Classroom Studies of Augmented Notebook Usage Informing the Design of Sharing Mechanisms

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Abstract

Designers today use a variety of artifacts—both physical and digital—in the course of documenting their work. Physical and digital media have significantly different affordances and organizing metaphors: most notably, paper remains the preferable medium for sketching but lacks the sharing affordances of digital media. Augmented paper interactions promise to mitigate some of this difference, yet there have been few real-world evaluations of augmented paper systems. To investigate their potential value for design, we conducted two studies of augmented paper interactions with student design teams. Across two ten-week-long studies, 56 design students used the system, authoring over 4,000 pages of content in the course of their class work. We discuss the impacts of augmented paper technology on design practice, including salient benefits (ease of integrating physical media into digital practices), shortcomings (insufficiency of naïve sharing mechanisms, barriers to adoption), and other emergent behaviors (changes in how physical and digital content coexist).

1. Introduction

Designers spread their work over both digital and physical artifacts. Today's designers use a toolbelt [24] of digital devices, from desktop computers and laptops to mobile phones, digital cameras, and portable music players. At the same time, many designers depend on paper for tasks both complex and mundane; in the so-called digital age, the use of paper has increased [22]. Yet the two worlds live apart, and common infrastructures for moving between them (scanning, printing) are heavyweight and cumbersome.

Previous work has introduced augmented paper interfaces to bridge this divide between the physical and digital realms (*e.g.*, [8, 10, 12, 14, 17, 23, 26]). Ethnographic work has shown the centrality of paper in work practices, especially for collaboration (*e.g.*, [11, 22]), and a few systems have used ethnographic work and short-term usability studies to inform the design of augmented paper systems (*e.g.*, [14, 17, 26]).

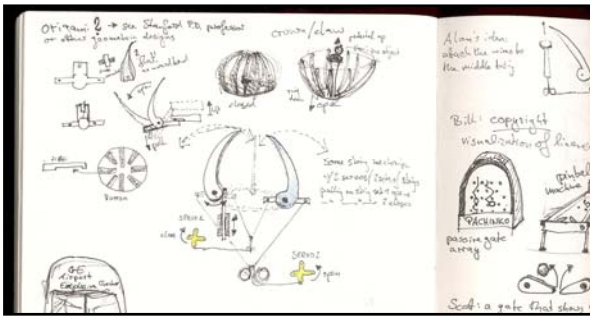

Figure 1. The Idea Log. A page of sketches from a student's design notebook.

However, the literature lacks an ecologically valid understanding of the design of augmented paper systems and their effects on practice. Achieving ecological validity in CSCW and ubiquitous computing is generally difficult [7]: with a few notable exceptions (*e.g.*, [3, 20]), there has been a dearth of longitudinal evaluation. From a methodological perspective, longitudinal use is the missing piece of the puzzle: *how does integrating physical and digital interactions change users' practices, and what implications does this have for the design of augmented paper systems?*

1.1. Current practice in design education

To investigate the potential value of augmented paper systems for design, we are studying their use among student design teams. One long-standing tradition in design education is the Idea Log [25], also known as a design notebook or research notebook. The Idea Log supports creative expression by providing a space for individual ideation and documentation (see Figure 1). Students take notes, record meetings, sketch designs, and write down ideas, observations and inspirations—wherever they are (see Figure 2).

Consistent with Sellen and Harper's findings about the paper use of office professionals [22], design students and practitioners employ physical notebooks for their flexibility, support for sketching, portability, and "displays" that have infinite battery life. However, as prior research has noted [10, 12, 22, 26], paper notebooks provide limited facilities for sharing, search, and content reorganization.

The distinct affordances of paper and digital technologies can yield awkward disfluencies in interaction when moving content between the two. In traditional Idea Logs, students print out important photographs to paste them into their notebooks. Assignments and project reports are generally composed on the computer, based on sketches and notes in the log, and excerpting physical materials in digital documents requires the use of scanners or cameras.

Another media tension arises during group collaboration. Recently, project-based learning and team-based activities have received increasing attention among educational researchers and practitioners [1, 6, 15, 18, 20, 21]. However, shifting the operational paradigm of the classroom from individual-centered learning to team-centered learning introduces a set of concerns around collaboration and document use (*e.g.*, [5]) into the classroom. In particular, one challenge we have seen is the extent to which the work practices of students are rendered visible to their teammates and the teaching staff in a lightweight manner, an important part of the reflective practicum [21]. In educational settings, this challenge is exacerbated because the physical space limitations of the university imply that student teams are—mostly—remote teams, making the sharing of physical artifacts difficult.

Prior work has demonstrated that augmented paper can support capture and transformation of data in domains with strong traditions of physical practice [26], and examined the effects of group dynamics on adoption and usage of augmented paper systems [18]. This paper is distinct in its concentration on the longitudinal impacts of augmented paper interactions on design practice, and their implications for system design.

1.2. Overview

This paper begins with an overview of the iDeas learning ecology, an augmented paper system. We describe results from two studies of the ecology, analyzing students' use of the tools and discussing the impact of the tools on practice, including the emergence of hybrid versions of design notebooks. Inspired by findings suggesting that powerful opportunities lay in enabling lightweight support for collaboration, we conclude by describing two design responses: integration with existing online tools, and a lightweight interface for group documentation and reflective activity.

2. iDeas ecology

As a research probe into how integrated interactions might influence the culture of design, we are developing the *iDeas learning ecology*. We use the term ecology [4] to describe how the system comprises a diverse set of artifacts from multiple users, and its role in facilitating collaboration among design students.

The iDeas learning ecology integrates designers' existing digital tools with an augmented version of their primary physical tool. To capture written content, design students use the Anoto digital pen system. When used with an Anoto notebook, the pens record a vector-graphics representation of each stroke, along with the page, date, and time. Users may upload and view their digitized notes by synchronizing with a PC. Unlike purely digital systems, the Anoto digital pens also act as normal ballpoint pens: should the pen digitizer fail (*e.g.*, if the pen runs out of battery power), users may continue taking notes and sketching as if they were writing with a normal pen. Likewise, if the physical notebook is lost or unavailable, users may refer to the electronic version of their notes. Users can import any digital images into iDeas: designers may document fieldwork with digital cameras, take snapshots of serendipitous moments using camera phones, or integrate material downloaded from the web.

Users interact with captured content through the ButterflyNet browser [26], which integrates digitally-captured notes with photographs and other media

Figure 2. Students brainstorming, observing, and presenting, using augmented Idea Logs, large sheets of paper, cameras, laptops, and large digital displays.

through a faceted metadata browser (see Figure 3). Notebook pages currently in focus are displayed in the *content panel* on the left; the browser offers the ability to zoom in or out and display multiple pages at a time. The *context panel* on the right automatically presents data related to the pages in focus, such as images taken around the time the page was written.

At the top of the browser, a *timeline visualization* allows users to jump to content by date. The height of each bar represents the amount of content written on that date. Flags representing course milestones, indexed by date, provide links to course web pages while also providing a visual aid for locating content related to a given milestone. Users can also easily export notebook pages as images to other programs, allowing them to complete common tasks such as pasting sketches into documents or sharing their design content through email without the burden of scanning.

In the first of our studies, collaboration support in the iDeas software was limited: users could only view their own digitally captured notes, then export their sketches and writing to office productivity and email applications, and share through other channels. For our second study, we added several networked collaboration features to the iDeas ecology. Users then could create and join groups, and group members could view each others' content in the browser. We also added *tags* (text labels of pages) and *annotations* (text or image labels of page areas) to the system. Group members could comment on each other's work by highlighting and annotating interesting pages. These tags and annotations were indexed and searchable for later retrieval. To encourage the use of iDeas as a classroom tool and communication channel, we also added the concept of *staff members*, who had access to aggregate views of the entire class, as well as the ability to view and annotate any notebook.

3. Method

We have conducted two ten-week-long studies of the use of iDeas in design education. The first study ran during the fall quarter of 2005, when we deployed parts of the iDeas ecology to selected sections of the undergraduate introductory HCI design course at our university. The following quarter we ran the second study, deploying iDeas to all students enrolled in our university's HCI design studio course.

During both quarters, we conducted evaluations through five methods: *observations* in class and videotapes of group meetings; *logs* of activities within the iDeas ecology and some electronic exchanges across groups; *analysis* of the students' Idea Logs, associated coursework, and performance metrics; *interviews* of students that extensively used the iDeas system; and *pre- and post-experience questionnaires*. Survey questions were drawn from earlier studies' findings about collaboration, feelings of belonging to a group, interpersonal closeness, friendships among teammates, satisfaction with project outcomes, group interactions, and learning, among others. Questions about technological proficiency, assessment of the iDeas tools, and prior workgroup experience or experience in maintaining logbooks—including Idea Logs, blogs, and journals—were also included.

While the Idea Logs themselves were graded for the courses, no explicit remuneration—whether monetary or in terms of grades—was given to encourage the use of the system; the authors were not involved with notebook grading at any time. Students were free to use the technology as much or as little as they desired. The electronic versions of the students' notebooks were not used to grade the students' work unless the students requested it from the course TAs.

In the first study, one section of the introductory HCI course, comprising 18 students (11 male, 7 fe-

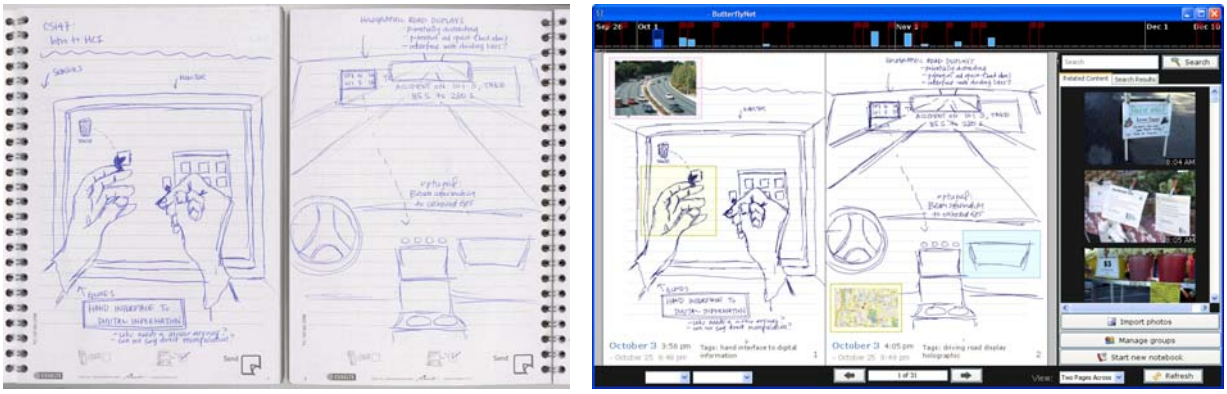

Figure 3. *Left*: Pages 1 and 2 from a student's Idea Log. *Right:* The same pages viewed in the ButterflyNet browser. Notebook pages and annotations are presented in the left-hand content panel, while contextual data (*e.g.*, related images, search results) are presented in the right-hand panel. Above, a timeline shows class milestones along with a bar graph visualization of the amount of notes collected on days throughout the quarter.

male) with diverse academic backgrounds, was randomly selected to participate and provided with Anoto digital pens, A5-size notebooks (148 mm × 210 mm), and an initial version of the iDeas ecology for archiving and browsing notes and images electronically.

For the second study, all 48 students enrolled in the HCI Design Studio course [15] during winter quarter were asked to participate in the evaluation of the next version of the iDeas ecology. Of these, 38 (10 female, 28 male) consented and were provided with digital pens and notebooks of a similar size to those used in Study 1 (137 mm × 203mm), and the iDeas software. An additional eight students participated in the surveys without using the technology. Participants were predominantly engineering students, and were evenly split between undergraduate and graduate programs.

4. Results and discussion

In this section we analyze data from questionnaire responses and activity logs, and discuss the larger impact of the iDeas ecology on current practice.

We identify some salient benefits of the ecology (increased ease of incorporating sketches into digital documents for sharing and documentation, an integrated repository for sketches and photographs), shortcomings of its current implementation (lack of support for lightweight, persistent sharing of content with teammates; a fragile research infrastructure which, combined with other perceived and actual costs, discouraged adoption), and other emergent behaviors, including observations on how physical and digital content coexists in the new media space.

4.1. General user feedback

In Study 1, participants rated the iDeas system as significantly useful, easy to understand, and easy to learn (median 4, 5-point scale). For exporting and sharing design content, students preferred using iDeas to traditional means such as copiers and scanners (median 6 in a 7-point scale). Several students commented that the ability to share notebook content quickly and fluidly (via exporting the page image to office productivity and email applications) was valuable.

In Study 2, several aspects of the revised system were reviewed positively by the participants. Students resonated with the broad value proposition, responding, "I like the idea of having a digital copy of my notes, and the ability to annotate them," that "It was easy to import and export images, from and into other programs," and that "I like the idea of seeing/copying/sending notes. Tagging, importing pics, *etc*. is also great." Participants also responded that they found value in "the ability to import pictures to view with notes" and "sharing data across remote locations." As a caveat, these positive comments may have been influenced by the fact that one of the instructors is a co-author on this research.

Complaints from both studies focused on the research instantiations of the software and hardware, particularly the poor pen ergonomics. We expand on these issues in our discussion of adoption (below).

4.2. Media integration and collaboration

Users from both studies cited the ability to quickly insert excerpts from paper notebooks into digital documents as a standout feature. We found corroborating evidence of this in students' class assignments: several groups inserted sketches from their Idea Logs into project reports as samples of their ideation, a practice not prevalent in previous offerings of the courses.

Four participants in Study 1 requested more direct integration of sharing into iDeas; in response, a simple sharing mechanism was introduced in Study 2. When we invited the seven most prolific users of iDeas to discuss the project, they repeatedly mentioned the high value of quickly sharing information among teammates. The perceived value proposition was twofold: the ease of sharing visual ideas; and the lesser need to document the same materials as their teammates, particularly during meetings. Course staff also found the server-stored digital version useful, as they could peruse student content and provide feedback without taking notebooks away from students.

However, the simple sharing model also had shortcomings. Automatic sharing of content in personal notebooks introduced privacy issues, even among friendly groups. We also found that simple sharing of notebooks was not sufficient to create and maintain a "common ground" for group members. This inspired us to introduce a more lightweight, persistent model of sharing (group notebooks, discussed below).

4.3. Adoption measures

In addition to its value as a research probe in understanding the user experience of augmented paper in design, iDeas has significant value as a *capture instrument* for studying students' design artifacts, allowing us to gather extensive data on design activity and tool usage. Figure 4 shows adoption patterns using the server-logged timestamp data, displayed as sparklines representing the number of pages each of these 38 students filled daily. During the 66 days of the quarter in the second study, the 38 students entered 3,637 pages in iDeas. Students varied greatly in the frequency and amount of content created, falling loosely into three categories: those that quickly adopted and *continued* using the technology throughout the quarter (11 students), those using the system for *ideation*, but less so

when programming demands took over (15 students), and those that only gave the technology an *early try* (12 students). Interviews indicated that the usage falloff was partially because the notebooks and pens are more relevant for the ideation and iteration that characterize the early parts of the course; later weeks focused on implementation and evaluation tasks.

4.4. Barriers to adoption

During the course of the studies, several barriers to adoption emerged. Eight students in Study 2 listed the poor ergonomics of the digital pen as the reason for their lack of continued usage of iDeas. The Anoto digital pens were sometimes described as big, clunky, and awkward, discouraging users from carrying them. Users also cited battery life as an issue; having to remember to charge the pens every day was a maintenance cost for participants. The notebooks, of lower quality than typical design notebooks, also drew some complaints, and interviews with students and teaching staff suggest that the lined Anoto paper discouraged freeform content in favor of textual content. Finally, several users had difficulties with software installation. In the study implementation of iDeas, users were forced to install software components from several manufacturers in addition to the ButterflyNet software, leading to a system with several potential points of failure. Each of these issues, while not intrinsic to the technological approach, point to a key concern for longitudinal deployments of ubiquitous computing systems: *technologies are adopted to the extent that the provided benefits outweigh perceived and actual adoption costs*.

Though it seems likely that future versions of augmented paper technology will overcome the limitations of early version, such issues must be taken seriously for development and longitudinal deployment of current technology hybrids. Consider, by analogy, the challenges of conducting a longitudinal study with the brick-sized smartphones circa 1999—while mobile email and other applications have since demonstrated their value, before the technology matured, this finding was confounded by ergonomic and technical limitations of early systems. The difficulties in longitudinal evaluation of emerging ubiquitous computing platforms remains an issue for continued investigation [7].

4.5. Coexistence of paper and digital

Pasting inspirational images or relevant materials into design notebooks is common practice for designers. The use of Anoto technology in iDeas implies that content written with traditional pens or pasted into the notebook does not transfer into the digital domain.

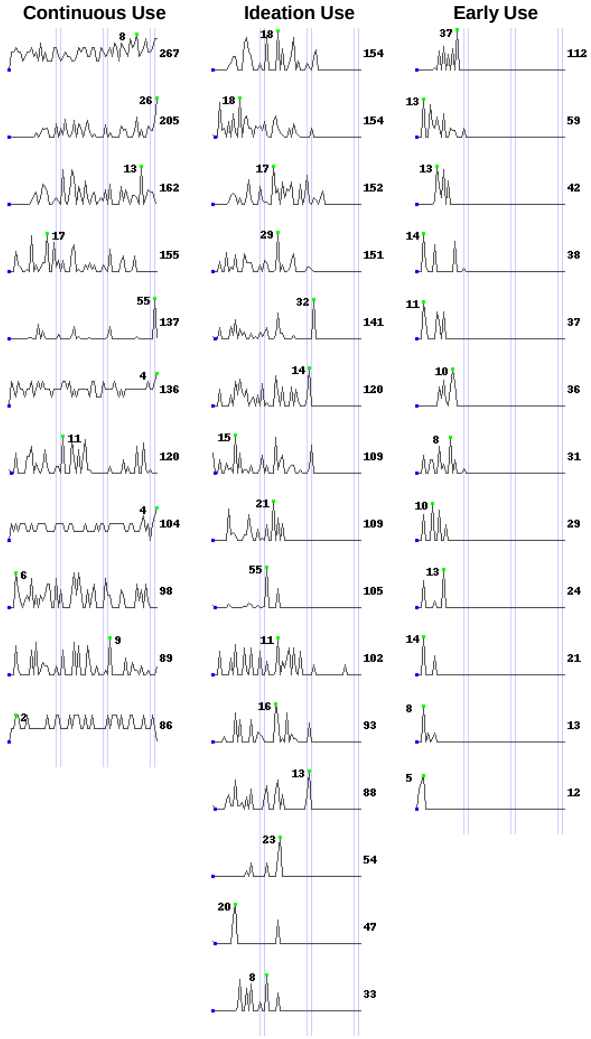

Figure 4. Sparklines showing the number of pages each student completed each day during Study 2, with the total number of pages filled throughout the quarter. Reprinted from [18].

Similarly, digital annotations and photos linked to the digital pages are unavailable in the physical notebook.

In this vein, analysis of the notebooks from the second study found cases of asymmetry, where students pasted in *different* images to their digital and physical notebooks, creating two slightly distinct versions: one with digital "extras" and the other with physical extras. This asymmetry in storage was also found in between digital repositories. In the second study, 194 images were pasted in to the digital notebooks, contributed by sixteen distinct users. Many students also uploaded photos to Flickr, a photo-sharing site. At the end of the quarter, there were a total of 550 images posted and tagged for the course, with contributions from 24 distinct users.

The coexistence of asymmetric representations, with physical materials pasted into the physical notebook while digital references are inserted into the vir-

tual, points towards another question: which, if any, is the "real" notebook? We believe that both the physical and digital representations will likely continue to serve complementary roles in design. In our studies, students appeared to maintain multiple distinct repositories of design content, moving media between them as the need arose. Tools like iDeas that augment paper lower the threshold for these transitions, thereby encouraging more mixing of media from different sources.

5. Design responses

Our observations led us to two conclusions. First, the benefits introduced by integrated systems should outweigh the overhead—such as poor pen ergonomics and syncing—that arises from integration with digital tools. Second, the need for lightweight collaboration presents a powerful opportunity for integrated tools. We outline two design responses below.

5.1. Mash-ups

These studies reinforced the importance of creating ubiquitous computing technologies that fit into *existing digital practices* wherever possible [9, 13]. As noted earlier, photo sharing on web sites such as Flickr is common among students. Importing photos into iDeas thus meant that students had the additional burden of maintaining two distinct image repositories. We redesigned iDeas to use Flickr as our photo store, integrating Flickr into the ecology to leverage its photo sharing and annotation capabilities. In the era of the service-oriented Web, we foresee *mash-up software* playing an important role in the integration of digital practices. Mash-up software allows new systems to incorporate the functionality of existing services into new digital practices.

5.2. Group notebooks

Our analysis suggested two potentially valuable directions for further research into augmented paper interactions: group practice and reflective activity. While personal and collocated practices are well-supported by traditional technologies, the physical/digital divide is more problematic for remote group activity. The realities of campus space imply that student teams in design classes often work in personal spaces and collaborate both remotely and asynchronously, coming together for team meetings. Learning and reflection suffer from a similar media break: while reflective artifacts such as reports and portfolios are usually composed electronically, early artifacts in the design process are often physical.

Augmented paper interactions are well-suited to filling both of these needs. Augmented tools can provide a lightweight, persistent mechanism for sharing—significantly less burdensome than meeting in person to share content with teammates or scanning paper documents. This in turn can help establish and maintain a shared context for remote design teams, including student project teams. Integrating physical and digital tools also opens up new avenues for epistemic communication and reflective activity. In addition to providing persistent common ground for groups in the midst of projects, an ecology of augmented tools can facilitate the creation of status updates, project reports, and electronic portfolios by highlighting vital content gathered over the course of a project. Such an ecology can provide the ability both to *capture* design activity more effectively using physical tools and to better *organize* and *share* design content using digital tools.

In response to these issues, we have introduced into iDeas a *group notebook*, which provides for explicit content sharing among team members (see Figure 5). Conceptually, group notebooks are shared digital repositories, similar to text-based Wikis but incorporating sketches and other media. Group notebooks can be used to share design content with group members and project mentors, to preserve important data for later retrieval, or to produce rich yet lightweight documentation of team activities.

Designers may place content from their personal notebooks, whiteboards, or any other sources (*e.g.*, links, text, documents) into the shared space. This pasting may be done either by gestural command on a captured writing surface such as a notebook, or by digital selection and tagging in the ButterflyNet browser. Later, group members may review the contents of the group notebook through the browser. The digital nature of the notebook allows users to add hyperlinks and to view content in a number of ways: sorting or filtering by date, by contributor, by tags, *etc.* Users

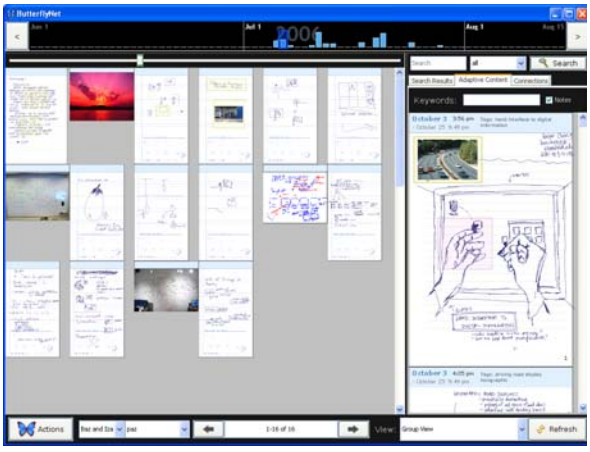

Figure 5. Group notebook view in the ButterflyNet browser. The group notebook contains heterogeneous content (photos and notes) contributed by different team members.

may also create custom orderings of shared content to suit their own perspectives or mental models. By exporting views of key group data, group notebooks enable both informal and formal presentations.

6. Related work

This research draws from prior work in three main areas: augmented paper interfaces and physical-digital hybrids, sketch-based tools, and tools for education.

6.1. Augmented paper interfaces

There is a growing body of research on integrating physical and digital interactions, and in particular on augmented paper. Mackay *et al.*'s augmented laboratory notebooks [17] showed the importance of taking advantage of human abilities and current physical practices when designing new technologies [9, 13]. NotePals [8] introduced the idea of shared electronic repositories for digital note-taking.

Several projects have explored the ability for augmented paper to provide lightweight integration with digital media. The Audio Notebook [23] introduced a paper notebook augmented with audio feedback, an early example of using paper as a query interface. The Designers' Outpost [14] augmented existing paper-based work practices by directly integrating physical and digital interactions through computer vision. Paper PDA [12] and PADD [10] allowed paper users to take advantage of electronic capabilities via synchronization. ButterflyNet [26], integrated paper notes and digital photographs into a capture and access system for heterogeneous media, and is used as the browser component of iDeas.

Our studies of the iDeas ecology extend prior work on augmented paper interfaces in three ways. First, this paper presents more longitudinal studies than have previously been reported about augmented paper tools, offering research insights from and design implications for longer-term usage. Second, these studies explore augmented paper interactions in the context of design. Third, these studies informed new affordances for sharing, visualization, and annotation of heterogeneous content in a collaborative context.

6.2. Sketch-based tools

Traditionally, interactive systems have addressed the processing and manipulation of "structured" content such as word processing, email, and web browsing. Learning technologies—from graphing calculators to electronic portfolios [6]—have generally followed this trend, though there have been some investigations of tools for creative, sketch-based content. One such tool, DENIM [16], introduced a sketch-based tool for informally prototyping web interfaces, highlighting the potential for using sketch-based tools for design thinking and the need to preserve the informal, free-form nature of the design process. Another inspirational system was Classroom Presenter [1], a system for digital ink annotation of lecture slides using Tablet PCs. Like iDeas, Classroom Presenter was deployed in university courses spanning several months, and evaluated with surveys and analyses of digital ink practices. Researchers found that users had a propensity to respond to new affordances by ignoring them, echoing our result concerning cost/benefit ratios and adoption.

6.3. Ubiquitous technologies in classrooms

Ubiquitous technologies are becoming prevalent at all levels of education. In the U.S., 28% of all school districts offered handhelds for student use in 2005 [2]. In terms of purchasing, one of every four computers bought by schools is a laptop [2]; some colleges are even presenting the incoming freshman classes with iPods. Presence alone, however, is not sufficient for performance gains, as Pea and Maldonado discuss in their review of successful classroom activities with wireless interactive learning devices [20]. Their survey and taxonomy describes how the integration of these handheld technologies into the curriculum varies from little relationship to a strong dependency, and how few projects concentrate on group work as a central component of students' learning: commercial applications focus primarily on the needs of school districts, administrators, and teachers. While collaborative learning is a valuable knowledge acquisition modality [19], many innovations concentrate on providing better access to traditional lectures (*e.g.*, [1, 3]). The iDeas research contributes to both these areas: by tying technology development to the curriculum and students' activities, and by scaffolding collaborative tasks as central to the learning experience.

7. Conclusions and future work

This paper has contributed two longitudinal studies of an augmented paper system—the iDeas ecology—in the context of design education, the first longitudinal study of this class of interface in the literature. Data was collected through observations, server logs, questionnaires, interviews, and analyses of notebook content. These studies found the benefits of the system to be fluid incorporation of paper content into digital documents and an integrated repository for sketches and photographs, and prompted us to create new models of sharing to support emerging practices. There were also significant barriers to use. Augmented paper interactions for designers work best as calm technology [14], yet research prototypes, almost by definition,

are more brittle, and less calm, than a production system might be. We suggest that longitudinal studies still have significant import in emerging domains, but that the un-calmness of prototypes may depress usage.

In future work, we plan to increase the reach and utility of the iDeas ecology by integrating additional design artifacts, including walls and whiteboards (prominent physical tools in the designer's arsenal) and mobile devices (increasingly digital parts of everyday life). We will also implement future components of the iDeas ecology as web applications rather than desktop applications, to reduce the overhead of software installation and maintenance. Finally, we will continue to observe the evolution of the designer's information ecology. As digital tools and hybrid technologies become more commonplace, they will likely have profound effects on how designers create, share, and think about design.

The iDeas software is open source, and is available at _____.

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