2003 Sellen and Harper theorized that paper would not be so easily replaced in their seminal book "The Myth of the Paperless Office" [24]. They pointed to the vast inferiority of digital technology to paper, specifically in the activities of responsive reading, as the culprit for the absence of a digital-only workplace.

Twelve years later, many of the technological limitations of the past are no longer relevant, which necessitates a new set of observations into the suitability of digital technology in regards to the activities of responsive reading. Not only has digital technology as a set of alternative form factors, applications and interaction techniques developed rapidly, but our exposure to it has fundamentally altered the way we read and access information. For the first time, despite tremendous variability within the population [11], we are on the verge of seeing a cohort enter the knowledge workforce for whom digital technology was not a novelty but a frequent companion throughout their scholarship. Digital devices are increasingly being used for traditionally paper-based tasks, while paper is relegated to a largely supporting role. Our research shows that neither paper nor any specific digital technology is solely optimal for academic reading and that we will be designing not reading appliances, but reading ecosystems of complementary devices that may include paper or an equivalent technology for years to come.

RELATED WORK

We see our work at the confluence of three major streams of research.

Technology Imposition

Developing a single digital appliance that can be deployed across an institution and meet the wide variety of student reading needs is a long-standing goal for universities. To that end, e-readers were evaluated for use in higher education in the early 2000's [7, 27] and showed considerable potential while spawning a set of design considerations. However, even with over a decade of research and technological advancement, every widespread pilot project or deployment of a single digital reading device in a higher education context has failed to gain traction among students. In a digital textbook pilot project with a basic e-reader conducted by Young [28], students overwhelmingly rejected the devices and reverted to printed textbooks. Behler's [3] student readers were unimpressed with e-readers' support for companion activities such as annotation. Thayer et al. [25] issued a 10-inch e-reader to 39 computer science graduate students. Although initially enthusiastic, many participants in the study quickly phased the device out of their reading routines. All studies cited a combination of companion activity support issues and differences in individual workflows as the reasons for the lack of adoption.

It is to be expected that every academic reader will have a different set of strategies and technologies to successfully complete reading tasks. This is strong evidence against attempting what Thayer et al. [25] called the imposition of digital reading technology. Rose [21] found that students make a conscious and conscientious effort to integrate digital devices into their study practices. In the absence of a widespread standard for such integration, students are using different technologies (including paper) according to each one's particular strengths and availability.

Responsive Reading

A second stream of research has tried to understand the habits of responsive readers, the variability among responsive reading tasks, and the importance of supporting its companion activities. O'Hara and Sellen [19] conducted a direct comparison of paper and digital environments for responsive reading with knowledge work professionals. Their participants strongly preferred paper due to annotation issues and layout inflexibilities of the desktop reading environment. Marshall and Bly [15] investigated kinaesthetic navigation strategies on paper by observing magazine readers, while Marshall [14] explored the challenges with supporting digital annotation. Schilit et al. [23] designed XLibris, an e-paper digital reading appliance, to address some of the issues of digital responsive reading with support for freeform digital ink annotations. In a deployment with academics, readers generated as many annotations, and as easily, with XLibris as they did on paper [16]. XLibris also enabled readers to aggregate their annotations, a useful feature that paper could not provide.

O'Hara [18] generated a set of reading goals for knowledge workers, some of which are highly applicable to graduate students: reading for research, text summarization, discussion preparation, revision, and critical review. He noted that each reading goal requires a different set of strategies, approaches, and related activities. O'Hara et al. [20] also explored the characteristics of writing from multiple sources with respect to spatial layout, materiality and cognition.

Multi-Device Workflows

The third research stream is concerned with a multi-device synergy and conceptualizing individual tasks as occurring in a landscape of interconnected devices.

Multi-device integration has great potential benefits to academic reading as it enables collaboration between devices with different strengths and capabilities and simultaneous engagement with multiple documents. To that end, Chen et al. [5] created the United Slates framework, using four 10" stylus-enabled e-paper digital readers that were arbitrarily arranged across a workspace and could display different pages, documents, or views. Evaluation with graduate students elicited positive feedback, especially for the devices' annotation capabilities, seamless PC integration and synchronization [6].

In a broader context, Santosa and Wigdor [22] studied multi-device usage among knowledge workers across disciplines. They noted several patterns of multiple devices being used simultaneously and in service of the same task. They also noted the role of non-digital artifacts such as scrap paper, printed documents, and whiteboards for collaborative work. Recent work by Hamilton and Wigdor [9] has demonstrated synchronizing and sharing data, views and UI elements across devices. Although not yet adopted into mainstream use, such multi-device work signals an important potential shift away from the prevailing trend of individual, weakly connected devices.

STUDY

In our exploratory study we aimed to understand the kinds of reading activities students engaged in, the technologies they used, and how their tasks and attitudes influenced their choice of technology. Unlike other studies on the subject, our participants were asked to alter none of their reading habits, no new technologies were introduced, and available technologies were not feature-matched for direct comparison. Instead, we set out to determine what kinds of workflows students used in the absence of external technological bias or imposition. Given all the constraints of paper and digital technology and, at long last, the availability of a wide range of digital reading devices, we asked: *"What are students actually using in the wild?"* We expected that annotation, navigation and spatial layout would continue to play a central role in selecting responsive reading technologies, but that a more diverse set of devices may have made paper less prevalent.

Participants

We conducted the study with 10 graduate students (4 female, aged 23-30, mean=25.6, sd=2.6) in computer science. All had normal or corrected-to-normal visual acuity and a high degree of comfort with digital technology. Graduate students have a greater freedom in selecting relevant documents, meaning that they are responsible for deciding not only how, but what to read. They may also take on mentorship and evaluation roles, reading others' documents critically for the purposes of grading or peer review and having the power to recommend changes. We decided to limit our participants to those pursuing degrees in computer science. We believe that due to their attitude towards digital technology and the widespread availability of relevant academic materials in digital repositories, computer scientists constitute early adopters of digital technology and they may use it more frequently and with greater confidence as part of their reading workflows. This decreased the likelihood that document availability or unfamiliarity would bias our participants away from digital reading.

Study Design

We set out to observe how individuals read and chose reading technologies in the absence of a perfect or even a candidate solution. Our participants were instructed to change as little about their reading habits as possible and no new technology was introduced by us.

Questionnaire

Participants met with an investigator in a 30 minute introductory session where they filled out an informed consent form and a demographics and reading technology questionnaire. They were then instructed on the procedure for the diary phase of the study and given access to the reporting forms.

Diaries

Participants were asked to record at least 11 reading sessions over a three-week period. A reading session was defined as an instance of reading for academic purposes that lasted at least 10 minutes in the same location. Reporting a session involved filling out a structured form, either in a paper booklet that participants had received at the introductory session, or on an online portal optimized for desktop and mobile viewing. Participants were asked to fill out no more than one form per day.

Interview

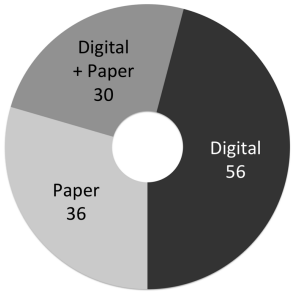
A semi-structured interview was conducted with each participant using the completed diary forms as prompts. They were asked about their reading, navigation, annotation practices, and specific instances of technology use, as well as document management strategies and ideas for ideal reading technologies. Interviews lasted between 40 and 65 minutes and all ten participants completed the interview stage. One interview recording was corrupted, so only 9 interviews were analyzed. The interviews were transcribed and thematic analysis was applied using inductive coding techniques to identify themes emerging from the data [8].

RESULTS

We present our findings in an order vaguely reminiscent of the lifecycle of an academic document. Each of these aspects can and, we noticed, does affect the choice of reading technology.

Technology Availability and Ownership

Every one of our 10 participants owned a laptop, all but one had a smartphone, all but 2 used desktops, 3 owned tablets, 2 had e-readers, and 1 had access to a stylus-enabled hybrid laptop but never used it for academic reading. Participants reported a total of 122 reading sessions over the course of the study (9-20, mean=12.4, sd=3.1), each lasting an average of 81 minutes (10-180 min, sd=40.5). Of all sessions, 36 were conducted solely on paper (including all combinations of loose/bound and handwritten/printed), 30 involved a combination of paper and digital, while the remaining 56 were digital only sessions. Only 4 sessions involved a tablet, and e-readers and stylus devices were not used for academic reading at all. Smartphones were not used either, even though their owners used them frequently in other contexts.



Device	# owned
Laptop	10
Smartphone*	9
Desktop	8
Tablet	3
E-reader*	2
Stylus device*	1

Figure 1. Reported sessions by technology (left) and device access by number of participants (right). * - devices that were not used for academic reading

Our choice of population (i.e., graduate students working in the labs of a well-funded university) largely precluded a full investigation of the wide variety of economic factors that may influence students' choice of reading technologies. All of our participants had access to a workspace, a lab-issued personal computer, and, crucially, free printing at work. Even so, their choices regarding paper often cited economic or environmental factors, especially for documents that would only be used temporarily. Some transitioned to digital reading partly to reduce the amount of waste that printing generated.

"The reason I stopped printing so many papers, like, in the past was because I just, y'know, don't want all that clutter and I don't wanna waste all that paper, right." - RS-33

The cost of displaying a document on a digital screen is very close to constant with respect to the length of the document. In contrast, printing costs are linear; at a certain number of pages, documents become too costly to print, be it financially or environmentally, too heavy to carry and too cumbersome to store. This relationship is likely why printing actions were often weighed against these considerations, and even though some participants stored enormous stacks of paper, these are arguably some of the most significant objections to the continued widespread usage of paper.

Location and Ergonomics

Participants mostly read in locations established for and highly suited to academic reading (home and work offices), but also in coffee shops, friends' homes, while commuting, etc. Established locations were often optimized for ergonomics and multi-document navigation to help them handle cognitively demanding or time-sensitive composition tasks such as writing degree checkpoints or literature reviews:

"I was having trouble writing ergonomically because uh, [...] if I'm writing for 8 or 10 hour days, which is what I was doing, I need a proper setup." - RS-23

Established locations contained useful peripherals such as external keyboards, wrist rests, and, in one case, a mouse to alleviate the significant ergonomic challenge in repeatedly selecting, copying and pasting text using a trackpad.

"I also have a mouse for when I'm doing things that require a lot of highlighting 'cause my thumb gets sore [...] when [I'm] highlighting on a trackpad" - RS-01

Another crucial peripheral was the external monitor: five participants used one, and for two of them it was configured in a vertical (portrait) orientation specifically to facilitate reading paginated documents or code.

"I sort of have a almost like dedicated reading monitor because it's vertical rather than horizontal." - RS-30

Overall, participants had a very well-developed sense of what locations were appropriate for different types of reading. The choice of moving to, or reading in non-established location was often deliberate, with readers benefitting from the change of scenery, the ability to socialize while working, or the perceived implicit accountability that comes with working in a public space.

"I guess I read a lot in coffee shops. I didn't realize that. I guess it's just the environment there is uh, nicer than in in my office [which] is kind of gloomy and dreary" - RS-29

One participant reported on the usefulness of tablet computers while in transit, provided they were appropriately synchronized beforehand:

"So, I- I decided to get [a tablet] and I- I have been, I- it's- it's been pretty useful actually just to keep a bunch of relevant papers on that, being able to read it quickly and anywhere." - RS-31

When it came to paper, they had to make the additional effort of printing and carrying the appropriate documents with them, which was only feasible for a limited number of pages.

While many reading tasks could be performed in sub-optimal locations and while paper has the definite benefit of untethering one from the requirements of power and connectivity, for time-sensitive work, multi-document reading or scenarios that also involved writing, readers needed the flexibility of a comfortable desk and large amounts of screen space. Other ergonomic considerations cited were the optical properties and readability of paper and increased eye strain from reading on digital screens.

Relevance, Permanence and Storage

When beginning research for a new project, academics look at many documents in order to determine their relevance. The vast majority of documents that were skimmed in this way came from online computer science repositories such as the ACM Digital Library. We observed that documents were typically evaluated in browser tabs and those deemed irrelevant were dismissed without any record.

"If I decide I don't need it, I'll just close the tab." - RS-30

In our interviews, we encountered two broad types of readers: record-keepers and reference-keepers.

Record-keepers valued preserving copies of the documents they read in their possession, either physically, as paper printouts, or digitally, in folders or in a reference management system. They often added interpretive value to their documents by making notes, annotations and summaries and storing them alongside.

In terms of technology, several participants kept printed and annotated paper documents in folders sorted by project, although they found it somewhat unwieldy:

"So I sort my printouts by topic. So um yeah. So then I file them into the appropriate folder. [...] So, I don't have like subfolders for example. Yeah, because it's hard to do with with physical paper." - RS-29

These record-keepers expected that each document's relevance to their work would be time-limited, lasting anywhere from a week to several months. They were prepared and eager to recycle their paper copies as soon as they were no longer needed but had no qualms keeping the digital equivalents.

"As soon as my depth oral is done, I'm just going to recycle these 'cause I've got I've got all the citations that I need." - RS-30

On the contrary, some record-keepers chose to store and annotate their documents digitally precisely because they sought a sense of permanence in digital storage. They recognized the transience and unwieldiness of printed paper and they appreciated the ability not only to store as many documents as they liked without any clutter or spatial considerations, but also to search for, and search within, documents.

"Because, I mean, as an academic, you do a lot of reading. Even if I kept a stack of all the papers I've read, how would I find anything in that, right? Um, and and then, like handwritten notes, how like I can't search for that." - RS-30

Reference-keepers were less concerned with retaining copies of all documents read. Instead, they relied on the reference sections of their own papers, on recalled author's names or title keywords, or on enormous BibTex files to help them find previously read documents if the need arose.

Deep Reading and Distractions

In contrast to the skimming behaviour described in the previous section, participants were often tasked with gaining a thorough understanding of a single document and its details through the practice of deep reading.

"But for the paper that I'm presenting, um, that one [...] I'll try to understand every sentence in the paper." - RS-33

All participants read on paper, on computer screens, or (rarely) on tablets. One also used a digital text-to-speech engine to listen to documents while simultaneously following along and making handwritten notes on a paper copy.

"I'll have my paper open on the desktop and then the paper in front of me as well, and I'll like make notes on the paper but then I'll just use text-to-speech to, like, read the paper?" - RS-01

In addition to finding it easier to understand and edit documents with text-to-speech, RS-01 cited the added benefit of improved focus:

"It's harder to zone out and, like, stop reading and procrastinate when there's something that's metered." - RS-01

It was in the context of deep reading that participants found it most essential to remain focused and to stay on task. They were sometimes interrupted by colleagues, notifications, or the temptation to surf the Internet. Some actively tried to disable or limit their digital devices' capabilities when they were trying to focus:

"I turn off the internet - the wifi on my phone usually. [...] I do sometimes banish my laptop." - RS-05

Predictably, participants had fewer issues with notifications and tempting distractions when reading on paper.

"Um, I actually started to print out papers when I realized that I can focus more when they're printed out." - RS-05

Also, deep reading on paper led to a perceived improvement in comprehension and performance:

"And the main reason I print it out is because I don't have the same reading comprehension on screen as I do on paper." - RS-10

There were other benefits to reading on paper, many of them relating to the companion activities of responsive reading, notably freeform annotation and non-linear navigation.

"Uh, when you're reading on paper, it's easier to flip between different sections of the paper I find, so [...] Yeah, and and you can make notes and comments as I mentioned in just in free form." - RS-29

Using general-purpose digital devices for highly specific, focused tasks, comes with the temptations of all other activities that are possible on these devices. Readers cope by disabling features, which is becoming harder as more connected devices are added to their ecosystem, or by reverting to paper for deep, focused reading.

Multiple Documents, Devices and Activities

Deep reading is a single-document activity and paper seems well suited to it. However, in our study reading was often coupled with reviewing, proofreading, grading, or incorporating salient details from multiple documents into one's own writing. In these contexts there is significant tension between paper-only single document reading for immersion and focus, and multi-document reading and writing activities, which are all but certain to require a digital device.

90 of the 122 reported sessions involved more than one document. Remarkably, 106 of 122 included some form of concurrent content creation, be it annotation, notetaking, copying text verbatim, or composing new documents. However, contrary to Santosa's findings with knowledge work professionals [22], no two autonomous digital devices were ever used in the same academic reading session, let alone in service of the same task, during our diary study. One participant considered using a tablet to display the reference section of a paper while reading the body on their desktop, but did not do so.

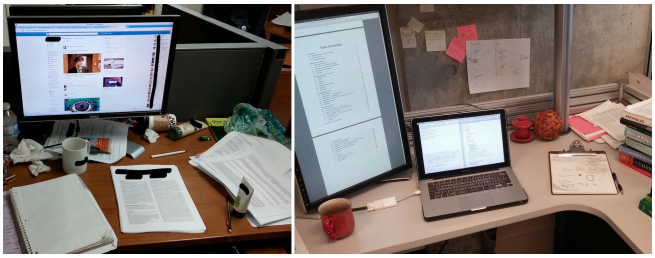


Figure 2. An example of a hybrid paper-digital scenario (RS-10, left) and a digital-paper scenario that includes a vertical monitor (RS-23, right).

Instead, we observed two major categories of synergy: between paper and a digital device and between a digital device and an external monitor. Where paper and digital were used together (in about 25% of reported sessions), paper contributed additional reading space, freedom of navigation and layout, and the ability to intuitively annotate. 86 of 122 sessions included a digital device and in 23 of those it was connected to an external monitor in order to increase the available document workspace.

Depending on the context, academic readers arranged in their visual workspace different documents, different sections of the same document, different formats of the same document (e.g., LaTeX and PDF), references, text and code, and, in the case of RS-01, they even simultaneously used different modalities (auditory and visual) to proofread documents. Since many of their composition tasks involved digital workspaces or documents, they encountered many of the layout and navigation issues posed by mainstream digital interfaces.

When participants switched between full-screen applications or full-screen workspaces, maintaining context became a challenge.

"When I go to [window manager] to like figure out what document, there's this [...] cognitive delay where I'm like, 'Wait, what, what am I doing? What? Why am I here?' when I'm looking at like 20 windows that are open." - RS-23

Paper was used successfully to provide additional reading space in many digital reading scenarios, and was found to be the preferred choice for simultaneous viewing of multiple documents:

"I find glancing down at a paper copy to be much less disruptive. [...] Because it's way easier to even though it's just a couple couple keyboard clicks to shift desktops, I feel like it's way more disruptive." - RS-10

On large screens participants relished the opportunity to arrange different visible documents on their screens. Combinations varied widely and included multiple windows, desktops and documents. Many of these combinations also included paper, for instance when a printout, raw LaTeX and a PDF version of the same document were used simultaneously.

When it came to navigating through documents, even when citations linked to a reference section, it was difficult to keep one's place in the body of the text while jumping forward.

"On a PDF, a lot of times they have a link with the citations and then you click on the link that takes you to the references. And if you want to go back to the page, um, I often find myself having to basically scroll through, y'know, numerous pages until I get to the [original one]" - RS-33

It also proved to be non-trivial to display two sections of the same document side by side in different windows, as many PDF viewers cannot open two copies of the same file.

"I'll open and use [PDF viewer 1] to look at the whatever page in the document that I'm reviewing and then I just open the document again in [PDF viewer 2]. [PDF viewer 1] will refuse to open two instances of the same document." - RS-23

These issues are practically non-existent on paper where layout was highly flexible, non-linear navigation was easy and intuitive, and the vertical page perfectly matched the intended layout of most academic publications.

"So I think, um, the advantage of having a paper reference is you can basically place one finger on whatever page that you're reading and then the other one on the references, right. So you [...] can flip back and forth." - RS-33

When these documents were displayed on widescreen horizontal monitors or on smaller tablet screens, difficulties with layout arose, particularly in the two-column format.

"You have to sort of horizontally sort of pan back and forth, then you hit the bottom of the column, you have to pan all the way up to the top of the other column, uh, and then move to the next page, it's just a giant pain in the ass, uh, to the point where I prefer to read academic papers on paper or on my reading monitor" - RS-30

It is telling that almost three-quarters of reported sessions involved multiple documents, meaning that the majority of academic reading occurs in multi-document scenarios. These invariably require more reading space, on a combination of screens and desks. In addition, specialized reading devices such as dedicated e-readers which do not easily support content creation would be poorly equipped to handle the nearly 87% of all reading sessions that involved some form of writing or typing in addition to reading.

Annotation

Annotation is a crucial process in the interpretation of new documents in responsive reading contexts [10]. It is distinct from other content creation activities in that annotations are overlaid onto an existing document using the same technology, and it was the most frequently reported type of content creation in our study, occurring in 55 of 122 sessions. All of our participants concurred with the previous generation of research [14, 19, 25] in their subjective preference for annotating on paper over any digital interface available to them: it was easier, more precise, less cognitively demanding, and required no training.

"I've I've done it on occasions, so when I'm reading, um, an e-book sometimes I will highlight things [...] It's still just a giant pain in the ass where it's a lot easier for me to just if I'm highlighting, then just grab a highlighter and do it on paper." - RS-30

Even participants who were annotating or reading digitally recognized that there were significant issues with digital annotation interactions:

"It's pretty good most of the time. So I- I don't, um, it's not as simple as highlighting on paper. Because [it's] kind of difficult to [...] highlight the right portion." - RS-33

However, despite the near-universal consensus on paper annotations, the additional effort of managing, reincorporating or searching through them was often enough to push readers to digital. When proofreading, for instance, participants saw the value in marking up errors and changes on paper, but were daunted by the necessity to do another pass just to update the digital text with the corrections they had made on paper.

"There's such a big turnaround to fixing [errors found on paper]." - RS-23

The appeal of digital markup was especially strong for record-keepers who valued their annotations and saw themselves revisiting or searching through them after the initial reading stage.

"Um, super important to search them, super important to understand them, in terms of my handwriting is terrible and, whenever I take handwritten notes, it's a very short-term thing." - RS-30

To our participants, it seemed that annotation served a combination of purposes, each of which influenced their choice of technology. Some annotations, such as brief summaries or margin notes, contained important information and participants made an effort to ensure they were stored with the relevant documents. Others, like highlighting and freehand formula derivations, were used to aid the processing of a document but had little value afterwards.

We saw an emerging pattern; when participants placed greater importance on maintaining a record of their annotations and notes, they tended to use digital annotation. In contrast, when annotation was used to process and understand a document, participants used paper to annotate quickly and precisely without interrupting their reading flow. In that case the

product of the activity, the annotations themselves, were seen as having very limited utility in the long run.

"I'll go through and underline but I recognize that the underlining activity is more like my mental processing, it's not like I'm going to go back later and look at those underlines. Frequently, I just end up recycling those papers immediately." - RS-23

One participant was extremely conscious of the unintuitive and slow nature of digital annotation and preferred to print digital assignment submissions from dozens of students, grade and annotate them on paper, then re-scan them so they could be returned digitally.

"Yes, I print up all the assignments and I print off the marking sheets and then I have text-to-speech, mark up the assignments, grade them, put them all together, add all the grades up, scan it, [...] and then divide it into individual PDF's, and then I upload those to [online grading portal]." - RS-01

While digital technology offers the promise of permanent storage and easy searching, it is still sorely lacking in the immediacy, intuitiveness and control over annotations. Until the requirements of process annotation are supported digitally, those who rely on them will continue to use paper whenever they can.

Subjective Attitudes and Social Factors

In addition to its objective benefits, paper elicited a subjective, almost emotional attachment in some participants. Early education and history may play a part in this, as even this generation of early adopters was educated on paper:

"Up until this point in my life, I've always been, y'know, reading textbooks [on paper] [...] I dunno how to explain it but [paper] just feels more natural and intuitive to use." - RS-33

Attachment to paper as a technology is not always matched by attachment to individual paper artifacts. In fact, we have already discussed the transient nature of paper printouts that bear participants' annotations. While paper was definitely seen as expendable, bound books elicited a very different attitude. They were considered valuable as objects, had definite owners, and participants took care to keep them pristine and unaltered, especially if they were borrowed.

"I prefer not to mangle my real live books" - RS-30
"[They were] my dad's books, so I'd rather not [mark them up]." - RS-05

Some participants obtained a similar sense of permanence and value from their research notebooks. For them the notebook was the best place to collate and process ideas that did not immediately need to be incorporated into another document. They guarded their notebooks carefully, filed them when they were full and knew how to find information inside.

"[I have a] bookshelf of past research [notebooks]." - RS-01
"Um, so as long as it ends up in my notebook, I don't have much of a problem finding it." - RS-10

RS-01 switched away from notebooks for a short time but reverted soon afterwards and ended up scanning hundreds of pages of loose paper in order to maintain a record of their ideas.

"The notebooks are harder to scan [than loose paper] but they're easier not to lose." - RS-01

While bound books and notebooks are seen as objects, with a sense of gravitas and ownership attached to them, loose paper sheets are more communal and casually sharable. This property also makes it relatively easy to share in group reading scenarios like seminars.

While paper was preferred in group contexts, some technology fared comparatively well. For instance, RS-31 was reluctant to bring their laptop to discussion groups because they feared that others would perceive the screen as a social barrier and a distraction, but had no such reservations about their newly-purchased tablet.

"Because with a laptop, the screen faces you and not others, and whereas for a tablet if you have it on the desk, it acts almost like a paper, and has the same shape as a paper [...] and you can also share it to the other people really easily." - RS-31

Subjective and social factors influence our choice of technology in every realm, and academic reading is no exception.

Transitions to Digital Workflows

Despite this subjective attachment to paper, several participants shared instances in which they adopted digital solutions to replace paper, sometimes adopting a less optimal interface in order to streamline a broader workflow. One participant went from storing piles of annotated papers to a digital solution.

"So, um, part of the reason [I switched to digital] because over time I've accumulated this huge stack of paper, [...] So, I thought it would be just more convenient for me to highlight directly in the PDF and then just store it in my computer." - RS-33

RS-31 bought a tablet to replace the paper printouts they were bringing to meetings and began annotating on it, while RS-23 annotated for review on a PC in order to save time on a digitizing pass:

"I think, a few years ago, I would um I would print out papers when I was reviewing them and then I would write comments on them, and I'd go back and that'd be one pass. And then I'd do a second pass where I'd write, um, where I'd do what I do now but I think I stopped doing that cause I was really inefficient." - RS-23

RS-01 stated that they had no general qualms with transitioning to digital annotation if the interfaces and tools were more intuitive and worked for them.

"If [marking portal] had a useful markup tool that was functional, one could, in theory, streamline this process." - RS-01

These instances of transition are important glimpses into the task-oriented minds of our participants. In every case they were solving an issue or optimizing their workflow.

DISCUSSION

While many of our findings are consistent with previous work in the area, there is a clear shift in attitudes and usage towards digital technology. We believe this shift can be greatly accelerated if we can pinpoint its underlying factors and opposing forces.

The Path of Least Resistance

As we attempted to understand the ways in which participants chose to read, we were struck by the amount of variability within each of our readers. Rather than expressing a strong affinity for a specific technology, readers were highly task-oriented: at any given moment they selected the combination of tools and devices that allowed them to optimally complete the task at hand. The prevailing principle for selecting technology was not conscious and explicit preference, but rather something we call the path of least resistance. This process is similar to the route electricity takes, or the way water flows around rocks on a river bed: just as efficient, leaving no gaps and wasting no space, and almost as unconscious. This metaphor also allows us to frame our own mandate, not to influence the properties of water, but rather to understand and reshape the rocks it cascades over.

In academic reading we saw numerous examples of technology choices being made under time and resource pressure to deliver the best possible result with the least amount of overhead devoted to mechanical tasks, format conversion or learning unfamiliar interfaces. These choices were, above all, flexible to the demands of the task. Participants who would not normally read papers in full in a browser window nevertheless opened them and skimmed them in one because it was the easiest way to display their content, determine their usefulness, and dismiss them without any additional effort if they were not relevant. They annotated on paper if the marked-up document was not important to save, but they did so digitally when they wanted to preserve their work.

When RS-30, who did not store previously read documents, needed to remember an article they had cited, they found it in the reference section of their most recent paper, which they downloaded from their own personal website. This was the least cognitively demanding path to the goal as it required no memory of a local folder structure. Faced with copying passages from a book, RS-23 chose not to scan it or photocopy it, but to take a photograph of the page with their smartphone camera, creating a copy of the printed passage that was only as faithful as their needs demanded, and no more. Such an approach may seem motivated by an attempt to minimize effort in general while satisfying the bare minimum requirements of the task, but there are examples that refute this notion.

The path of least resistance does not always minimize effort across the board. When RS-01 printed, marked, and re-digitized dozens of student essays, that took far more effort overall than marking them online would have. This sequence of steps was selected by RS-01 because it decreased the cognitive load and distraction in the crucial aspect of the academic reading task: the grading itself. RS-01 chose to exert extra effort before and after their marking task in order to grade unperturbed.

Applying this insight to the choice of reading technology, our data indicates that readers are still using paper in more than half of their reading sessions largely because the digital alternative would take too much time or cognitive effort. For casual process annotations, quick non-linear navigation, deep, focused reading, and even for keeping papers relevant to a project stacked on a desk within reach, paper was chosen for its immediacy and ease of use.

The Costs of Digital Technology

Through decades of innovation, digital technology has become a dominant force in our lives, as evidenced by its use in three quarters of the academic reading sessions we observed. Despite the constant improvements over the wide array of digital devices available to readers, there are costs to using digital technology. Some of these costs are financial; to purchase a device with a stylus to replace or to complement the general purpose computer one already owns is much more expensive than a pencil which costs pennies. Some are dimensional tensions: the carry-anywhere device and the sufficient-screen-space device are currently not the same device. Some costs are transactional: transitioning between the e-ink device optimized for reading and the full-keyboard laptop optimized for text entry, synchronizing them, charging them and disabling the capabilities of one's devices in order to focus on the task at hand. Some costs are cognitive: maintaining competing mental models for multiple digital interfaces or enduring and ignoring the temptations of a myriad distractions. Finally, time is less kind to digital devices than it is to paper, and device failure, file format obsolescence or system-wide disruptions can eradicate years of work.

Those Magic Changes

Let us accept for a moment that the path of least resistance biases users towards paper for certain reading scenarios. Even so, while in reading participants may have the real option of choosing paper, this choice is severely limited in many related aspects of academic work. Information retrieval is far more likely to occur digitally, certainly in computer science, but also increasingly across the breadth of human knowledge. Communication, storage, and composition are also firmly in the digital domain, as are specialized tasks such as text search, version control and programming.

We must remember that, despite all its benefits to academic reading, paper is theoretically dispensable, whereas digital technology is not. It is destined to play an integral role in all knowledge tasks, and reading cannot be any different.

Academic readers in our participants' age group (i.e., born after 1980) use more digital technology for learning than their older counterparts [13]. We also observed them transitioning to digital devices for tasks for which they would have used paper in the past: document storage, collaborative reading and discussion, document review and annotation. The immense potential of digital technology for rapid iteration, innovation and diversity leads us to believe that paper will play a less and less significant part in academic activities. The question remains, what will take its place?

Multiple Documents, Multiple Technologies

Academic reading involves *"a larger system of documents, technologies, and reading-related activities"* [17]. We have seen all three borne out in this study. Academic reading does not happen one document at a time, it does not happen on a single platform or in a single desktop window, and it is almost never the sole activity for a given session. In the absence of a single device that is both portable and spacious, glare-free and rendering in full colour, stylus-enabled and with an ergonomic keyboard, it is clear that academic readers will make use of multiple devices, applications, and technologies to complete their work.

There has been considerable success in building prototype ecosystems that can seamlessly manipulate documents and share a single layout between connected devices [6, 9]. The next challenge lies in creating such working ecosystems from commercially viable and widely available devices, each of which is suitable to a particular task or facet, seamlessly integrated into the workflow and with complete access to readers' documents, notes and related metadata. New devices must also fit into the existing technology profiles of academic readers, for whom sudden large-scale changes may be too disruptive. As many have observed, devices that demand too great an investment of time and cognitive effort to adapt to risk being sidestepped and doomed to non-adoption.

What Is Paper?

The advantages of loose paper for reading are total layout flexibility, effortless freehand annotation, seamless navigation that relies on the kinaesthetic properties of material objects, and the fact that it is an inexpensive, practically communal artifact. Paper's primary failures are its environmental impact and its inability to integrate with our otherwise digital workspaces.

Our current concept of paper conflates a functional description with a material one. We use paper for academic reading not because it is made of wood pulp and that somehow helps us; we use it because it is cheap, readable, expendable, and easy to manipulate. Is there any reason why the near future cannot bring us erasable, cheap digital devices that work exactly like paper, then surpass it to complete the gap, incorporating their contents intelligently into a digital ecosystem? Nascent attempts such as the Boogie Board LCD writing tablet achieve a device thickness comparable to paper. Multiple companies (e.g., [26]) are working on flexible, paper-thin electronic paper which may become ubiquitous within a decade. How far could we go with two dozen interchangeable, stackable Letter-sized stylus tablets of negligible thickness? We may indeed see a device or stack of devices that can perform the full range of our favourite material, kinaesthetic, and visual functions, resulting in the obsolescence not of paper as a functional concept, but merely of its wood-pulp, analog incarnation.

BRIDGING THE GAP

We asked our participants what kinds of digital technologies would make their reading tasks easier. The answers they gave hint at ways to close the conceptual chasm between paper and digital and to bring some advantages of paper to digital interfaces while combining them with the strengths and affordances of digital text. They spanned three themes: the reading environment, freeform annotation, and better management of document collections.

RS-32 insisted that references in a document should be displayed separately from the document to eliminate navigation challenges. RS-30 believed that pagination was an obsolete notion and that text should reflow dynamically, intelligently adapting figures and layout to any screen size in order to make a broader range of technologies capable of displaying academic documents without the need for 2-D pan and zoom. RS-29 would have liked the ability to customize multiple document views to see two portions of a document side by side, while RS-23 advocated for better window management that maintained the reader's sense of spatial context. RS-01 dreamed of a way to disable distracting features across all devices for a set amount of time.

RS-33 asked for a stylus-enabled tablet that could support freeform annotation. This is the easiest wish to grant: a broader range of affordable stylus-enabled devices that have made it past the prototype stage [1, 6].

Finally, RS-32 hoped for better integration between document search portals and the corresponding storage options, while RS-01 wanted a way to spatially arrange documents in two-dimensional space, to cluster them in category-specific mind maps and to understand not only each paper's contents, but also their relationships, at a glance.

Even a cursory look at this wishlist indicates that all of these ideas are well within our capabilities, and many have been tried as prototypes and only await their critical mass of adopters. We believe that at this moment we are on the verge of seeing them succeed as mainstream solutions that might be able to provide the key to academic reading moving forward:

"A screen that feels like paper, looks like paper, but isn't paper." - RS-05

CONCLUSION

We present an exploration of current reading habits and technology preferences in academic readers. Participants interleaved reading with content creation activities while selecting technologies and tools that best suited their reading tasks. We found that while certain downsides of digital reading technology still persist, a slow and momentous change is at hand; digital technology is now ingrained in academic life, perhaps to the point of no return. Although paper has not been outcast, our participants speak of a growing need to re-imagine or replicate paper, and we predict that mainstream technology will catch up within a decade. We are reporting on the cusp of a new world order and of a transition headed by the next generation of academic readers. Our findings will help successfully navigate this push, and inform designers on what is wanted, and used, at the forefront of this movement. We expect our contribution to help harmonize long-standing tensions [24] while opening doors to new challenges in re-imagining paper into a world where digital and paper are indistinguishable, a world of "digital+paper".

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