As We May Ink? Learning from Everyday Analog Pen Use to Improve Digital Ink Experiences

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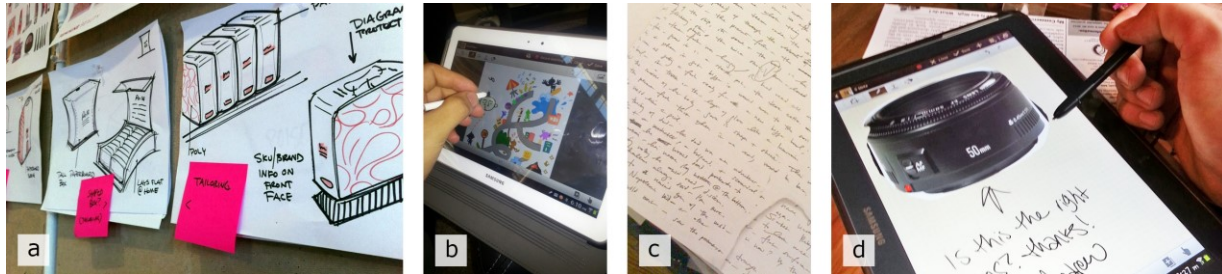sarahgwilliams@
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Figure 1. Diary entries from analog and digital pen usage © Microsoft

ABSTRACT

This paper sheds light on gaps and discrepancies between the experiences afforded by analog pens and their digital counterparts. Despite the long history (and recent renaissance) of digital pens, the literature still lacks a comprehensive survey of what types of marks people make and what motivates them to use ink—both analog and digital—in daily life. To capture the diversity of inking behaviors and tease out the unique affordances of pen-and-ink, we conducted a diary study with 26 participants from diverse backgrounds. From analysis of 493 diary entries we identified 8 analog pen-and-ink activities, and 9 affordances of pens. We contextualized and contrasted these findings using a survey with 1,633 respondents and a follow-up diary study with 30 participants, observing digital pens. Our analysis reveals gaps and research opportunities based on pen affordances not yet fully explored in the literature.

Author Keywords

Ink, notes, sketching, writing, annotation, pen input, tablets

ACM Classification Keywords

H.5.2 Information interfaces and Presentation: Input

INTRODUCTION

Although the idea of writing on a computer screen goes back at least to Ivan Sutherland's *Sketchpad* [51], if not the classic 1945 Vannevar Bush essay *As We May Think* [11], the pen has long lingered on the fringes of mainstream computing.

The rise of tablets that support multi-touch and high-quality pen input has reinvigorated pen computing. Yet, even for basic mark-up scenarios, they do not seem as natural as analog pen and paper: their *affordances*—defined as perceived and actual properties of objects suggesting activities people do and think they can do with them—differ in many ways.

The body of literature on analog and digital pen experiences is extensive. The research community has generated informative, inventive and inspiring research for many scenarios such as annotations [16,33,34,41,50,61] and note-taking [4,10,37,47,58,60]. While exploring compelling scenarios in-depth drives innovation forward, it is also important to gain an overview of the breadth of activities and understand which ones matter most to people. With this work, we embark on a complementary perspective looking at the breath of pen use, including frequency and the identification of key pen affordances. Our goal is to illuminate disparities and disconnects between digital *vs.* analog pen experiences. Our work thus contributes an observational foundation for "how we may ink" that allows reflection on existing products as well as future innovations.

We tackle this problem first by gathering a large diversity of everyday analog and digital pen activities via two diary studies, and second by quantifying the frequency and importance of these activities in a large survey. In our analyses, we tease out the affordances specific to the pen. This angle allows us to uncover several fundamental differences in activities people do (or think they can do) with an analog pen versus a digital pen. For instance, we found that people tend to associate the analog pen with a *drafting* tool to ideate and think (Figure 1a); whereas they associate the digital pen with a *crafting* tool to refine and share work-products (Figure 1b). Our analysis also reveals that many

scenarios addressed by an ecosystem of individual apps in the digital world, are, in fact, tightly and fluidly interwoven in the analog world such as tearing out piece of a journal entry to use as an in-place reminder (Figure 1c). We also identified which unique affordances of digital pens are particularly compelling to people, such as annotating digital content, or sharing instantly across large distances (Fig. 1d).

In summary, then, this paper contributes the following:
- A first attempt at presenting the breadth of pen activities people perform in daily life; as well as their frequency, popularity and people's perception of their importance;
- A first attempt at identifying *9* affordances of the pen (plus 3 for digital pen) and their impact on activities;
- A study of digital pen-and-tablet activities and an analysis of gaps, limitations, and advantages compared to analog;
- Reflections on research opportunities for digital pens;
- A data corpus of ~600 anonymized diary entries and codes available at https://aka.ms/aswemayink.

RELATED WORK

The literature on pen and ink is incredibly rich and the body of knowledge on mark-up for specific scenarios is certainly deepening every year. For instance, research efforts have investigated active reading [8,13,18,20,40,54,55,62], note-taking [4,9,43,53,62,65], the use of pen for creativity and design [5,9,17,25,27] and collaborating with others [15,29,31]. Research also probes the types of marks people make on walls [41], whiteboards [60], and as annotations [16,33,34,41,50,61]. Most of these previous studies of mark-up focus on specific activities or task domains. However, mark-up pervades a diversity of tasks and workflows, a rich ecology that only partially overlaps that of 'office work' and 'documents.' Our work provides a glimpse of this diversity, while further updating and contextualizing our understanding of these pen tasks in the smartphone era.

Affordances of the Pen

To uncover the fundamental differences between the analog and digital pen experiences, we focus on the unique affordances of pens. We use the term *affordances* in the spirit of Sellen and Harper's seminal work [43], as *a set of perceived and actual properties of objects suggesting activities people do and think they can do with them.* Our goal is to identify affordances specific to pens, so as to compare the analog *vs.* digital experiences, and identify gaps.

The Myth of the Paperless Office [43] enumerated key affordances of paper in knowledge work and compared these to the affordances of digital technologies, pointing out gaps and opportunities for future research. Note that several of these affordances of paper—such as 'Marking up a document while reading' or 'Interweaving reading and writing'—are intimately tied to the pen. And, although comprehensive, the nature of the studies still leaves some questions unanswered. Do further affordances emerge if we focus primarily on the pen? What if we extend our view beyond office work, to mark-up in everyday life? How is the pen interwoven with other tasks, or modalities of expression? Has the role of paper

evolved with the popularization of smartphones, tablets, and e-paper devices?

In general, it is difficult to disentangle the affordances of pen from those of paper in the literature. At times this is warranted; Kidd [22], for example, points out the significance of ink lies not in the marks upon the paper, but rather the lasting impressions left on the knowledge workers themselves. Yet, still, to deeply process information it often seems necessary for office workers to set pen to paper, or for designers to sketch out ideas on a whiteboard [14,57], and when we venture into the would-be digital equivalents of these media, it becomes clear that some affordances of pens are not wholly unified with the (no longer co-present) affordances of paper. Not only is paper interwoven with a great many activities, but also for many of these—such as work-related reading [1]—the pen plays a critical role that only partially overlaps that of paper itself. For these reasons, we believe that taking a closer look at the affordances specific to the pen is essential.

Affordances of Pen & Ink vs. Digital Media

With our studies, we seek to contrast analog and digital behaviors. Previous research reports similar efforts. For instance, some subtle nuances of affordance for analog vs. digital touch have been noted even for the simple physical act of turning pages while reading [32,46], in part because incidental contact is a key negative affordance of touch-enabled displays, a problem exacerbated when people rest their palm on a screen while writing [2,3]. As such, on digital devices the perceived affordances of 'pen' may be influenced by those of 'touch.' In early work O'Hara et al. contrasted use of paper vs. on-line documents [38]. Terrenghi et al. [56] contrast physical versus digital media on tabletops, but did not include stylus interactions in their analysis. However, like our work, they find insidious and at times non-obvious nuances of affordance between analog and digital actions that *seem* identical (but perhaps not nearly enough so).

Morris et al. [36] compared active reading on paper to a vertical desktop, horizontal tabletop, and multiple tablets. While some differences emerged, many classic observations (such as reading interleaved with writing [43]) still held in the digital settings. Yet, the study focused only on active reading in a laboratory task—not a wide diversity of tasks—and the work's focus was not on the affordances of the pen. Our approach differs from these efforts as we draw our observations from participants with diverse backgrounds using pen and ink for their own purposes, and in their natural environments—home, office, or the many places in-between.

APPROACH

Building a perspective on the wide range of pen activities and scenarios as well as their frequency and importance to people and comparing them to their digital counterparts is an ambitious and challenging task. As a first step, we opted for a mixed method approach, combining qualitative diary studies with a small set of individuals, and quantitative answers to a survey with a large audience.

In the first diary study, we selected heavy analog pen users with a diverse set of backgrounds and occupations. We wanted to elicit insights about a variety of activities and tease out the role of analog pens from people who use them frequently. The goal was not to quantify or generalize findings but to gather new, rich and diverse entries. We then contrasted insights from analog pen use with insights gained from a complementary diary study with digital pen users. The participants in this second study had a unique perspective since they already owned (and used) a digital pen. This allowed us to elicit affordances specific to the digital pen. Finally, to contextualize insights from both studies with a broader population, we conducted a survey to quantify the frequency and popularity of the pen activities we had identified. The survey also served to tease out the relative importance of pen affordances to a larger population.

STUDY 1: ANALOG PEN

To develop a holistic view of how and why people use a pen in their daily life, we conducted a diary study with a small yet diverse set of participants. We simply asked them to share with us a photograph of an activity they carried out with a pen, pencil or marker, commenting on their reasons for doing so. Our goal was to unpack the diversity of day-to-day activities that people engage in with a pen, and their motivations to do so, to tease out unique affordances of the analog pen. Thus, we asked participants to vary the intent and context of these entries as much as possible. The resulting 493 photos and comments revealed a diversity of activities.

Participants and Data Collection

We used an online diary research service called *dscout* to recruit participants and collect data. We used a survey to screen for frequent use of analog pen and paper (daily or more). A few open-ended questions helped us assess the motivation of the participants and their ability to articulate their thoughts well. We carefully selected 26 participants, for their diversity of background and occupations which we hypothesized would lead to a diversity of activities. We recruited students, teachers, engineers, designers, writers, architects, physicians and home-makers, 12 male and 14 female. The mean age was 31 (sd=8) and all lived in the US. Each owned a smartphone and a computer. Participants used their phone to take a photo and enter comments to capture what is in the photo and why they chose analog vs digital. We asked them to provide at least 20 snippets.

Data Analysis

Our participants provided between 4 and 24 snippets each, with a majority providing 20, for a total of 493 snippets. Out of the 493 entries in the original dataset, we could classify 466 (94.5%), the rest being too blurry or including comments too vague to be coded.

A complete, anonymized view of the diary entries, along with supplemental study material is available at:

http://aka.ms/aswemayink

AF1: Externalizing thoughts and memorizing
AF2: Producing high-fidelity marks
AF3: Tacit and automatic use
AF4: Capturing non-committal information
AF5: Interweaving symbolic and figurative content
AF6: Integrating information in context
AF7: Rich personal expression
AF8: Reliability and dependability
AF9: Immediacy of capture

Figure 2. List of the pen affordances

PA1: Ideation
PA2: Collaboration and coordination
PA3: Information scraps
PA4: Personal communication
PA5: Annotations
PA6: Recordings
PA7: Crafts
PA8: Doodles and Games

Figure 3. List of the pen activities

Using a grounded theory approach [49], we initially coded the data along many axes: the type of activities conducted with a pen, the types of marks and pens, writing support used, and motivations and possible intent for each activity. Via iterations and discussions, three researchers developed in parallel a final code set for pen activities and pen affordances, finalized after an inter-coder agreement of 95% on 10% of the data. Our code set included low-level codes which we then aggregated into the set of categories presented below. While the lower-level codes are perhaps more exhaustive and indicate subtle nuances in types of affordances and activities, they are difficult to convey efficiently in a conference paper. We chose to report a higher level of abstraction while making the full code-set available. Figure 2 provides an overview of the analog pen affordances, and Figure 3 of the high-level analog pen activities we coded.

Nine Affordances of Pen

To analyze how pens are particularly suitable devices for information capture, we first describe nine key affordances of pen, which we also seek to contrast with prior art.

The affordances (denoted hereafter as AF1-9) are distinct from those associated with the paper itself [43]. We also separately categorized the entries into eight core pen activities (PA1-8) that draw upon and relate back to the affordances in a variety of ways—and thereby provide another layer of depth and motivation to the affordances themselves. For each affordance and pen activity we draw out specific examples, usually with a direct quotation from the user's diary entry, and identify the entry in our online corpus with a notation such as '[#12345].' Also, to authentically capture the 'voice' of user remarks, we report all of their comments verbatim (including typos).

AF1. Externalizing thoughts and memorizing: Many participants surfaced the cognitive benefits of using a pen: "*I find that I take in a lot more information when I write it down as opposed to type it.*" [#12564]. Externalizing thinking by writing and sketching when solving problems offloads working memory and enhances cognition by creating persistent referents [24,53]. Evidence also suggests that hand-writing notes promotes deeper processing and recall of information [6,21,37].

AF2. Producing high-fidelity marks: Most adults have invested a tremendous amount of day-to-day experience in the skilled production of marks, if not design-sketching and artistic expression. As a lever-arm controlled by a tripod of opposing muscle groups [30], the pen becomes an extension of the hand—if not an extension of thought itself [24]—offering high precision and fluidity of expression.

AF3. Tacit and automatic use: With experience the pen becomes so familiar that its use is completely tacit, and automatic, to the extent that the tool itself seems to disappear [42]. "*It feels like more "work" if I start out taking notes on a computer*" [#12414]. As such, the pen consumes minimal attention and cognitive resources, keeping the writer "in the flow" of creative work [5]—or free to multi-task and interleave other real-world activities such as listening to a teleconference call, attending socially to colleagues at a meeting, or reading a book.

AF4. Capturing non-committal information: Hand-written artifacts communicate an implicit 'draft', 'working', 'incomplete' or 'uncertain' nature. Indeed, ambiguity, sketchiness, and incompleteness can spark new associations and re-interpretations of design sketches [15,47]. Ink allows capture of information in non-committal form, which can feel safer than typing something into a report or spreadsheet when one is uncertain of the quality or provenance of the data. Yet, the notation might gain value with the mere passage of time, or upon revision—or it can simply can be disregarded if later deemed incorrect or unimportant: *"Jotting down my to do list in my note pad..will be discarded once i've checked things of...would never use my phone or computer because this list is constantly changing"* [#12433].

AF5. Interweaving symbolic and figurative content: Pen affords a versatile input, allowing users to capture and style text while interweaving it with non-alphanumeric content and illustrations. Pen naturally integrates multiple textual attributes (e.g. location, size of the print, weight, orientation) that would require adjusting many settings in document editing software. Many thoughts do not have a pure written form, but can take the shape of, or benefit from, other visual additions such as diagrams, or symbols and equations, which often require effort to create on digital devices. *"there tend to be a lot of mathematical symbols that are in the text and it is a pain to type them out.*" [#12755].

Figure 4. Writing on fingernails and on the fridge © Microsoft

AF6. Integrating information in context: We observed that inking is frequently driven by context. Examples include leaving a personal note in a loved one's lunch bag, or jotting a reminder on a post-it and leaving it on the boss' computer. Here, the ink has double value: it first indicates some action to take, or attribute, through the textual content; and second it modifies or 'selects' the object of concern by the very act of marking it up. This can also be used as a form of layering of information on top of another context, sometimes referred to as a 'palimpsest' [57]. This context might be a typeset document, a whiteboard with a collaborator's mark-up already on it that one now partially over-writes, or perhaps even a calendar page with appointments penciled in at an earlier time. These uses point to the pen as a cross-surface implement: it enables people to lay marks upon various physical media, often placed strategically at the location that a particular task or activity occurs. For instance, one participant wrote crib-notes on his fingernail for an exam [#12805]; another left a reminder on her fridge regarding meal preparation [#12724] (Figure 4). These examples show how the location of the content—as well as the identity of the marked-up object—both serve the information need.

AF7. Rich personal expression: Handwriting is easily identifiable as a human-made artefact, unique to one person. In pedestrian form this makes it clear who contributed a particular idea to a whiteboard session, for example; but in more profound examples a hand-printed note serves as a form of symbolic gift-giving that can help to deepen social ties or tighten the bonds of intimate relationships. The organic, freeform, and artisanal nature of handwritten artefacts affords such expressiveness: "*Typing a personal note feels like it would defeat the purpose. That would take the personality and sincerity out of the gesture.*" [#12642].

AF8. Reliability and dependability: Pens are cheap and ubiquitous in most home and office environments. The availability (or ready replacement) of a writing implement is therefore far more dependable than digital capture devices with screens that shatter if dropped, innards that short-out if drenched during field-work, batteries that drain after a few hours of use, and when (not if) the user loses the special pen. As a result, the reliability of handwritten notes as an information capture method is hard to beat: "*you never know when the computer might freeze, crash, the note-taking program might rainbow wheel and you have to force quit [...] I can always rely on my hand to be working properly*" [#12588].

AF9. Immediacy of capture: Defaulting to note-taking with a pen often results from time urgency to capture fleeting thoughts [17] as well as during rapid ideation [45]. "*When I come up with an idea, I need to capture it quickly.*" [#12431]. The pen, often tucked between the fingers or behind the ear, is quick to access and one can start writing immediately. By contrast, getting out a device, turning it on, and signing in— not to mention finding the right area of the right application in the right mode of use—can effectively kneecap the quick capture of information. "*We didn't need to wait for something to load or click through a program, we had it all right there in front of us*." [#12874]

Eight Pen Activities

To complement our analysis of pen affordances, we also sought to provide a holistic view of the types of activities people use analog pens for. We describe here eight meta-activities (See Figure 3) extracted from the diary entries, and provide a discussion of how they relate to pen affordances. While these pen activities (PA1-8) provide general categories for what the participants produced, it was not uncommon for some to overlap. For instance, a collaborative brainstorming session generated artifacts that we classified as either ideations, collaboration, or both.

PA1. Ideations correspond to artifacts produced when participants brainstorm ideas or think through problems either by themselves or with others (Figure 1b). As outlined by our participants, this activity is tightly coupled with the supportive nature of the pen for ideation and problem solving (AF1): "*I'm sure I was working on this on the train or waiting for an appt or something. I find it much easier to sketch and work out ideas on paper.*" [#12766]. Another theme is the non-committal capture of ideas (AF4): "*It helps me to organize my thoughts and determine if my swirling ideas and concepts even make sense before committing the show to a digital treatment format.*" [#12414]. Participants also emphasized the pen's ability to help focus on the task at hand (AF3): "*I can't follow what I'm doing as easily as when I handwrite things.*" [#12414].

Additionally, several affordances of pens are tightly coupled with those of paper, making pen and paper a particularly compelling combination for ideation. Paper enables people to capture information without any constraint of format or layout, and the pen's flexible input nature (AF5) enables concentration on the content rather than the means of capture (AF3). Not only can pens write on many substrates in the physical world, paper also allows people to (re)organize artefacts they mark in space, and to layer ideas on top of each other (AF6): "*We're constantly rearranging, grouping, and drawing on top of our ideas.*" [#12774].

PA2. Collaboration and coordination correspond to artifacts produced when communicating or performing collaborative activities with others. The artifacts were produced to articulate difficult models or concepts as a live communication aid, to externalize information by creating a shared workspace, and to create common ground for a shared

"*Here I just had a discussion with my director about a concept we were working on. Basically, I started sketching my understanding of the idea and then he grabbed the pen and started sketching over and next to my sketch.*"[#12874]

"*Whenever something pops into my head I have to write it down before I forget. As you can see from the photo, I'll grab whatever piece of paper is around ... My goal is to write down my idea, and as much of it as I can, before I forget it.*" [#12431]

Figure 5. Examples of collaboration and information scraps © Microsoft

understanding and coordinating efforts. This activity is tightly coupled with versatility of the pen to convey visual concepts (AF5)—many of the entries here included sketches or diagrams. The ease of layering information using ink (AF6) also seems to be a factor in choosing the pen for such activities (Figure 5, top). Collaboration and coordination activities also benefit the ability to ink in many locations and contexts (AF6). For instance, placing the content in a shared workspace enables group members to notice it, read it, and act on it. The availability (AF8) of pens also makes it easy for collaborators to contribute at moment's notice (AF9).

PA3. Information scraps are 'micro-notes' that are often created in the moment to fit a short-term goal [7,28]. At times information scraps are derived from other contexts because there is no 'good' location to file or note the information. This category includes todo, packing, and grocery lists; reminders to oneself or others; driving directions and other brief instructions; and short-term memory aids, and logs. In these activities, participants often mentioned immediacy (AF9) and the contextual role (AF6) of pen and ink. Immediacy is critical for information scraps (Figure 5, bottom): in a task that might take only two seconds to complete, a 30-second context switch to an electronic tablet is a non-starter. Contextualization, in turn, allows tying the content to the proximity of where it is needed—such as an asterisk in a document margin or a '*dirty*' post-it on a dishwasher. "*Children respond better to visual notes so they can constantly be reminded, especially younger children.*" [#12606].

I made lunch for my boyfriend, wrapped it in a napkin and then put it in a plastic sandwich bag... I know that his job is difficult and stressful and I try and take any opportunity I can to make him smile throughout the day." [#12642]

Figure 6. Example of personal communication © Microsoft

PA4. Personal communication corresponds to artifacts created specifically to contribute to a personal relationship. They included hand-written letters, postcards, or messages embedded in context. The personal (AF7) and unique (AF2) nature of handwriting and drawing plays an essential role in these activities. In an environment where emails and texts become the norm, using the pen to communicate with others can strengthen social bonds and reflect the uniqueness of the relationship. *"Handwritten thank-yous are a must; typing one would just seem lazy & rude. Too impersonal if done digitally."* [#12533]. The additional effort required by hand-crafted communication signifies the value of the relationship: *"On special occasions I will write cards for friends. People know more effort is put in with real stuff."* [#12730]. The contextual placement of the content (AF6) may be key, emphasizing the intimacy of the relationship. For instance, one participant was thoughtful of when and where the recipient would see her message (Figure 6).

PA5. Annotations refer to handwritten content on top of reference material, in a clear figure-ground relationship. With annotations, the handwritten content would lose its meaning if removed from this context. Activities included writing on a printed calendar or engaging in active reading to enhance understanding and recall (AF1). Non-alphanumeric marks (AF5) such as underlines, arrows, and highlights are often prevalent in annotation scenarios [41]. We also coded tasks such as filling forms or signing checks and documents as a form of annotation. The mark-up is layered on top of such forms, and the location (context) is what gives the marks their meaning (AF6), both of which fit our definition for annotation. This category also includes labeling documents or objects (Figure 7 top left) to communicate information to others, such as a description of the contents of a box, or a list of required actions for a co-worker. Because pen and paper combine the content being captured (the label) with a specific context in the physical world, people leverage this unity of context and content as terse, complementary, and information-rich modalities.

PA6. Recordings are artifacts of pen activity concurrent and related to another ongoing activity. Recordings occur in both work and personal contexts, and are often created for oneself to afford reference and recall (AF1). For students, writing is motivated by the need to understand and retain the

Figure 7. Examples of annotations, crafts, doodles, and recordings © Microsoft

information. *"I don't know exactly why, but I think the tactile feeling of actually writing something engrains it in my brain much more than just pressing keys."* [#12564]. The ability to flexibly intermingle notes, figures, sketches, and diagrams (AF5) is also a recurring motivation. *"Writing out note is quicker and I can draw arrows and do math more easily."* [#12560]. Other recordings, such as lab or field notes, capture details for later use in reports, emails, or other documents. In such situations, an individual's attention is often primarily occupied by a real-world task for long periods of time (1 hour or more), so capturing information without distraction is critical (AF3). The faith that the content would be reliably recorded (AF8) was also a common motivator: (Figure 7 bottom right): *"When talking with a client, I like all my notes to be on a hard copy because of the chance a digital file may be deleted or lost."* [#12654].

PA7. Crafts correspond to artifacts carefully crafted with pen and paper for oneself or for others. In these entries, the product of the writing or drawing is an artifact that has a purpose and a value of its own, akin to an art piece (Figure 7 top right). These artifacts often end up being shared, and/or kept as mementos. The long standing relationship of people with pen makes this input mechanism a natural extension of their body (AF2) and often enables them to feel an emotional connection to the material they produce. *"I do find writing long hand to be relaxing and I have a closer relationship to the material then if I was writing on my computer."* [#12749]

PA8. Doodles and games. In contrast to crafts, doodles are short-lived artifacts that may never be looked at again. Examples include squiggles drawn on the corner of a page during phone calls, or playing games such as Sudoku while waiting for an appointment. The most common motivation for using pen for doodles is the serendipitous access and the spontaneous and inconspicuous nature of the activity (AF8, AF9). *"I doodle on the agenda cause it keeps me occupied during the boring meeting! No computers allowed."* [#12545] (Figure 7 bottom left). Due to its tacit use (AF3), immediate readiness (AF9) and the uniqueness of the output (AF7), freeform mark-up with a pen offers a more expressive medium than a computer screen. *"I drew this guy to capture my feeling about the subject. I wouldn't want to have to open a program to be able to express my thoughts"* [#12716]

Figure 8. Digital pen devices in the diary study

Figure 9. Quantifying the use of digital pens

STUDY2: DIGITAL PEN

In this section, we contrast the affordances for analog pens derived from our observations against those of digital pens. To achieve this, we first performed a follow-up diary study with *digital* pen users to tease out activities and affordances of digital pen technologies and identify any discrepancies with their analog counterparts. Second, we conducted an online survey to understand the prevalence and frequency of scenarios in both analog and digital pen use. This allowed us to identify popular and frequent activities related to pens, with an eye towards identifying any that appeared absent or degraded in digital pen-based experiences—and vice-versa.

Methodology for Diary Study of Digital Pen Use

We again used *dscout*, with a similar methodology as for the first diary study, but with a focus on digital pens, which include active digital pens as well as passive capacitive pens for touch devices such as iPads. While we consider hybrid augmented-paper technologies (such as Anoto) to be 'digital' pens, none of our participants reported owning such a device. We recruited 30 participants (13 female, 17 male) who used digital pens (Figure 8). None participated in Study 1 and all participants used their digital pen at least weekly. Mean age was 36 (sd=9) and occupations included student, homemaker and graphic artist.

Each diary entry consisted of a photo, plus comments on the activity. Participants also provided their motivations for using a digital pen, and on the importance and quality of the experience. Because they had to answer more questions for each entry than Study 1, we requested only five entries. They provided between 1 and 10 entries, for a total of 178 entries. We coded the data with categories from Study 1.

Survey Methodology

We recruited 1633 participants (excluding partially filled surveys or participants failing to answer captcha questions) via Amazon Mechanical Turk, compensating them $2 for their participation. Most respondents (71.8%) were between 18 and 39 years of age and 59% reported using a computing device more than 4 hours a day. They reported a variety of occupations in IT (15%), education (15%), healthcare (12%), retail (11%) and 35% were students. The survey contained 60 questions to gather demographics (8), type and use of analog pen (20), electronic devices (15) and digital pen (14). Note that only 185 out of 1633 owned a digital pen (11%) and answered the latter questions, including Galaxy Note, Surface Pro, and iPad combined with a capacitive stylus.
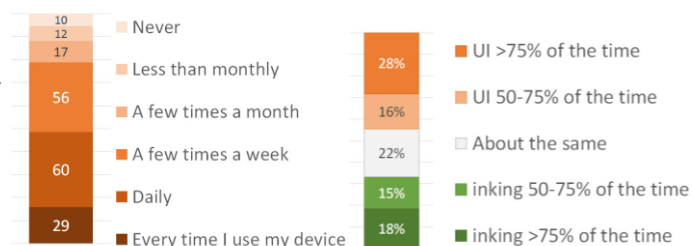
In the rest of this section, we report the results from both our diary study and the survey to contrast the use of analog pens vs digital pens. We use the quantitative results from the survey to provide frequency and prevalence of activities and motivations for using analog or digital pens; and the qualitative results from our diary study to illustrate some of these activities and identify reasons for differences in usage or expectations.

New Digital Pen Affordances and Activities

The entries from our diary study confirmed that most analog pen activities (PA1-8) have a digital counterpart, although not many entries dealt with collaboration and coordination (PA2) or personal communication (PA4). Our coding of these entries also led to one additional activity:

PA9. UI interactions and non-ink traces. This activity includes tapping, scrolling and pointing to interface elements (somewhat analogous to gesturing and pointing with a pen) as well as interactions with the app content such as lasso selection. These entries showcased a variety of context for interacting with the pen: from inputting text on a keyboard to navigating a map or playing a game. This activity reveals the digital pen as a substitute for touch, mouse or trackpad.

In addition, our analysis of the entries revealed three affordances specific to the pen:

AF10. Accuracy for pointing and dragging. Participants felt that the pen was more precise than touch. This affordance is related to (AF2, high-fidelity marks), where users leverage fine-motor skill with a tool. "*I prefer with my digital pen because it feels better when touching the screen and it's more accurate*" [#98951]. "*I just have got used to using a pen--using a mouse just feels clumsy to me.*" [#98057].

AF11. Versatility in the style of traces, where a single pen produces strokes of various colors or shape: "*I'm an artist […] while I typically like to use a more variable material like ebony pencil or charcoal, it's nice to use a digital pen and iPad while laying on the couch.*" [#99148]

AF12. Dynamic editing and history, where the digital trace can be easily deleted or edited: *"I love that i can record our sketching while we play and we then edit it to playback and sometimes the top best we edit and make our own home movies ..."* [#99178].

Contrasting Analog and Digital Pen Usage

Results from our survey confirmed that analog pen and paper plays a significant role in people's lives: 72% of respondents reported using pen and paper 1 hour or more per day, 32% at 3 hours or more. Yet, for those who owned a digital pen—11% of the survey respondents—its use was rather limited (Figure 9). Over 50% used their digital pen less than daily. Note also that digital pen owners did not report using analog pens less than the rest of the respondents. To gain insight into what people do with digital *vs.* analog pens, we asked respondents what their frequent pen activities were, and if they used digital pens *more* or *less* than expected for each.

Most popular and frequent analog pen activities reported by our respondents are information scraps (PA3, 79%) and annotations (PA5, 73%). However, over 40% of digital pen users reported that using their digital pen less than expected for these activities. To understand why, we analyzed the reasons respondents gave for using analog pens, identifying affordances of the pen that may not hold for digital pens. In particular, the contextualization of information (AF6)—a motivation for using analog pens over computers for 76% of survey respondents—is critical for annotations. Yet in-place annotation experiences are vastly inconsistent for digital pen users, making it difficult to support this activity. Digital artefacts are siloed in different file types, often unreadable or uneditable by other apps, and the UI for pen annotation differs widely across apps as well—if supported at all.

Regarding information scraps, any immediacy of the pen (AF9) is often lost as it takes far longer to find and launch an app than to grab a piece of paper and click a pen.

We also looked at what activities people performed most often with digital pens. Using the digital pen to interact with the UI (PA9) represents a substantial part of today's digital pen experiences. Many digital pen owners (67%, see Figure 9) reported using their pen as much or even more for interacting with the interface than for actual inking. While device manufacturers might tout this new use as a putative benefit of digital pens, one could equally well argue that it poses a fundamental shortcoming if it compromises the natural affordances of analog pen-and-ink. But either way this finding underscores the shift in expected use that participants experienced for digital pens: over 50% reported using the digital pen for inking far less than anticipated when making the purchase in the first place.

Digital Pen Falls Short of Expectations

To reflect on compelling scenarios for the digital pen, we need to consider not only the frequency and popularity of activities, but what matters to people. The top 5 reasons cited by digital pen owners for purchasing a device revolved around ink's ability to engage cognitive processes more deeply with better recall (AF1). Yet few respondents reported using their devices for daily ideation (15%), or recording (39%), and overall 37% reported using their digital pen less than expected for these activities.

To contrast with the survey findings, we looked for instances in the digital pen diary study where participants surfaced benefits from externalizing thinking and deeper processing of information with digital ink (AF1): *"I feel more creative and mind flows better vs typing."* [#97663], or *"This activity is best done with a pen because of muscle memory already associated with taking notes."* [#97662]. While this suggests that several affordances of the analog pen at least partially hold for its digital counterpart, comments also indicated compromised dependability in the digital realm (AF8): *"Sometimes The pen wouldn't pick up my marks which was kind of frustrating."* [#99310]. Participants also noted technological barriers to the fidelity of their marks (AF2): *"A better feeling pen, and more accuracy with handwriting digitally would be preferred."* [#97027]. Or, regarding the feel of digital inking, *"The only thing that is missing is a bit of tactile feedback"* [#98961].

Compelling Scenarios for the Digital Pen

The personal expression afforded by a pen (AF7) is the top reported advantage of the analog pen over computing devices in our survey (77%), followed by uniqueness of what is created (74%). Several activities for which this affordance matters most may even be enhanced by a digital pen. For example, our survey indicates that crafts (PA7) were among the most compelling for digital-pen users. Over 20% of digital pen users reported using their pen more than they had anticipated for these activities. Several diary study entries point to the versatility of the digital pen offering a virtually unlimited set of stroke styles (AF11), and the dynamic editing of the output (AF12) contributing to make the digital experience more compelling than analog. Yet, other activities for which AF7 matters, such as keeping a diary or handwriting correspondence, are not supported much by today's software. Investigating these scenarios further could showcase the unique affordances that digital pen offers.

Another example of a potential asset of digital technologies is the ability to archive and retrieve handwritten notes. The survey revealed that 66% of respondents are confident that the computer keeps their content safe, and 58% that it makes retrieval easier. However, even if ink is archived, ease of retrieval does not yet seem to be fully realized: *"Wish I could search through it, I.e. handwriting recognition."* [#97748]. Even if we make the dubious assumption that handwriting recognition is always available, and accurate, it still lacks consistent integration across applications and platforms.

STUDY LIMITATIONS

Our approach combines two diary studies with a limited number of participants, to provide a rich corpus of examples, and a survey with a larger population, to assess the prevalence of activities and scenarios for analog and digital pen. As with all studies, they have a number of limitations.

The participants of our diary studies are certainly biased towards more heavy users of ink and, while we selected for a diverse set of people, it remains probable that the set of activities we collected is not exhaustive nor representative of

the general public, and could certainly be augmented with additional studies. There are also several limitations pertaining to the survey. In particular, many questions asked participants to self-report their most frequent activities or rank them by importance. As with all self-reported measures, these responses may not be representative of reality.

Note that we also focused primarily on pen as a mark-up tool. Yet pen is often used in the analog world in conjunction with meaningful, non-mark-up gestures [52]. Hence, when considering the affordances of the pen we must remember they are intimately interwoven with those of the hand [59]— that is, the many forms of 'touch' observable on modern touchscreen devices [19] that we did not capture in our studies. Issues only become more complicated and nuanced when one considers hybrid analog-digital inking solutions (e.g. [27,48,58]), or when one inks with an ordinary pen on post-its that are tracked by a sensing system [25], to name a few examples that weren't included in our studies.

DISCUSSION AND RESEARCH OPPORTUNITIES

Our ambitious goal is to bring a new, wider perspective on the types of activities people perform with analog and digital pen, teasing out the specific affordances of pen. We discuss research opportunities resulting from our studies below.

Affordances of Pen vs. Affordances of Paper

Our work takes an orthogonal and complementary perspective from Sellen and Harper's affordances of paper, focusing on the input mechanism rather than the capture medium. This angle enabled us to collect data that revealed intersections between pen and paper affordances, sometimes expanding them; and also outlined some of the unique affordances of the pen, independently of the capture medium, hinting at a different set of research opportunities.

Several affordances of pen and of paper are tightly coupled: AF6 (integrating information in context), for example, is partially covered by *marking up documents*. When focusing on the pen, this affordance also includes the marking up of physical objects and spaces, pointing to a different set of research directions in augmented reality for example. Other affordances are unique to the pen and the quality of marks produced, such as AF7 (the personal expression inherent in an individual's handwritten artefacts).

The data we collected also suggest the possibility of further affordances of paper. For instance, participants mentioned how paper can be easily transformed (cut, torn, folded) to fit in different contexts (ripped out of a notebook, placed in one's pocket, or passed to someone else), illustrating how paper artefacts can easily be repurposed in new contexts after-the-fact (pinned, taped, inserted). And even though paper is cheap and easily disposable, it can also serve as a reliable medium for storage, in contrast to the "dark ages" of digital photography, for example. These examples hint that a broad re-analysis of the affordances of paper (either from our data, or future studies focused on this aspect) may very well extend the affordances identified by Sellen and Harper.

(Re)focusing on Scenarios and Affordances that Matter

Insights from our studies indicate that most frequent analog scenarios performed by a large portion of our participants (information scraps and annotations) are poorly supported by digital pens today. Scenarios perhaps less frequent but that matter to people, often motivating them to own a digital pen in the first place, (ideations and recordings) do not transfer well to digital either. Tacit use (AF3), contextualization (AF6), reliability (AF8) and immediacy (AF9) play an important role in making these scenarios compelling with a digital pen. We encourage the community to search for solutions to better transfer these to the digital world. Clearly the solutions in existing commercial practice fall short of the potential here. For instance, one could design a digital pen scenario that avoids distraction by limiting system notifications during inking activities. Our studies also showcase scenarios (e.g. personal communications) and unique affordances of digital pens (AF10-12) that could perhaps motivate greater adoption of digital ink, if done well.

Flexible Data: Fluid Interweaving of Varied Ink Scenarios

The data we collected suggests that different analog pen activities are often intertwined. Our survey indicates that 41% of people report conducting three or more analog pen activities daily, and diary entries at times reveal complex interstitial activities afforded by analog pens. For instance, a notebook meant to be used for class notes might also contain a 'contact'—the phone number of a peer—with whom a student needs to coordinate on a project.

In the analog world, flexible data leads to seamless and opportunistic transitions. But in the digital world, ink loses its flexibility—and, if recognized, may even lose its underlying ink-stroke representation—as it becomes siloed in applications that support specific scenarios (taking notes vs. managing contacts vs. reading and annotating documents). The user is thus forced into a premature choice of which app to use, even though at the time of making the note, the user doesn't know its future use (or uses)—if any. Designing for fluid transitions between activities may avoid the traps of such premature commitment, or perhaps more deeply mapping the interdependence of activities may be instrumental to enable "flexible data" scenarios with appeal to a wider audience.

Conflicting Affordances of Digital and Analog Ink

A fundamental issue for digital ink is whether pen input always leaves behind ink strokes, in a manner faithful to marking with an analog pen, or whether it is sometimes takes on a special digital interpretation, such as a scratch-out or lasso gesture [12,35,39], or even mouse cursor control. Perhaps surprisingly, our observations of both digital and analog pen use suggest that there is not yet any clear-cut answer to this design dilemma.

Should our guidepost to digital ink be the analog pen? Analog pens, by sheer virtue of laying down ink no matter the context, shed these technology-laden expectations. One could design a digital pen that only ever lays down ink. Yet,

current digital pen owners seem to purchase these devices with the expectation that an expensive digital pen can do more than just lay ink on the screen.

The alternative is to accept that digital pens will shift in function depending on the current device, application, and mode. Although good mode-switching techniques [26,44] can mitigate such shifts, a designer with a critical eye would be correct to point out that presence of one interpretation competes with and undermines the affordances of the other. If a pen only inks, it cannot serve as a precise pointing device for interacting with UI elements. Yet a device where the pen is primarily a pointing device and secondarily an inking device seems equally unpalatable. Such a dual-purpose approach, where the pen can serve as an inking device *and* a pointing device, would seem to place a burden on the user to remember (or predict) what effect the pen will produce when they bring it to the screen. Thus either design decision seems detrimental to the analog (and digital) affordances of ink.

Resolving this conflict in a satisfactory manner may be one the greatest challenges facing the design of future digital-pen devices. We suspect the solution lies in extreme attention to detail in design. Achieving predictable, consistent, and habit-forming behaviors requires the app ecosystem to provide consistent experiences as opposed to heterogeneous interface components with numerous interactions for switching modes, or for features such as changing the ink color. Much research and design is needed to fully unlock the the nimble representations afforded by the 'flexible data' inherent in ink strokes, which may ultimately manifest as cross-application (and cross-device) paradigms for laying down and interacting with ink. In the meantime, understanding the tradeoffs of inking-only vs. mixed-use devices may offer a more practical avenue.

Beyond the heterogeneity of digital pen apps, our observations suggest that ink recognition itself may be at odds with the value (and affordances) of ink that remains *ink*. The pen affords an infinite vocabulary of shapes, lines, and symbols that cannot be recognized perfectly in a context-independent manner. By enticing people with the value of easy and exhaustive retrieval enabled by ink recognition, one risks turning an organic and artisanal modality which serves an imprecise, ambiguous, and pervasively flexible mode of expression into one that is a well-ordered but sterile set of pre-defined symbols so that it conforms to the structure and formality demanded by most experiences with computers.

Draft vs Craft
One recurring theme in our data is the idea that while digital pen experiences might be well-suited for *crafting* and polishing artefacts, they currently lack critical affordances for *drafting*—ideating to decide what needs to be crafted. In other words, people associate analog pen with creativity and ideation, and digital technologies to producing a finished product. So how do we reconcile the two? How do we make make the leap from *freeflow* to *workflow*, such that a digital

pen compelling for ideation can transition to the creation of a more polished and shareable end-product as well?

While this question remains open, we propose several considerations. Earlier, we noted how analog pen affordances are well-aligned with some of the processes at play in ideation. Analog pens are tacit (AF3), allowing the tool to disappear from attention such that only creation of the idea itself remains. Analog affordances such as immediacy (AF8) and jotting down ideas in non-committal form (AF4) are key to creativity, areas which remain barriers to use of the pen for "craft" in digital contexts due even to mundane issues such as start-up time and the accuracy and feel of the pen digitizer. Indeed, some advantages of digital experiences—such as archiving and multi-tasking—seem to fundamentally conflict with the "drafting" experience. Reconsidering automatic archiving of ink, or the role (or even appropriateness) of recognition features, may provide people with a place more akin to paper, where information can either mature and become valuable for archiving and sharing; or be discarded without any traces as time demonstrates its lack of usefulness (e.g. [23]). While intentionally leaving out such "must-have" features of digital ink might seem an extreme design stance, such a shift in perspective may ultimately prove necessary to change how people perceive digital ink.

CONCLUSION
This work attempts to build a comprehensive view of analog and digital pen experiences. We contributed insights on the breadth of activities conducted with a pen today. And, to compare and contrast the two, we teased out affordances of the pen, distinguishing them from the affordances of paper versus those of digital technologies. We believe these affordances will lay a foundation for reflecting on *"how we may ink,"* raising key implications for the design of a rich and sustainable set of digital pen experiences. Our approach revealed several critical affordances that are either lacking or poorly supported in current digital experiences—insights that can and perhaps should encourage closer scrutiny of the assumptions underlying digital pens so as to better inform future generations of electronic paper and digital screens.

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