UNIVERSITY OF CALIFORNIA, SAN DIEGO

Public Digital Note-Taking in Lectures

A dissertation submitted in partial satisfaction of the
requirements for the degree
Doctor of Philosophy

in

Computer Science and Engineering

by

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2009

The dissertation of Roshni Malani is approved, and it is acceptable in quality and form for publication on microfilm and electronically:

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University of California, San Diego

2009

DEDICATION

To my beloved family.

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ACKNOWLEDGEMENTS

I cannot begin to express the depth and sincerity of my gratitude to my advisor, Bill Griswold. From our first meeting and in every conversation thereafter, you have listened to me, you have been patient with me, you have supported me, and you have guided me. You have challenged me when I am confident in my ideas and have encouraged me when I am not. You have helped me weigh the benefits and consequences of my decisions. Your unfaltering faith in my abilities and your constant championing of my work has been invaluable. Your insight and vision has driven much of this work. You have shared so much of your wisdom with me. I am forever grateful to you, Bill.

Thank you so very much, Beth Simon, for sharing your constant enthusiasm, amazing energy, and sage advice with me. Your daily experience with and intuition of classroom technologies, has greatly influenced my thesis. Thank you for being an avid advocate of Ubiquitous Presenter. Beth, I aspire to be as extraordinary of a teacher as you are.

I am very thankful to my other committee members. Thank you, Jim Hollan, for guiding my understanding of human cognition and how it can be distributed, for allowing me to participate in your lab meetings, and for exposing me to emerging digital paper technologies. Thank you, Jim Levin, for enlightening me about how human learning can be distributed and for providing me with invaluable references to related work. Thank you, Akos Rona-Tas, for clarifying various social research methods. I truly appreciate the different perspectives that you have all brought to my dissertation.

I am indebted to all the users of Ubiquitous Presenter, instructors and students alike. In particular, my heartfelt gratitude extends to Beth Simon, Akos Rona-Tas, and Ed Price for permitting my experiments in their classrooms. I am also very thankful to all those that have contributed to the design, development, and evaluation of Ubiquitous Presenter, especially Krista Davis, Michael Kelly, Tammy Denning, Erik Buchanan, David Lindquist, James Lintern, David Ouyang, Aaron Heiber, Mark Kinsella, Aaron Presley, and Micha Heffron.

Thank you, Geoff Voelker, for helping me through a very difficult turning point in my research direction. Thank you very much, Alex Thornton, for instilling the idea of graduate school in my head and motivating me through the toughest times of self-doubt. Thank you, Dick Taylor, for giving me the opportunity to do research as an undergraduate.

My fellow graduate students have commiserated and celebrated with me, helping me survive the ups and downs of research. Thank you so much, Lisa Cowan, for your enduring friendship. Thank you, Ross Tate, for always cheering me up. Thank you, Elizabeth Bales, for being so sweet. Thank you, Krista Davis, for becoming a dear friend while we collaborated on NoteBlogs. I am also sincerely grateful to Brynn Marie Evans, John McCullough, Diane Hu, Shiaokai Wang, Roy Liu, Pat Rondon, Macneil Shonle, Tim Sohn, Kevin Li, Nathan Bales, Barry Demchak, Patricia Shanahan, Laura Pina Rosenzweig, and Vanessa Evans. I am very thankful to my dear friends, especially Christin Hwang, Wendy Qiu, Tina Perng, Yennie Chen, Bindya Shah, and Ratha Chea.

Lastly, but most importantly, I thank my family. My parents, Chandrakant and Rajkumari Malani, inspire the best in me. Thank you, Mom and Dad, for your love and your patience. My brother, Prakash Malani, has always encouraged me to challenge myself. Thank you, Bhaiya, for giving me perspective when I need it the most and for showing me how to achieve anything I want by just focusing every element of myself on it. I don't think I'll ever be able to fill your big shoes, Bhaiya, but I will keep on trying. I am very appreciative of my sister-in-law, Clare Malani, for always believing in me. My precious nephews, Arun and Yash Malani, always put a smile in my heart and made this journey worth it.

Thank you, all.

This work was supported by equipment donations from Hewlett-Packard and Livescribe, by a gift from Microsoft Research External Research and Programs (MSR ER&P), and by a National Science Foundation Course, Curriculum, and Laboratory Improvement (NSF CCLI) grant (DUE-0618511).

Chapter 4, in part, is a reprint of the material as it appears in NoteBlogging: Taking Note Taking Public. Roshni Malani, Beth Simon, K. M. Davis, William G. Griswold, and Michael Kelly. In SIGCSE 2008: Proceedings of the Special Interest Group on Computer Science Education Technical Symposium, pages 417–421, ACM press, March 2008. The dissertation author was the primary investigator and author of this paper.

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K. M. Davis, Michael Kelly, Roshni Malani, William G. Griswold, Beth Simon, "Preliminary Evaluation of NoteBlogger: Public Note-taking in the Classroom", *Proceedings of the 2nd Workshop on the Impact of Pen Technologies in Education (WIPTE)*, June 2007.

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Tamara Denning, Michael Kelly, David Lindquist, Roshni Malani, William G. Griswold, Beth Simon, "Lightweight Preliminary Peer Review: Does in-class peer review make sense?", *Proceedings of the Special Interest Group on Computer Science Education (SIGCSE) Technical Symposium*, March 2007.

ABSTRACT OF THE DISSERTATION

Public Digital Note-Taking in Lectures

by

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Doctor of Philosophy in Computer Science and Engineering

University of California San Diego, 2009

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Note-taking during lectures is a predominant activity among students. An analysis of current technologies in the classroom using cultural-historical activity theory and social constructivism yields pedagogical opportunities and design challenges. Digital notes provide for low-cost, networked notes that are embedded in lecture materials and extend beyond the classroom. Making notes public allows all students to benefit from individual, selfish actions with minimal cost of sharing. We hypothesize that public digital notes do not disrupt existing classroom dynamics and ingrained note-taking practices and enable active learning, peer learning, and inquiry learning, while sustaining attention, maintaining interest, and minimizing distraction. Public digital notes are democratic in nature and motivating to students.

The design space of public digital note-taking includes several dimensions: (1) the form factor can vary based on available technologies, (2) the time of sharing can either be during or after lecture, (3) the percentage of students generating content can vary, and (4) the direction of information flow relative to lecture can also vary. The scope of sharing always includes all of the students in the class. We explore the breadth of this design space with three different projects. (1) NoteBlogs are notes taken by a few self-selected students using Tablet PCs on top of instructor prepared slides. These notes are shared instantaneously during lecture. (2) Collaborative SearchNotes bring outside resources into the lecture. All students can search for lecture terms on the Web and view their peers'

findings. (3) Integrative Notes are written with a digital pen on digital paper and imitate traditional student note-taking as closely as possible. This project explores the benefits of superimposed versus juxtaposed notes shared publicly after lecture. These projects support the traditional flow of information from inside the classroom to outside. Also, NoteBlogs supports information flow within lecture and SearchNotes supports the reverse flow from outside to during lecture. User studies of each of these projects suggest that some students will produce content, while the majority will consume the content. Yet, we find that the process of sharing is beneficial to both producers and consumers, whether as a means of explanation, self-expression, or reassurance.

Chapter 1

Introduction

> Man differs from animals in that he can make and use tools. [These tools] not only radically change his conditions of existence, they even react on him in that they effect a change in him and his psychic condition. [Lur28]

Early Russian cultural-historical psychologists make this well-known assertion about tool mediation. A tool, or *artifact*, is "an aspect of the material world that has been modified over the history of its incorporation into goal-directed human action" [Col96]. Mediating tools include the physical, such as hoes and axes, and the psychological, such as language and speech. Language, in particular, lets us "deal with things that [we] have not perceived even indirectly and with things which were part of the experience of earlier generations" [Lur82]. Another distinguishing characteristic of humans is our ability to accumulate these tools across generations. As Michael Cole summarizes, cultural-historical psychologists believe that "in addition to using and making tools, human beings arrange for the rediscovery of the already-created tools in each succeeding generation. [...] In the aggregate, the accumulated artifacts of a group—culture—is then seen as the species-specific *medium* of human development. It is 'history in the present.' The capacity to develop within that medium and to arrange for its reproduction in succeeding generations in *the* distinctive characteristic of our species" (emphasis not mine) [Col96].

Language is considered the "tool of tools" that has been used to transmit knowledge across generations for thousands of years. Oral, spoken language, in the form of epic poems, folklore, legends, ballads, and proverbs, has propagated the wisdom gathered by previous generations to the next. Verbal repetition, direct observation, and imitation were the primary modes of learning in prehistoric times. As the skills of ancient civilizations became more complex, apprenticeships and guilds emerged as formal structures for training. Since the emergence of writing systems over 6,000 years ago, information expressed in a language could be recorded persistently and retrieved accurately, independent of the initial formulation. Language mediates social activity (by enabling participants to coordinate their actions) as well as mental activity (through internal discourse). Language also encodes the experience with and knowledge of the use of all other tools. Thus, the advent of language has enabled modern humans to have "far more complex forms of knowledge accumulation, more efficient enculturation, and more complex social organization" [Col96].

1.1 Lecturing and Note-Taking

The primary method for using language to disseminate knowledge is *lecture*. Deriving from the Latin *lectus*, meaning "to read aloud," the lecture method often consists of oral reading of a text, followed by some interpretation. As Figure 1.1 demonstrates, the ideology of schooling, intelligence, learning, and classroom practices have remained largely unchanged over the last 6,000 years. In the photograph, rows of desks fixed in stone undeniably face forward towards where the instructor must have stood, guiding them in the repetitive tasks of writing. Instead of inkwells, the classroom contains bowls of wet clay, used to refresh tablets containing notes imprinted in a proto-cuneiform script. Thus, the activities of teacher and students, the architecture of the classroom, and the organization of the learning activities from the very earliest schools are surprisingly similar to that of today.

What is the intended purpose of this lecture format? According to Bligh [Bli00], the commonly held opinion is that lectures are most suitable for conveying information or facts from an expert to a novice, yet the available evidence demonstrates that lecture is as effective as other methods of transmitting information, such as discussion sections, laboratories, etc. In addition, Bligh provides evidence to support his claims that lecture is

Figure 1.1: Excavation of an ancient Sumerian classroom [Col05]

a relatively ineffective method to promote thought, inspire interest in a subject, and teach behavioral skills. However, lecture has endured through the ages as a cost-effective means to teach an increasing number of students enrolling in universities.

Just as enduring and pervasive as lecturing is student *note-taking* during those lecture presentations. The practice of writing information on paper while listening to lecture is universally perceived as an important skill for students, the responsibility of students, and the key to academic success [CWD88]. This perception is held by faculty and students alike [HD78].

What is the intended purpose of taking notes? The seminal work of DiVesta and Gray has lead many researchers to believe that (1) note-taking is a process of encoding information during lecture and (2) the resultant notes are a product that stores information for later review [DG72]. Researchers have concluded that both encoding and storage functions are equally important, and both contribute to academic achievement [Kie87]. Both functions of note-taking are useful for (1) aiding memory and recall, (2) understanding the organization and structure of topics presented, (3) identifying the important information, and (4) maintaining attention [Bli00].

Although student note-taking is such an ubiquitous activity, most students are not explicitly taught how to take notes. A survey of 223 University of Georgia students revealed that 99% of them took lecture notes but only 17% had received any formal instruction in note-taking [PB74]. As a result, students generally capture a relatively small percentage of critical lecture ideas [Cra25a, Kie87]. In addition, the work of Van Meter et al. revealed that although students claimed to be proficient at interpreting the instructor's cues about important material in a genetics course, a thorough examination of their notebooks indicated a failure to notice two important cues (one about the importance of figures and the other about classic genetic experiments). Furthermore, even though the students claimed to modify their note-taking techniques according to the demands of the course, interviews of the students uncovered that most of their strategies for improvement were idiosyncratic, hit-or-miss attempts [VYP94].

The majority of these studies on note-taking have been performed by educational psychologists, most of whom presume that note-taking is a solitary student activity, performed in intellectual isolation from others. This presumption is valid given the currently ubiquitous technologies of pen and paper and the widespread popularity and tradition of private note-taking. Furthermore, students may prefer to take their own notes for selfish reasons such as (1) they do not trust the note-taking abilities of their peers, who are likely also novices in the field of study, and (2) they value the opportunity to paraphrase what they are hearing and reading as a way to reinforce their own understanding. Despite the rational justifications for students taking individual notes, the fact remains that educational psychologists who have studied this behavior have found evidence that students are not as good at note-taking as they perceive themselves to be. Theories of cognition and learning, such as activity theory and social constructivism (presented in Chapter 2), indicate that many *pedagogical opportunities* exist for improving the metacognitive skills of student note-takers.

1.2 Technologies for Lecturing and Note-Taking

Technologies, like language, are tools created and used by humans that have accumulated and evolved across generations. The field of computer science has generated both hardware and software tools. The cultural psychological perspective reminds computer scientists to consider how these tools mediate human activity and to study how the introduction of new tools changes existing mediation mechanisms.

Over the past few centuries, while the lecture format has persisted relatively unchanged, technologies for lecture presentation have continually evolved. With the invention of the printing press, scholars did not need to spend enormous amounts of time laboring over the replication of valuable texts, and instead could travel from place to place reading the texts to the masses. Approximately 200 years ago, the invention of blackboards allowed instructors to share text and drawings with their students, thus conveying visual information in addition to auditory information for the first time. Another leap in instructional technology came about 50 years ago with the invention of cheap projectors, such as slide projectors and overhead projectors. The major benefit of projectors is the ability to share pre-prepared materials, which can be reused. Projectors also allow the educator to face the students (thus facilitating better communication) and provide a more comfortable, natural writing position. Approximately 10 years ago, slide preparation programs, such as Microsoft PowerPoint, decreased the amount of labor involved in the preparation of visual information and facilitated sharing amongst educators.

In contrast, technologies for the activity of student note-taking have made little progress. Individual students have been recording their own thoughts and interpretations with chisels on stone or clay tablets, with pens on papyrus scrolls or parchment, and more recently, with pencils on paper. The writing surface may be loose leaf sheets or bound in a notebook, blank or lined, part of the course textbook, or have some background content (such as the lecture's presentation material) to minimize the amount of writing. The writing implement may come in different colors and may be augmented with highlighters. Even with the advent of inexpensive duplicating machines, such as scanners, printers, and photocopiers, which equip instructors to provide students with copies of detailed lecture notes or allow students to share their notes with each other, the archaic practice of recording and reviewing notes solitarily continues to be pervasive.

The metaphor of an *ecology* provides an interesting perspective on the development of technologies for lecturing and note-taking. According to John Seely Brown, an ecology is "an open, complex, adaptive system comprising elements that are dynamic and interdependent. One of the things that makes an ecology so powerful and adaptive to new environments is its diversity" [Bro02]. Bonnie Nardi and Vicki O'Day also evoke this metaphor to understand the evolving role of pervasive, distributed technologies in society. They propose the concept of an *information ecology* with the following properties: (1) it is a complex system of parts and relationships, (2) it exhibits diversity and experiences continual evolution, (3) different parts of an ecology coevolve, changing together according to the relationships in the system, (4) several keystone species necessary to the survival of the ecology are present, and (5) it has a sense of locality and habitation. The metaphor evokes engagement and participation in the construction of an ecology as well as the sense of urgency in maintaining its fleeting state [NO00].

In his article "Growing Up Digital: How the Web Changes Work, Education, and the Ways People Learn," Brown proposes the concept of a *learning ecology* to understand the role of the Web-based technologies and the changing way in which they mediate every aspect of our lives. A learning ecology in the era of the Web is "a collection of overlapping (virtual) communities of interest, cross-pollinating with each other, constantly evolving, and largely self-organizing." Brown argues that the following three properties of the Web create a new medium for learning and distributed intelligence: (1) it is a "two-way, push *and pull*, [in that] it combines the one-way reach of broadcast with the two-way reciprocity of a mid-cast", (2) it is the "first medium that honors the notion of multiple intelligences, [such as] abstract, textual, visual, musical, social, and kinesthetic", and (3) it "leverages the small efforts of the many with the large efforts of the few" [Bro02]. Thus, the Web is an ideal medium for building student-oriented technologies that implement the principles of modern theories of cognition and learning. The technologies have the capacity to empower students to become more actively engaged in and motivated about their learning, regardless of the instructor's ideologies. The emergent properties of the Web, as characterized by

Brown, motivate a clear opportunity for the development of computing technologies that support and encourage student note-taking in the ecology of university lectures.

The design of Web-enabled note-taking technologies must support all of the functions described above, including capture during lecture and access after lecture. Orthogonal functions of manipulation (adding, deleting, editing, organizing, and searching notes) and collaboration across time and space must also be supported. The design of these technologies face some *challenges*: (1) ubiquitous, inexpensive hardware technologies must be used, so that all students can afford to use it, (2) the technology must be simple to learn and easy to use, because students are already cognitively overloaded with the task of comprehending new lecture material, and (3) technologies that involve the aggregation of student-generated content must scale well.

1.3 Public Digital Notes

Based on the observations above and on the principles of activity theory and social constructivism, we hypothesize that what we call *public digital note-taking* supports active learning, peer learning, and inquiry learning, while sustaining student attention and maintaining their interest. Public digital note-taking is the sharing of individual student notes capture electronically with everyone in the classroom. All students in the class may view and contribute to the public digital notes, which are embedded within the instructor's prepared materials and may extend beyond the classroom. *Public* notes enable students to benefit from each other's different perspectives and to improve their metacognitive skills. *Digital* notes can be easily and quickly edited, reorganized, searched, copied, and shared. Thus, public digital notes are democratic in nature and motivating to students. In addition, public digital notes do not disrupt existing classroom dynamics and ingrained note-taking practices. Emerging technologies that emulate handwriting interfaces and that leverage the affordances of paper are becoming cheaper and smaller. Embedding public notes in lecture materials also minimizes distraction. A brief review of recent research reveals that the design space of public digital notes has yet to be fully explored. Some dimensions of this design space include form factor, the time of note sharing, the percentage of students generating content, and the direction of information flow. We present three different projects that explore various aspects of this design space, from sharing notes live during lecture to incorporating search results into lecture materials.

1.3.1 Hypothesis

Note-taking technologies must support capture of new information and access for later review, while allowing for easy reorganization and cooperation. All of these functions can be provided effortlessly by *digital* notes, that is, notes recorded using a computing device, such as a Tablet PC, a PDA, or a digital pen. The computational affordances of digital notes enable sharing of individual notes with little overhead. *Public* notes may benefit all students in the classroom by using networked technologies to share notes. These notes should be embedded in lecture materials to minimize distraction and may extend beyond the content presented during lecture to provide a broader context for learning.

The fundamental hypothesis underlying this thesis is that public digital notes (1) do not significantly change ingrained note-taking practices and existing classroom dynamics, (2) support pedagogical practices, and (3) consider the student perspective. Note-taking in lectures is a practice that has evolved over thousands of years and appears resistant to change. We claim that public digital note-taking is more likely to succeed if it minimizes the amount of change introduced into the classroom. Additionally, technologies for public digital notes should strive to facilitate pedagogical practices based on theories of cognition and learning, such as activity theory and social constructivism. These theories advocate active learning, peer learning, and inquiry learning. And finally, the design of public digital note-taking technologies should consider the student perspective, by sustaining their attention, maintaining interest, providing motivation, and minimizing distraction during lecture. Students are already cognitively overloaded during lecture, and new technologies that integrate smoothly into their natural habits will minimize any additional cognitive load.

1.3.2 Design Space

The design space of public digital notes consists of at least the following four major dimensions: (1) form factor, (2) time of sharing relative to lecture, (3) percentage of students generating content, and (4) direction of information flow.

The form factor of public digital notes includes the physical size, shape, and weight of the hardware technology used, and the power consumption and network connectivity. For example, a Tablet PC in comparison to a digital pen consumes a lot more power and is significantly heavier, but provides more computational power and wireless network access. A more generic laptop might tend to be smaller, but does not provide the affordances of a handwritten interface. Form factor is a very important dimension to consider because most students often carry the technology all day and use it in the confined space of modern lecture chairs, which are bolted in neat rows, have small desks, and limited or no access to electrical outlets.

When the notes are shared relative to lecture is another design dimension of public digital notes. Most notes, with some amount of effort, can be shared after lecture. For example, notes captured with a digital pen can easily be transferred to a computer connected to the Internet. In contrast, technologies that provide easy access to wireless networks during lecture, such as laptops and Tablet PCs, can enable the instantaneous sharing of notes. The time of sharing, that is, when the digital notes are made public, may influence the content and nature of the notes themselves.

The percentage of students in lecture who are generating public digital notes can vary. This percentage depends on the affordability and ubiquity of the note-taking platform, as well as the nature of notes. For example, small Post-It-sized notes generated by all students may be more feasible to review compared to lengthy freeform notes from all students. Additionally, the relative percentage of students generating content affects the design of how software aggregates and presents the public digital notes.

The final design dimension to consider is the direction of information flow relative to lecture. Traditional note-taking involves the transfer of information from inside the classroom to outside: students capture content during lecture and review it later outside of the classroom. Another possible flow of information may occur from outside the lecture to inside, for example, when students read the textbook prior to lecture and reference it during lecture. Furthermore, information can flow from student to student within lecture, for instance, when students communicate with each other during lecture.

1.3.3 Prior Work

Research on technologies that explicitly support note-taking activities in lectures has focused on providing notes that are either superimposed on or juxtaposed with prepared lecture slides. Most of these technologies have focused on individual note-taking, some have explored taking small Post-It sized notes, and a few have supported small group note-taking. For example, StuPad and Classroom Presenter support individual student annotation superimposed on lecture slides [TAB99, AMS05]. LiveNotes allows each student to take their own superimposed notes, while concurrently viewing the annotations of a small group of their peers [KWI+05]. This system provides no explicit division of labor or management of space conflicts. NotePals enables students to take small notes during lecture. Afterwards these notes are juxtaposed with the lecture slides and are shared with the entire class [DLC+99]. In contrast to LiveNotes, students using NotePals are unaware during lecture of other students' notes, which minimizes space and content conflicts but may result in duplicated effort.

Interesting research has also been done on different types of note-taking activities, such as while reading or brainstorming, and technologies to support these activities can be adapted easily into the ecology of traditional lectures. Some of these technologies focus on narrowing the gap between physical and digital worlds, while others focus on novel methods to mediate collaboration. Papiercraft allows delayed execution of computing commands (such as copy, paste, link, search, and email) on physical paper using pigtail gestures [LGH05], whereas InkSeine focuses on immediate feedback for in situ search for related material [HZS+07]. In contrast to these systems for individual note-taking, Group-Scribbles provides explicit mediation of collaborative exercises. This system is based on the metaphor of each student holding a pad of Post-It notes and contributing thoughts to a shared whiteboard [RTC+07]. Each of these systems, as well as others, are discussed in more detail and compared in Chapter 3.

Most of these systems support individual note-taking in novel ways. Only NotePals supports *public* notes, which are limited in size and shared after lecture. What happens when notes are shared during lecture? How can technology encourage students to gather and share different resources during lecture? What is the tradeoff between affordable, lightweight technology and the time at which notes are shared?

1.3.4 Specific Projects

We explore the design space of public digital notes with three different tools: NoteBlogs, Collaborative SearchNotes, and Integrative Notes. Table 1.1 provides an overview of where each technology is located along the various design dimensions.

Table 1.1: Dimensions of public digital notes

	NoteBlogs	SearchNotes	Integrative Notes
Form Factor	tablet	laptop	digital pen
Availability	live	live/delayed	delayed
Communication	few → all	most → all	some → all
Information Flow	in → out in → in	in → out out → in	in → out

NoteBlogs are primarily based on the concept of blogs, which are ongoing narratives or personal diaries that are published on the Web. Blogs provide a medium for communicating thoughts and feelings, and a forum for reflecting on experiences. Traditional notes could similarly be viewed as ongoing personal narratives, and can be published instantaneously on the Web. The NoteBlogging application, designed for a Tablet PC, enables a small percentage of self-selected students to share notes taken on top of instructor prepared slides immediately. These notes are shared live during lecture, and all students can view them during class, creating a flow of information amongst students within lecture. Thus, all students can benefit from the thoughts and reflections of a few students.

Collaborative SearchNotes is based on the metaphor of collecting relevant resources in a shared place when investigating a new topic. This technology aims to integrate resources that are easily accessible and searchable on the Internet as part of the lecture content. All students can cooperate to find and share relevant resources. Collaborative SearchNotes enables all students who have a laptop or other Web-enabled device to bring outside resources into lecture.

Finally, Integrative Notes aims to mimic traditional student note-taking as closely as possible, using the familiar form factor of digital pen and paper. Individual notes taken by self-selected students are shared after class in the context of lecture slides. This technology explores the tradeoff between form factor and time of sharing.

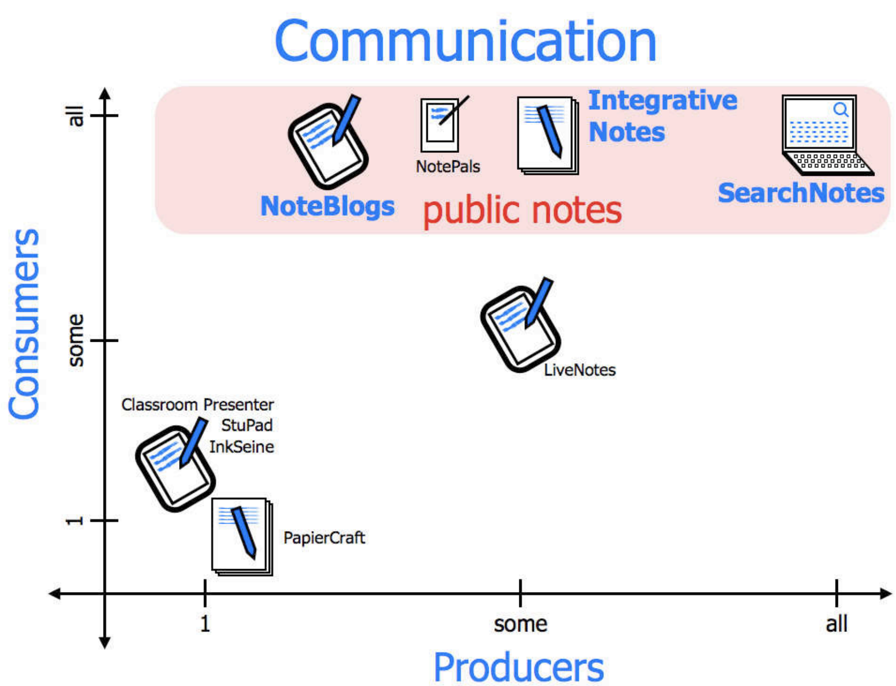

Figure 1.2: Communication aspect of public digital note-taking

These three projects span the breadth of the public digital note-taking design space, exploring aspects of communication and sharing that have not been researched extensively yet. Figure 1.2 presents the communication aspect of public digital note-taking. The horizontal axis is how many students are producing, or taking, notes and the vertical axis is how many students are consuming, or reviewing, those notes. Each work is plotted on this chart, with an icon of its form factor. For example, NotePals enabled a few students to take notes on PDAs during class, and allowed all students to review after class by posting the notes next to the lecture slides on a Web site. As another example, LiveNotes allowed a small group of students to take notes during class using a Tablet PC, but only that small group of students could review the notes afterwards. As the figure demonstrates, the projects presented in this work span the space of public notes, that is, the space where all students in the class consume and review the notes. Furthermore, all three projects use different form factors, which in turn, effects the number of students who can produce notes.

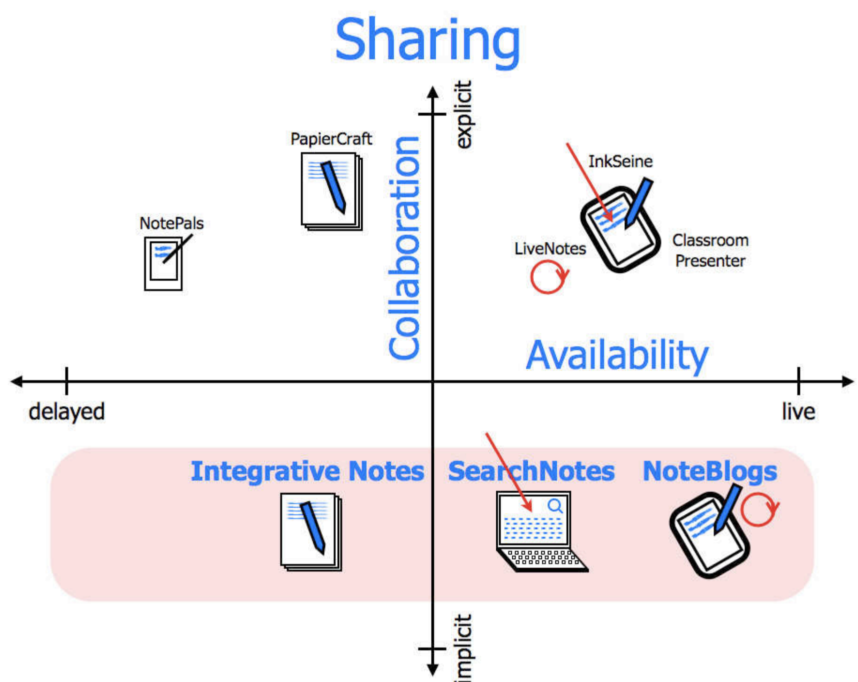

Figure 1.3: Sharing aspect of public digital note-taking

Figure 1.3 presents the sharing aspect of public digital note-taking. The horizontal axis represents when the notes are made available for sharing, whether delayed until after lecture or live during lecture. The vertical axis depicts whether the collaboration around the shared notes is explicit or implicit. Explicit collaboration is when the notes of one student directly affects the content of another student's notes, which in turn may affect the original student. Implicit collaboration is when a student takes note of what he/she thinks is important, with little concern for the effect that note may have on other students. Most prior work has studied explicit collaboration, whereas the work here is more concerned with means of implicit collaboration. Another thing to note about this chart is the red straight and circular arrows. When notes are shared live during lecture using a Web-enabled device, such as a Tablet PC or laptop, other flows of information may result. In traditional note-taking, information generally flows from within lecture where it is captured and stored to outside of lecture for later review. In contrast, InkSeine and SearchNotes emphasize and encourage the opposite flow as well, that is the bringing in of information from outside lecture to within lecture. LiveNotes and NoteBlogs allow students to share their own interpretation of lecture material, creating a new flow of information within lecture.

The purpose of this thesis is to examine the breadth of possible ways to instantiate the idea of public digital note-taking by building many systems, rather than to examine one particular system in depth. We want to evaluate what can happen, rather than quantify what does happen. Learning is a highly dimensional phenomena with too many factors to control. For example, students try to strike a balance between what grade they are willing to receive, how much time and effort they can spend on that particular class, and how confident they are with the material. They try to minimize their grade anxiety and any other risks they perceive. In this dissertation, systems for public digital note-taking are designed, developed, and deployed in actual lecture settings. The goals is to find qualitative data that suggests any changes in student behavior or in student perceptions. The data for each of these projects involves an analysis of the content of the notes, a survey of all the students in the course, and interviews with a select number of students. This qualitative data is an important precursor to end-point quantitative measures.

1.4 Contributions of the Thesis

This dissertation establishes the pedagogical opportunities and design challenges of the prevalent student note-taking practices in traditional lectures, motivates and defines a design space for public digital notes, and presents three projects that explore the design space. In particular, the contributions of this thesis are:

1. *The motivation for public digital notes, based on pedagogical opportunities and technological challenges.* Pedagogical opportunities arise from the discrepancy between what the prevailing student note-taking practices actually are and what the contemporary theories of cognition and learning, such as activity theory and social constructivism, imply that they should be. Technological design challenges stem from the ecology of lectures, with large numbers of students who may all participate only if the technology is ubiquitous, inexpensive, and does not add much cognitive load.

2. *The formulation of a design space for public digital notes in terms of four dimensions of interest.* These dimensions are form factor, time of sharing, percentage of students generating content, and direction of information flow. The design space, considered in at least these dimensions, delineates interesting aspects of public digital notes and directs the development of different projects that explore this space.

3. *The development and evaluation of three different technologies that span the design space.* I developed a full scale deployment of Collaborative SearchNotes and created an experimental setup of Integrative Notes. I evaluated all three public digital note-taking technologies in authentic lectures covering a variety of subjects, including computer science, physics, and social science.

4. *A set of guidelines for the development of student-oriented technologies and for their successful adoption in the classroom.* These guidelines include designing for various student capabilities, allowing for various modes of interaction, and providing outlets for student self-expression and reflection.

1.5 Outline

This thesis is organized into two main parts: (1) the foundation, background, and justification for public digital notes, and (2) the design and evaluation of specific projects that explore the public digital note-taking design space. Chapter 2 provides a comprehensive overview of the theories of learning and cognition that have influenced this work and concludes with an activity theory based analysis of prevailing note-taking practices. Chapter 3 discusses recent note-taking technologies designed for active learning, active reading, group note-taking, and mediated collaboration and concludes with a discussion of the four main aspects of note-taking that technologies should support. The subsequent three chapters detail each of the projects in turn: Chapter 4 focuses on NoteBlogs, Chapter 5 focuses on Collaborative SearchNotes, and Chapter 6 focuses on Integrative Notes. Each of these chapters describes the system design, presents the data collected, and provides a detailed analysis. Finally, Chapter 7 summarizes the key contributions of this thesis and conclude with an outlook on student-oriented technologies in the classroom.

Chapter 2

Cognition, Learning, and Note-Taking

This chapter presents the theories that set the stage and provide the perspective for this dissertation. Theories of cognition and learning, such as activity theory and social constructivism, are essential to the design and implementation of new computing technologies for public digital note-taking. Human-computer interaction is concerned with providing guidelines for developing not just usable computer-enabled tools, but also useful ones. However, the complexities of human information processing and of understanding the relevant context of the interactions are the main challenge faced by this discipline. Theories of cognition and learning provide deeper insights into the ways and the means in which computers can be used for note-taking. Not only do these theories guide the development of the technology, but they also provide a framework for analyzing how the technology is used.

Based on a comparison of cognition theories, cultural-historical activity theory emerges as an invaluable framework for design. This theory argues that human cognitive activity and interactions with the environment are mediated by culturally-constructed artifacts. A survey of some theories of learning reveals that contemporary work advocates social constructivism. This theory asserts that knowledge is not a fixed object; rather it is constructed by an individual through active participation in meaningful contexts based on prior understanding. Pedagogical practices derived from these theories include active learning, peer learning, and inquiry-based learning. The chapter concludes with the application of activity theory to the task of student note-taking during university lectures.

2.1 Theories of Cognition

Cognition, a topic of much interest and study in disciplines including psychology, education, cognitive science, and computer science, is the process of thought and the acquisition of knowledge. Cognition involves processes of sensation, attention, learning, memory, language, thinking, and reasoning. Some theories of cognition, including activity theory, situated action, and distributed cognition, are explained and then compared below.

Activity Theory

The cultural-historical theory of activity is a psychological framework for studying the individual and social aspects of human cognition. The fundamental tenet of this theory is that "the structure and development of human psychological processes emerge through culturally mediated, historically developing, practical activity" [Col96]. Activity theory is a "powerful and clarifying tool, rather than a strongly predictive theory" [Nar95] that seeks to understand everyday practice within a broader historical and cultural context. Inspired by the work of German philosophers Kant, Hegel, Marx and Engels, this theory was primarily articulated and refined by Lev Vygotsky, A. N. Leont'ev, and Yrjö Engeström.

During the 1920s and early 1930s, Vygotsky argued that humans did not merely respond directly to the environment, like many of his contemporary psychologists claimed, but instead that humans' interactions with their environment is mediated by culturally-constructed artifacts, such as physical tools or symbolic languages, as described in the beginning of this chapter. Leont'ev, a disciple of Vygotsky, stressed that human activity is socially mediated, and he distinguished between activity, action, and operation. More recently, Engeström developed a model for an activity system, described in detail below, that extended Vygotsky's representation of mediated behavior by reflecting the collaborative nature of human activity.

An *activity* is a "coherent, stable, relatively long-term endeavor directed to a definite goal” [Ros98]. It is a “form of doing directed to an object, and activities are distinguished from each other according to their objects. Transforming the object into an outcome motivates the existence of an activity” [Nar95]. Furthermore, an activity is the basic unit of analysis and provides “the minimal meaningful context for understanding individual actions” [Nar95].

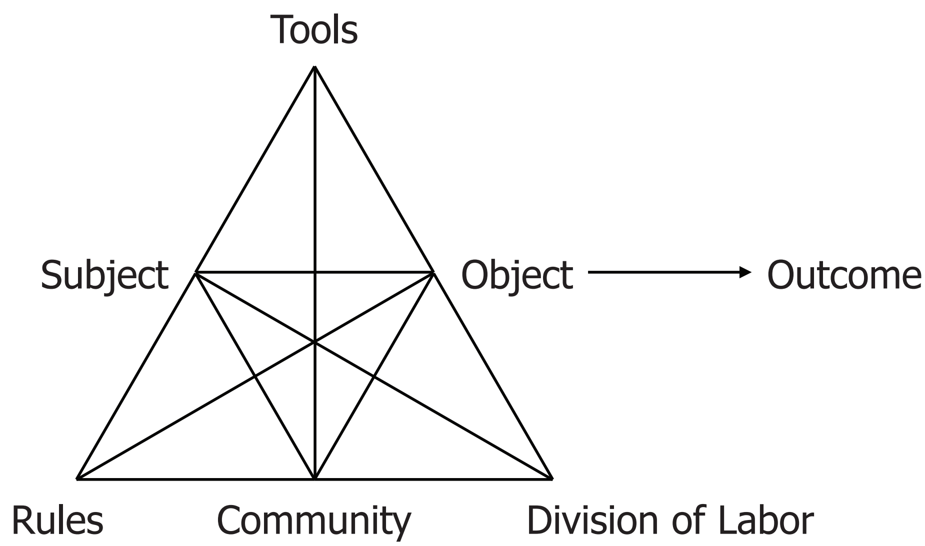

Figure 2.1: Engeström’s Activity System [Eng87]

The structure of an activity is depicted in Figure 2.1. The basic triangular relationship exists between a *subject* (a person) who is motivated toward accomplishing some *object* (outward goal, concrete purpose, objectified motive) using a historically- and culturally-constructed *tool* or artifact. The tools may be physical, used to manipulate objects, or psychological, used to influence behavior. The activity is performed in collaboration with a *community* of others who share the same object. The subject relates to the community via *rules* (explicit conventions or implicit norms), and the community relates to the object via a *division of labor* (explicit or implicit organization of the community related to the objective). The interaction of these elements eventually transforms the object into a desired *outcome*, which motivates the activity [Eng87, Nar95, Col96, Ros98, Mwa02, GH04].

Thus, activities, the fundamental unit of analysis, are conscious, coherent, practical endeavors by human subjects to a definite, concrete goal, mediated by culturally and historically constructed tools. Activity theory also reminds researchers to understand the role of community, the cultural norms and conventions that lie within, and the division of labor involved to complete the activity. As demonstrated in Section 2.4.2, the triangular structure of an activity can be mapped to note-taking, providing a solid foundation for exploring the design of various computer-enabled tools.

Situated Action

The situated action theory of cognition emphasizes the emergent, contingent nature of human activity occurring in a real setting. The focus is on the context or environment in which the activity occurs, and how it affects the nature of the activity. The classic "cottage cheese" example, presented by Jean Lave [Lav88], involves a participant in a weight loss program who was assigned the task of serving three-quarters of the normally alloted two-thirds cup of cottage cheese. Rather than calculate that half a cup is required, the participant "filled a measuring cup two-thirds full of cheese, dumped it out on a cutting board, patted it into a circle, marked a cross on it, scooped away one quadrant, and served the rest." Thus, such *in situ* studies reveal "how people use their circumstances to achieve intelligent action" [Suc87] and the flexible way in which people leverage the affordances of their changing environment. Furthermore, the setting is a critical element, "shaping the structure of the activities, individuals' goals, and the constraints on achieving those goals" [Col96].

When applied to learning, situated learning contends that decontextualized, conceptual knowledge can not simply be transfered from one person to another, but rather knowledge is constructed in a specific, social and physical environment. Bruner argues that "learning and thinking are always *situated* in a cultural setting and always dependent upon the utilization of cultural resources" [Bru96]. An important pedagogical practice that emerges from this theory is legitimate peripheral participation [LW91], which describes how novices become knowledgeable experts in a community of practice through increasing levels of involvement. Access to resources of the community, involvement in productive activity, learning the discourse of the community, and willingness of the community to accept newcomers are all essential to success in a situated learning environment. Furthermore, the perspective of situated cognition encourages problem solving activities to be as authentic as possible, creating motivating scenarios for students to learn difficult concepts. Another important concept that emerges from this theory is the term "affordance," coined by James Gibson [Gib79]. Affordances are properties in the environment that offer possibilities for action and are measurable objectively and independently of an individual's ability to recognize them. Similarly, signifiers are some sort of indicator or signal in the physical or social world that provide critical information. Signifiers may be an accidental byproduct or even unintentional. Perceived affordances and social signifiers have guided many human-computer interaction designers.

Hence, situated cognition theory recommends that the design of note-taking tools encourage students to perceive affordances and receive social signifiers. In addition, the design should allow for some students to participate legitimately in the periphery. Furthermore, the evaluation of such technologies is dependent on the situation under which it is studied, which both enables and constrains student behavior.

Distributed Cognition

The most recent development in cognition advocates that cognition is "stretched across mind, body, activity and setting" [Lav88]. Hutchins [Hut95], in his studies of navigation aboard Micronesian boats, naval ships, and airline cockpits, emphasizes that cognition must be studied occurring in natural human activity in everyday settings, rather than in the confined environment of a laboratory setting. As a result, he discovers that cognitive processes are computational in nature, "realized through the creation, transformation, and propagation of representational states." Cognition extends beyond the confines of the human mind into the "coordination among many structured media—some internal, some external, some embodied in artifacts, some in ideas, and some in social relationships." Thus, the major contributions of this theory of cognition is (1) to examine the structure of the larger system and the transformations that these structures undergo, and (2) to study such cognition "in the wild."

The distributed cognition view of the note-taking process examines the various representations involved. Cognition is spread across the teaching staff, the note-takers, and the artifacts involved, including the textbook, the instructor's prepared materials, the pen and paper notes, the laboratory exercises, the examinations, etc. Thus, technologies should be designed to empower the computational processes involved in transforming the various representations, and evaluated in real classrooms.

Comparison

All three theories of cognition have one important thing in common: all of them recognize the importance of *culture* and *context* in human cognition. According to Cole, culture "comes into being wherever people engage in joint activity over a period of time" [Col96]. According to Hutchins, culture is "an adaptive process that accumulates the partial solutions to frequently encountered problems" [Hut95]. Context is "a unit of culture" that provides the "most immediate frame of reference for mutually engaged actors" [Wen80]. Thus, Cole concludes that culture is the medium and context is "that which surrounds and that which weaves together," providing the basic unit of analysis for cognition.

Bonnie Nardi [Nar95], after examining all three theories of cognition, concludes that "activity theory seems the richest framework for studies of context in its comprehensiveness and engagement with difficult issues of consciousness, intentionality, and history" because it provides a "systematic conceptual framework encompassing the full context in which people and technology come together." An important difference amongst the theories involves the treatment of goals and motives: in both activity theory and distributed cognition, the object or goal precedes, motivates, and determines the activity whereas in situated action, goals are post hoc, retrospective justifications for actions. Thus, Nardi concludes that "it is severely limiting to ignore motive and consciousness in human activity and constricting to confine analyses to observable moment-by-moment interactions. Aiming for a broader, deeper account of what people are up to as activity unfolds over time and reaching for a way to incorporate subjective accounts of why people do what they do and how prior knowledge shapes the experience of a given situation is the more satisfying path in the long run." Furthermore, analyses based on the situated action theory of cognition "make it difficult to go beyond the particularities of the immediate situation for purposes of generalization and comparison," thus "not account[ing] very well for observed regularities and durable, stable phenomena that span individual situations."

In a comparison of activity theory and distributed cognition, Halverson [Hal02] concludes that activity theory provides researchers with more descriptive and rhetorical power, whereas distributed cognition is more inferential and applicable. The key difference is that activity theory provides well-named constructs whereas distributed cognition has few explicitly named constructs. In addition, the focus of activity theory is on the individual, whereas the focus of distributed cognition is on socio-technical systems. Distributed cognition applies the same language to people and artifacts, thus conceptually equating the two. Thus, activity theory, in treating people as sentient, moral beings, has "greater potential for leading to a more responsible technology design in which people are viewed as active beings in control of their tools for creative purposes rather than as automatons whose operations are to be automated away, or nodes whose rights to privacy and dignity are not guaranteed" [Nar95].

Because activity theory provides such well-named constructs, does not equate individuals with artifacts, and focuses on how the activity is motivated, an in-depth analysis of student note-taking in lectures based on activity theory is discussed in Section 2.4.

2.2 Theories of Learning

Learning is the process of acquiring new knowledge, behaviors, skills, and values, often by synthesizing different types of information. Knowledge has traditionally been defined as justified true belief. This formulation traces back to Plato's dialogue *Theaetetus*, in which Socrates discusses how in order to know that a proposition is true, one must not only believe that it is true but also have a good reason for believing so. This belief was widely accepted until the 1960s, when Gettier presented two effective counterexamples, stirring up a large epistemological debate. However, the classic conception of knowledge has led to the predominance of learning as transfer of knowledge, which is augmented by the universal tool of written language.

Another traditional influence is the learning theory of *behaviorism*, in which all human activity, including both publicly observable processes such as actions and privately observable processes such as thinking and feeling, are behaviors. Ivan Pavlov, in his famous experiment involving the salivary conditioning of dogs, found that if a neutral stimulus (such as a metronome) is presented with an unconditioned stimulus (such as food), then an association is formed between the two, resulting in a conditioned response (such as salivation). B.F. Skinner and others also focused on observable cause-and-effect relationships, and viewed the role of an instructor as modifying the behavior of students by creating situations that reinforce students when they exhibit desired responses.

However, over the last 60 years or so, this behaviorist model of learning has been shadowed by the cognitive revolution in psychology, which argued that privately observable processes are not observable behaviors and can be studied experimentally to produce theories that more reliably predict outcomes. The emerging paradigm, known as *cognitivism*, claimed that learners are like information processors, who require active participation and whose actions are a result of thinking. Learning is a consequence of the manipulation of discrete, internal mental states or schemas. Founded by John Dewey, cognitivism advocates that learning is an active process that results from experience. Jerome Bruner contributed that there are two primary modes of though: (1) the narrative mode, in which the mind engages in sequential, action-oriented, story-like thought and (2) paradigmatic thinking, in which the mind forms structures and categories based on propositions linked by logical operators. Jean Piaget describe the four cognitive developmental stages, and asserted that learners adapt to the stimuli in their environment by assimilating (accounting for new information relative to preexisting schemas) and by accommodating (altering existing schemas in light of new information). The shift from studying external behavior to examining internal mental processes however did not lead to a change in instructional design, in that the purpose of instruction remained the communication and efficient transfer of knowledge.

The ideas underlying cognitivism and the foundational work of Piaget instigated the constructivist theory of learning. The essential concept of *constructivism* is that knowledge is not a fixed object, but rather constructed actively by an individual through experiences with that object and based on understandings from past experiences. These experiences are set in socially, culturally, historically, and politically situated contexts, which motivate the learner. Piaget's contemporary Lev Vygotsky insisted that human intelligence is intrinsically social in nature and that individual cognition first occurs in interpersonal communication rather than intrapersonal dialog. According to Vygotsky, cognitive development occurs in the "distance between the actual development level as determined by independent problem solving and the level of potential development as determined through problem solving under adult guidance, or in collaboration with more capable peers" [Vyg78], a concept often referred to as the Zone of Proximal Development. Vygotsky also championed that language and learning inextricably intertwined, claiming that "thought is not merely expressed in words; it comes into existence through them" [Vyg62]. Focusing more on the construction aspect of constructivism, Seymour Papert contributed the idea that learning "happens especially felicitously in a context where the learner is consciously engaged in constructing a public entity, whether it's a sand castle on the beach or a theory of the universe" [PH91]. Thus, learning is essentially perceived as an active and social process and the learner as an autonomous agent who draws upon previous knowledge. The responsibility and the motivation for learning increasing resides with the learner. The role of an instructor shifts from a "sage on the stage" to a "guide on the side" who encourages and nurtures students' natural curiosity to explore a given framework or structure.

An emerging perspective of learning, drawing influence from both activity theory and distributed cognition, is distributed learning. This perspective focuses on capturing the dynamic relationships that mediate discrete landmark representations. The distribution of learning is across space, time, tools, cultures, etc. Both material distribution and social distribution of learning are studied. For example, Karasavvidis [Kar02] illustrates how students solving correlation problems are engaged in different cognitive tasks when using computer spreadsheets versus pen paper. Using computer mediate tools, students were more engaged in interpreting graphs and formulating hypotheses, while students using pen and paper were more focused on the algorithmic process of constructing the graph. Thus, the material distribution of the task fundamentally restructures the cognitive processes involved. Similarly, the social distribution of the task is evident even in the performance of an individual skill: “when the school child solves a problem at home on the basis of a model that he has been shown in class, he continues to act in collaboration, though at the moment the teacher is not standing near him” because the solution is “accomplished with the teacher’s help” [Vyg87]. Thus, the distributed learning emphasizes which aspects of learning are distributed and how those distributions are mediated.

Behaviorism, as a theory of learning, sharply contrasts with the other modern theories presented, maintaining that meaning exists in a world separate from personal experience. Learning is an immediate, recognizable change in behavior, rather than a process of interaction, discussion, reflection and collaboration among a group of learners. The work presented in thesis is mostly guided by the ideas of social constructivism.

2.3 Pedagogical Practices

Several pedagogical practices, or specific methodologies for instruction, derive from the ideas of activity theory and social constructivism:

- Active learning [JJS98], an umbrella term, foregrounds that the responsibility of learning eventually rests upon the learners. Students may cognitively engage during learning by working in pairs, role playing, debating, analyzing case studies, etc. The experiences of observing and doing in combination with a dialog with self and with others allows students to engage in their own learning.

- Discovery, or inquiry, learning [Bru79] focuses on student interaction with their environment, where they can explore and manipulate objects, grapple with questions and controversies, and perform experiments. This method promotes autonomy and encourages creativity.

- Problem-based learning [SD95] is a specific type of discovery learning that presents students with a problem to be solved rather than content to be mastered. Often, the problem to be solved challenges student intuitions. This method develops reasoning strategies.

- Peer learning [BCS01] emphasizes interaction and collaboration among students, by encouraging them to work in pairs or teams. This method provides opportunities for students to formulate their thoughts, communicate their viewpoints in a clear, coherent manner, and discuss different perspectives.

- Cognitive apprenticeship, or scaffolding, [CBN89] refers to the acquisition of learning by means of observation and guided practice. The instructor provides assistance, in terms of modeling and coaching, with tasks that are just beyond the students' current capabilities.

- Learning by doing [Sch95] is a colloquial phrase that highlights the importance of creating realistic, motivating scenarios in which students can apply theoretical concepts.

- Learning by teaching [GKR71], from the latin phrase *docendo discimus*, stresses the communication aspect of learning. The process of verbalizing one's thoughts reinforces the concept.

Many of these pedagogical practices overlap with each other, and indeed are more effective when used in combination. However, many of these strategies require significant ideological change on behalf of the instructor, which eventually percolates to the students. Perhaps, technological tools can implement the principles underlying activity theory and social constructivism to empower students to become more active, engaged, and motivated about their own learning, regardless of the instructor's theory of cognition and learning.

2.4 Application of Activity Theory

The ideas presented in activity theory provide a framework for understanding and evaluating note-taking. The five fundamental principles of this theory are presented first, followed by an operationalization of the theory to actual note-taking activities.

2.4.1 Five Fundamental Principles

Principle of Object-Orientedness

The first principle emphasizes the need to focus on the *object* of activity when trying to understand human practices. An object "can be a material thing, but it can also be less tangible (such as a plan) or totally intangible (such as a common idea) as long as it can be shared for manipulation and transformation by the participants of the activity" [Nar95]. Thus, the term "object" is used in the sense of "objective," reflecting the purposeful nature of human activity.

Principle of Hierarchical Structure of Activities, Actions, and Operations

At the cultural level are *activities*, which are oriented towards a motive. Participating in an activity consists of performing *actions*, which operate at the individual, conscious level to achieve some specific goal. One activity may be realized using different actions, depending on the situation, and the same action can belong to different activities, with different motives providing personal context [Nar95]. Actions consist of *operations*, which are automatic, unconscious behaviors controlled by the conditions of execution. Initially, each operation is a conscious action, but with enough practice, may fade into an operation, and vice versa, an operation may unfold into a conscious action when conditions change. For example, learning to drive a car with manual transmission involves conscious actions, such as easing the gas pedal, pushing the clutch pedal, changing the gear level, releasing the clutch, and giving more gas. With time and practice, these actions transform into operations. However, some situations, such as when the transmission is stuck in a particular gear, cause even an experienced driver to transform operations into conscious actions, even though the desired goal of changing gears remains the same. Similarly, the distinction between actions and activities are also blurred. Hence, this flexible hierarchy of activities, actions, and operations permits the examination of changing conditions that can reshape the structure of an activity [Mwa02].

Principle of Internalization and Externalization

The third principle of activity theory states that to perform an activity, the subject transforms an object, which is the externalization of mental processes so that they can be verified and corrected. Reciprocally, the properties of the object penetrate the subject and transform the individual. External social processes are thus internalized into a person's repertoire of actions. Since actions are performed by a person in cooperation with others, the set of possible actions that can be internalized is called the *zone of proximal development* [Col96].

Principle of Development

The fourth principle takes place at all levels. Operations are formed from actions that become automatic, actions are discovered as responses to new situations, and activities are restructured as the motives or environment change. The historical development of tools is also significant: “In addition to making tools, human beings arrange for the rediscovery of already-created tools in succeeding generations” [Col96]. Hence, the dynamic nature of activities often lead to *contradictions*, which “indicate a misfit within elements, between them, between different activities, or between different developmental phases of a single activity” [Nar95]. Working through contradictions are sources of development.

Principle of Tool Mediation

The final and most important principle of activity theory states that all progress by the subject towards achieving the object is mediated by, enabled by, and constrained by the tools. Tools are social entities that accumulate and transmit cultural knowledge: tools reflect the experiences of other people who have previously tried to solve similar problems and invented or modified the tools to make them more efficient. The history of the tool development is embedded in both the structural properties of the tools (such as the shape or the material) and in the cultural knowledge of how the tool should be used (which in turn influences external behavior and mental development). The underlying mechanism of tool mediation is the formation of “functional organs,” which are a combination of internal (mental) and external (physical) resources used in human activity. Similar to Engelbart’s seminal conception of computers as augmentation, the concept of a functional organ removes the boundary between the human mind and the tool, merging both to attain a desired outcome [Nar95, Ros98, Mwa02].

The significance of tool mediation arises not from the fact that subjects develop and use tools to help them achieve desired objectives, but from the fact that the development and use of tools changes the nature of the activity and transforms the internal mental perceptions. The design of a tool determines whether or not that tool is used in an activity, how it is used, why it is used, and under which conditions it is used. The design not only extends and limits the ability to achieve desired objectives, but also creates new means for coordination, control, and communication [Mwa02]. Note the distinction maintained between people and tools: people have goals, whereas tools merely mediate. Tools are not anthropomorphized, and people are not reduced to agents in a system. Activities are understood in terms of the role that tools play in everyday existence. Activity theory is thus “concerned with practice, that is doing and activity, which significantly involve ‘the mastery of ... external devices and tools of labor activity”’ [Nar95].

2.4.2 Analysis of Note-Taking Activities

How can activity theory be operationalized? How can it be used to analyze the particular situation of college students taking notes in their classes? Mwanza [Mwa01] outlines one simple approach: examine each of the eight components of Engeström’s Activity System and ask open-ended questions to facilitate the interpretation and cross-mapping between the situation under investigation and the triangular representation. The questions in the Eight-Step-Model are: What sort of *activity* is of interest? Who (*subject*) is involved in carrying out this activity? Why (*objective*) is the activity taking place? By what means (*tools*) are the subjects performing this activity? What is the environment and *community* in which this activity is carried out? Are there any cultural norms, *rules* or regulations governing the performance of this activity? When carrying out this activity, who is responsible for what and how are the roles organized (*division of labor*)? And, finally, what is the desired *outcome* from carrying out this activity? One set of answers for these questions is presented in Figure 2.2, and each aspect is discussed in detail below.

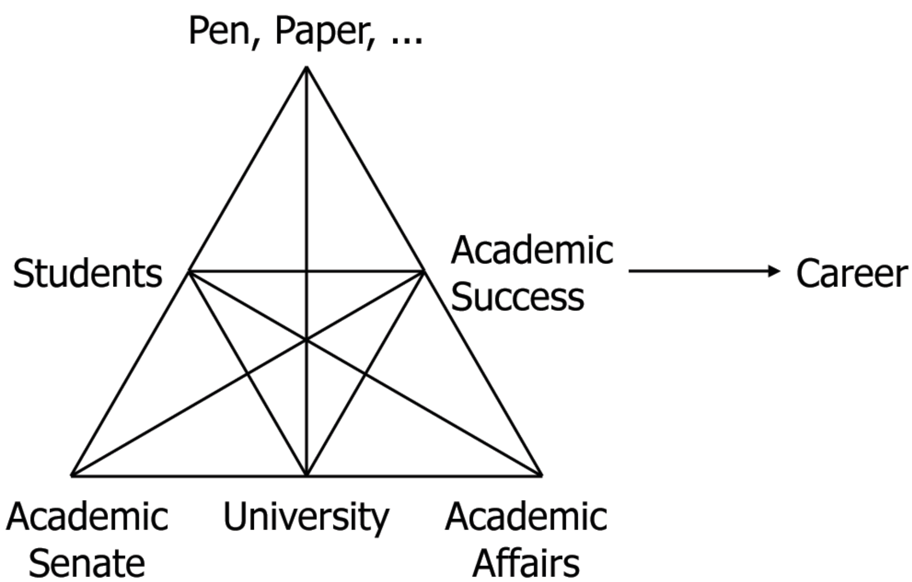

Figure 2.2: Engeström's Activity System operationalized for note-taking

Activity: Note-Taking

The activity under investigation is student note-taking in higher education courses. This specific activity has been the topic of educational psychology research for over 80 years. [Cra25a, ER59, DG72, Kie87, VYP94, BH06] Early studies explored the central question of whether taking notes or simply listening attentively would be more beneficial for students. These studies [Cra25a, Cra25b, ER59] involved subjecting students to a short-lecture, encouraging half of them to take notes and discouraging the other half. The results of evaluating student performance with post-lecture quizzes were contradictory: one study [Cra25b] found that students who took notes performed better, whereas the other study [ER59] found that students did not necessarily benefit from note-taking.

To further understand the effectiveness of note-taking, DiVesta and Gray [DG72, DG73] provided a seminal analysis of the specific functions of the activity. Their research investigated whether note-taking as a process of encoding information during lecture or notes as a product to store information for later review is more beneficial to students. They concluded that both functions are equally important, and both contribute to academic achievement. This research framework has been the focus of nearly 100 studies. Some researchers, such as Carter and Van Matre [CM75], found that taking notes was not as beneficial as having notes, whereas other researchers, such as Peper and Mayer [PM78], found that actually taking notes was of more benefit than merely having them. In summary, 23 of the 35 studies that explored the process function of note-taking suggested that taking notes is better than just listening (with just 3 reporting that note-taking is dysfunctional relative to listening only) and 24 of the 32 studies that explored the product function suggested that having notes and reviewing them is better than either not having notes or not reviewing them (and the other 8 reported no significant difference). [Kie87]

Thus, educational psychology researchers have discovered that the two main functions of note-taking are the encoding process and the storage product. The encoding process suggests that the recording of information facilitates learning, even in the absence of review, through the mediation of prior knowledge, through the recognition of underlying organization or structure, and through the increased attention required in performing the activity. The storage product suggests that the review of notes stored in written form facilitates retention. Note-taking is an important activity for managing the limitations in working memory and attentional capacity of humans, requiring selectivity of important, unfamiliar, and difficult concepts.

Subject: College Students

In general, many different subjects engage in the activity of note-taking: reporters take notes of interesting quotes during interviews, avid readers often note their thoughts in the context of their text, knowledge workers often note the ideas produced in a brainstorming session, field researchers record observations in their notebooks, and so on. However, this analysis is focused on students enrolled in university courses who engage in the activity of note-taking.

Van Meter et al. [VYP94] considered student note-takers as experts who engage in a complex, conscious problem-solving activity, and interviewed them to discover their detailed theories. A series of ethnographic interviews of 252 undergraduate students revealed the goals of note-taking, the content-structure of notes, the contextual factors affecting note-taking, and the post-class use of notes. From this data, these researchers generated an emerging model of students as self-regulated note-takers, who managed the selection of strategies depending on the appropriateness for the particular situation. Self-regulation of note-taking behavior involves (1) forethought regarding interest in the task, the personal goal, the self-motivation, and the strategic plan, (2) the performance of the task and awareness of various aspects of the performance, and (3) self-reflection and evaluation of the successes and failures.

Bonner and Holliday [BH06] investigated whether students actually apply the theory discovered by Van Meter et al. by conducting a longitudinal study of note-taking, situated in an academic course. The research methodology consisted of conducting a periodic series of five interviews throughout the semester with 23 of the 32 students enrolled in a 3rd year genetics course at a private, liberal arts college for women. In addition, the researchers examined the instructor's transparencies, the students' notebooks at the end of each lecture, and the students' textbooks at the end of the semester. The results of the interviews corroborated the theory proposed by Van Meter et al. for the most part. However, an analysis of the notebooks revealed inconsistencies in the application of the theory. Most participants claimed that "good notes" should be accurate, complete, and organized, but their application was not always consistent in each of these areas. Furthermore, the participants claimed that they had become proficient at interpreting the instructor's cues about important material, but their notebooks indicated a failure to notice two important cues (one about the importance of figures and the other about classic genetic experiments). And finally, even though the participants claimed to modify their note-taking according to the demands of the course, the researchers found that most of their strategies for improvement were idiosyncratic, hit-or-miss attempts. In addition to the inherent challenge of the course, limitations in participants' self-regulated learning prevented them from noticing the discrepancy between their theory of note-taking and their day-to-day application. More specifically, limitations in prior knowledge, in goals and strategies, in self-observation during the course, and in self-reflection after the course profoundly determined the participants' success in the course.

Object: Academic Success

Van Meter et al. [VYP94] concluded that the primary goal of the participants was to succeed in the course, with secondary goals of wanting to remain attentive in class, learning and organizing material, and creating a resource that can be used later to do homework and to prepare for exams. These participants reported that they almost always took notes during class, but were selective in choosing what to code into their notes. They discussed contextual factors that affected their ability to take good notes, including the lecture style of the instructor (fast or slow, organized or not), their prior knowledge related to the course, their increased proficiency in taking notes as they progressed through college, and the type of content and course demands. For example, the participants explained that they consciously selected either verbatim or paraphrased notes, depending on the cognitive demands of the course, which is a finding that contradicted existing note-taking literature. They also discussed how they adapted note-taking strategies based on previous assessments in the course, and how their note-taking style evolved most often in hard-to-take-notes courses that placed greatest demands on their note-taking skills, both aspects which had not been previously explored in the literature. And, finally, the participants described methods such as reviewing, rewriting, and recopying that were useful for processing notes after class to study and to do homework. The study found an important link between encoding and review: the participants claimed that their own notes are personally meaningful to them, represent their personal selection of important points, and are filled with comments and abbreviations only fully understandable to them.

In attempting to uncover what students actually think about the activity of note-taking, Carrier et al. [CWD88] designed the Note-Taking Perceptions Survey and concluded that female subjects valued notes more highly, utilized notes more, and were more confident in their ability to take good notes than male respondents. The same study also suggested that students who indicated less confidence in their note-taking ability had lower final course grades than those with greater confidence. Einstein et al. [EMS85] found that note-taking encourages students to process information in a qualitatively better way, increasing the likelihood of academic success.

Tools: Pen, Paper, and More

Traditionally, note-taking is a handwriting exercise, involving paper and a writing implement. The paper may be loose leaf sheets or bound in a notebook. The paper may be blank, may be lined for ease of straight writing, may be part of the course textbook, or may have some background content (such as the lecture's presentation material) to minimize the amount of writing. The writing implement may be a pen or pencil, may come in different colors, and may be augmented with highlighters and other attention drawing materials. Some students might prefer to augment their handwritten notes with pictures of the chalkboard from a camera or with audio captured on a voice recorder. Other students might prefer to take typed notes on a personal typewriter or laptop computer, instead of handwritten ones, for fear of illegibility or for ease of sharing with peers. However, the focus of this work is on handwritten note-taking, which is the more commonplace, natural interaction.

Even with handwritten interfaces, the interactions with paper documents differs from interactions with electronic documents, and both media have their advantages and disadvantages. Paper documents are relatively more tangible, portable, and versatile than digital documents. The higher resolution of paper documents makes them easier to read while enabling larger quantities of info to be transmitted. Paper documents are also relatively easier to access, even in harsh conditions, and easier to navigate. However, digital documents can support interactive computation, electronic communication, and multimedia embedding. Digital documents can quickly be edited, copied, transmitted, shared, organized, searched, and retrieved, relative to paper documents. The challenge for electronic tools for note-taking has been leveraging the advantages of both media.

Community: Faculty, Staff, and Students

The university setting fosters a community of faculty, staff, and students. The faculty include professors and lecturers, who are involved in teaching, research, and service. The staff provide the structure, organization, and support to help the university run smoothly. Staff members include systems administrators, student affairs coordinators, recruitment and admissions advisors, financial affairs assistant, human resources assistant, facilities technicians, computing resources managers, librarians, bookstore associates, food service workers, etc. Students, both undergraduate and graduate, constitute the largest percentage of the university community. Graduate students often serve as teaching assistants for undergraduate courses as well as research assistants. Undergraduate peers are also an important member of the student note-taking community.

Rules: Academic Senate

Both formal and informal rules govern the situation under which note-taking is performed. The formal rules, at the University of California, are specified in the bylaws and regulations of the Academic Senate. [Acab] The regulations of the Academic Senate specify the rules for admissions, enrollment, curricula, and requirements for bachelor's degrees. The Regents, which is the governing body of the University of California, also enforces some educational policies, especially on admissions, registration fees, and on course content.

In addition to these formal rules, there are several informal rules that affect note-taking practices. The academic calendar and course scheduling dictate the length of note-taking sessions. The lecture hall settings affect the physical aspects of note-taking: the desks affect the size of paper on which notes are taken, the lighting affects the pen color and width used, etc. The course breakdown into lectures, discussions, and labs affects the type of note-taking occurring in each of these sessions.

Division of Labor: Academic Affairs

At the University of California, the division of labor among faculty and staff is provided explicitly in the Academic Personnel Manual published by Academic Affairs. A very useful organizational chart is also available. [Acaa] Furthermore, the Human Resources Department and the United Auto Workers labor union specifies the job requirements and the compensation for staff and graduate students. The expected responsibilities of undergraduate students is outlined in the Academic Regulations of the General Catalog.

Outcome: Careers

The immediate goal of note-taking is academic success, but eventually, the desired outcome of this scholarly activity is a career that provides stable employment and financial security.

2.5 Conclusion

The activity theory of cognition and the social constructivist theory of learning form the theoretical basis for this dissertation. Cultural, historical activity theory, as compared to situated action and distributed cognition, provides well-named constructs, considers the motive of activity first, and does not equate people with inanimate tools. Social constructivism, in contrast to the traditional theory of behaviorism, contends that learning is an active and social process, in which the learner constructs new knowledge based on previous understandings. Many pedagogical practices are based on these theories, including active, peer, and inquiry based learning. Insights derived from these theories can be applied directly to the activity of traditional note-taking. Using the terminology and fundamental principles provided by activity theory, note-taking is decomposed into its constituent parts, highlighting the current interactions and mediations. This breakdown helps us analyze and evaluate the effect of new note-taking technologies.

Chapter 3

A Review of Note-Taking Technologies

This chapter surveys the recent research on how computing technologies mediate the student activity of taking handwritten notes during university lectures. Current technologies in the classroom support active learning, active reading, group note-taking, mediated collaboration. A detailed examination of these tools reveals that the four major sub-activities of note-taking are capture, access, manipulation, and collaboration. Approaching previous work from an activity theory and social constructivist perspective reveals that the design space of public digital note-taking has yet to be fully explored.

3.1 Active Learning

Active learning [McC96] is based on the premise that people construct knowledge in different ways based on different prior background. Although active learning places the responsibility of learning on the students, the responsibility for creating activities that involve students in doing things and thinking about what they are doing is placed inevitably on the instructor. Some classroom technologies that enable quick aggregation of student responses to active learning exercises include StuPad, Classroom Presenter, Ubiquitous Presenter, DyKnow, and Classroom Response Systems.

StuPad

Greg Abowd et al. at Georgia Tech developed StuPad as part of the Classroom 2000 project (which later was renamed as the eClass project). The main premise is that there are many streams of information viewable to all students, and note-taking can be seen as a personal stream. Some of the streams of information that are available to students include: the audio stream of the instructor, the video stream of the instructor, different Web sites used to provide alternative explanations of the current topic, multimedia demonstrations or short films to illustrate a point, etc. In this project, students were provided tablet PCs during lecture, but not all students had access to tablet PCs outside of lecture. Thus, the StuPad software provides different interfaces for capture and access. These constraints lead to some nuances, such as the ability to take handwritten notes during class but all additional annotations after class are typed text in a separate box. However, both interfaces use time to synchronize all the streams, which are all displayed spatially collocated to each other for context. The basic approach of this work is to capture automatically as much of the classroom experience as possible, but some basic questions remain, including how does all that captured information affect student review after class and does it contribute to academic success. This system does not explicitly support active learning through instantaneous aggregation of student responses, but does provide students with means for active note-taking in the classroom.

Classroom Presenter

Classroom Presenter (CP), developed by Richard Anderson et al. at the University of Washington, is a distributed tablet PC based classroom interaction system [AMS05]. The purpose of this system was to allow students to work on concrete examples (designed by the instructor) in class and to allow instructors to collect and review student work in real time and to incorporate selected student answers into the discussion. The students retain a copy of their submission, yet the instructor can review student work and provide comments. The instructor can also select a few submissions to project on the shared public display in the classroom to promote further discussion. Students are able to see instantaneously each other's work, learn from common mistakes, and receive immediate instructor feedback. This system was also not designed explicitly for note-taking, but students could take notes on top of instructor prepared slides by using the underlying system for submitting solutions (without submitting them). The system provided very limited support for later access and revision of student notes.

Ubiquitous Presenter

An extension of Classroom Presenter, Ubiquitous Presenter (UP) is a system developed at UC San Diego, to support both pen-based and typed-student submissions on the Web [WGS]. UP was developed to alleviate the burdens of setting up a local multicast UDP network for each lecture and the requirements for each student to have access to a tablet PC during lecture. UP extends the functionality of student interaction during lecture to any Web-enabled device, including laptops, netbooks, and smartphones. The system is based on a web-server architecture, where the server acts as a bridge and data repository for instructor-student interactions. Instructors use a desktop application for a tablet PC to project lecture slides, write on them during lecture, and review student submissions. Students may use any Web browser to submit solutions to the server, which relays the submission back to the instructor's machine. All lecture content, including the lecture slides, the instructor ink, and the student-generated responses are published online.

DyKnow

DyKnow is a commercial system that provides not only most of the features of Classroom Presenter and Ubiquitous Presenter, but also other features to monitor and control student computers [Ber06]. DyKnow allows the instructor to broadcast a student's screen in order to spark discussion, to transmit prepared or extemporaneous content to a student computer, and to poll students to quickly assess understanding. Furthermore, students can save class notes and audio recording on a central server, which can be accessed at any point. DyKnow is also built on the assumption that students will have tablet PCs during class.

Classroom Response Systems

Classroom Response Systems, also known as Clickers, are small infrared remotes, purchased by each student, to submit simple multiple choice answers to instructor-designed questions during class [FM06].

3.2 Active Reading

DigitalDesk

Note-taking on visual content is the most common, natural way to take notes, whether the notes are annotations in a book while reading or elaborations on a specific topic mentioned in a paper or lecture slide. The earliest attempts to bridge the gap between interacting with documents in the digital world of a computer and in the physical world of a desk was Wellner's concept of the DigitalDesk. [Wel93] This seminal work recognized that people like paper, and thus instead of replacing it with computers, the aim should be to enhance paper with computation. Thus, the DigitalDesk consists of a physical desk onto which a computer display is projected, and a video camera pointed at the desk captures image streams of interactions with paper documents, pens, and figures. Some sample applications include a digital calculator whose input can be selections on paper documents, a paper paint program that allows the user to select a portion of a physical drawing and duplicate it or move it as in a digital document, and a collaboration environment where the local user can draw on paper and view simultaneously the drawings of a remote user. Even though this work didn't explicitly focus on note-taking, the main contributions are an approach to bridging the paper and digital divide as well as an initial perspective on collaboration.

Paper Augmented Digital Documents

Ten years later, this approach of bridging the paper and digital divide via the cohabitation of both types of documents is still a challenging research topic. François Guimbretière has leveraged digital paper and pen technology to create Paper Augmented Digital

Documents (PADDs). [Gui03] Digital paper is normal paper printed with infrared dots (that are invisible to the human eye), such that every 3 square millimeters has a unique pattern of dots. A digital pen has an infrared camera that detects the dot pattern to record precisely the location of ink strokes. Using a printer with infrared-transparent ink, digital documents can be printed on digital paper, and annotations made with the digital pen on the document can be collected, synchronized, and later merged with the digital document. Thus, the ease of navigation, annotation, and discussion on a paper document can be leveraged along with the ease of editing, sharing, and archiving of the digital world.

PapierCraft

In collaboration with Liao and Hinckley, Guimbretière used gestures to bring more digital power to paper documents in the PADD system. Pigtail gestures, made by a digital pen on a paper document printed on a digital paper, indicate commands, such as copy, paste, email, create a link, or mark for search. Upon synchronization with the corresponding digital document, the gestured commands are executed to present the final document. Even though the feedback of the commands are delayed until synchronization with a computer, the ability to specify digital commands while working in the paper world expands the range of possible interactions available in the handwriting interface. Thus, this PapierCraft tool [LGH05] creates new methods of mediation between the subject and the object without changing the other elements of the activity, such as the community, rules, division of labor, and outcome.

ButterflyNet

Using the same digital paper and pen technology, Guimbretière further collaborated with colleagues at Stanford University to develop the ButterflyNet system, which also uses the cohabitation of paper and computers to aid field biologists in their note-taking. [YLK+06] In the design of this tool, the subjects were specifically field biologists, who tend to capture heterogeneous data in the wild and analyze the data in the lab. Digital paper best addresses the needs of mobile capture, while supporting ease of information association between heterogeneous data. Hence, the ButterflyNet system uses hotspot gestures (small corner brackets) in the digital notebook using the digital pen to create a real-time association between the current photograph captured with the smart camera and the specific portion of the notebook. By taking a picture of a 2-dimensional, human-readable barcode and hotspot associating it into the notebook, field biologists can tag physical specimens extracted in the field. The ButterflyNet Browser software imports information from all the sources, provides tangible navigation of media (for example, using the digital pen and paper to view the relevant data in the Browser), and transforms the data into multimedia spreadsheets for analysis. However, the system does not support novel mechanisms for searching the data or for collaborating with other field biologist note-takers. Thus, the design and evaluation of this system provides insights about how to support the mobility of note-takers as well as the integration of multiple sources in notes.

XLibris

Besides digital pen and paper, another medium to support note-taking on visual content is a tablet PC, which is a slate-shaped laptop computer with an active digitizer behind the monitor screen. This digitizer basically creates a small electromagnetic field, which the pen perturbs when it is in proximity. The change in the field is used to identify the location of the pen, whether or not it is touching the screen, and whether or not some electronic switches inside the pen are pressed. In 1998, Schilit et al. at FX Palo Alto Labs analyzed the novel opportunities for tablet PCs to support active reading, which involves underlining, highlighting, commenting, critical thinking, and learning while reading some text. Their XLibris system [SGP98] employs a paper document metaphor to bring familiar interactions to the digital world, such as freeform ink annotations and page turning instead of scrolling. This system further enhances reading with computation by creating a notebook of clippings derived from the reader's annotations and by creating links in the margin to related content based on the reader's annotations. Gathering all the clippings allows the salient portions of the text to be easily reviewed, as well as sorted, filtered, and compared with other texts. Related margin links provide for serendipitous discovery of related content, similar to the rewarding experience of finding similar books on the same shelf in the library. Thus, this tool is designed to replace student textbooks with a computationally more powerful one, while still preserving the basic interactions.

Sony Reader and Amazon Kindle

Supporting active reading by replacing traditional paper textbooks with electronic ones remains a challenge even today. Several commercial endeavors in this area include Sony's PRS-500 Reader (January 2006) and Amazon's Kindle (November 2007). Both of these devices use an electronic paper display, which differs from digital paper in composition. Electronic paper consists of two transparent silicone sheets filled with small spheres that are negatively charged black plastic on one side and positively charged white plastic on the other side. An electric field can be applied to rearrange the small spheres to display an image, and the image remains even when the field is removed. Thus, electronic paper is flexible like paper, consumes very little power, can be easily changed, and is not backlight like traditional computer monitors. The trouble with these efforts have been proprietary formats and content availability, as well as the lack of freeform annotations for the sake of longer battery life.

InkSeine

If, for a moment, we assume that technologies such as electronic paper and tablet PCs will overcome difficulties in deployment, how can they support active note-taking in general, not just active reading? At Microsoft Research, Hinckley et al. explored how tablet PCs can help manage "task detritus" and support creative sense-making while minimizing distractions and maximizing focused attention. The key idea behind their InkSeine software [HZS+07] is to leverage the existing digital ink in the notes to trigger searches for related content. With a simple, incomplete-circle gesture around a word, a search can be initiated, either for now or for later. Search results that are viewed are left as small breadcrumb icons near the query, and clips of relevant content can be brought directly into the notes. The search can be performed over files on the local machine or for any file on the Internet. Thus, in-situ search in the context of note-taking is an example of the novel interactions available when traditional pen and paper is replaced with computing-based counterparts.

3.3 Group Note-Taking

Tivoli

Since computers are more and more seen as communication devices than computation devices, how can they mediate note-taking in a small group of people? The earliest attempt at collaborative note-taking was by a group of researchers at Xerox PARC who used the Xerox Liveboard, a large pen-based interactive whiteboard, for informal group meetings. The core functionality of this system, called Tivoli [PMMH93], included pen scribbling and gestured-based commands for editing, saving, printing, and importing background images. The system supports multiple users at the same Liveboard as well as multiple users at different geographical locations, but the minimal evaluation presented in the paper suggested that even at a single board, only one user tends to use the system at any given moment. Even though it is not physically feasible for small groups of students to take notes on whiteboards during lecture, computer-enabled tools can simulate such an environment. In such a simulation, the subject of the activity changes from one student to a group of students, which in turn, changes the division of labor and rules that mediate the relationship between the students and the rest of their community.

LiveNotes

An example of such a simulated environment is the Livenotes [KWI+05] system, developed at UC Berkeley. Using wirelessly connected tablet PCs during lecture, this system provides a shared whiteboard for taking lecture notes cooperatively on top of prepared instructor slides as well as for real-time discussion among group members. The goal of this collaborative and augmented note-taking system is to provide all students with multiple perspectives, and encourage them to reconcile the differences as a sense-making exercise. The evaluation of Livenotes involved randomly assigned groups that changed every lecture session, resulting in students mediating their desire for complete notes and minimal space conflicts with a new social norm of synchronized turn-based note-taking. Since the tool provided no explicit division of labor among the members of the small group, and since the normative rules of lecture provided no time to negotiate the division, the situation degenerated to one person taking notes while others watched and provided additional information or corrections as necessary. No group dynamics emerged, such as negotiation of abbreviations and other annotation shortcuts, due to the evaluation method. In addition, the focus of the entire paper was on collaborative capture, with no consideration of cooperative review after class.

3.4 Mediated Collaboration

MicroNotes

A special class of note-taking activity focuses on informal, hurried personal jottings, called “micronotes” [LLK04]. These small notes contain notable information, such as list of topics on Friday’s quiz, the address of an interesting Website related to the current topic, a reminder to ask the TA about the grading of the previous assignment, or the pages of the textbook to read before the next lecture. These jottings are often doodled in the margins of the notebook, on Post-Its or the back of store receipts, or even on the skin of hands. Many of the arguments of Lin, Lutters, and Kim for why mobile phones do not support adequately micronotes are important to consider in the design of informal note-taking tools.

NotePals

An interesting approach for supporting collaborative note-taking has involved the recording and sharing of micronotes. For example, the NotePals [DLC+99] system involves recording private micronotes on PDAs during a lecture or conference talk, and later reviewing collaboratively everyone’s micronotes on a Web interface. The advantage and disadvantage of this system is the unawareness of other student's notes: one user does not have to wait and wonder if another user is about to write the same thought, but then many users may have written the same thought in basically the same terms, resulting in duplication of effort. The micronotes are synchronized in chunks of time, such as on the same slide or referring to the same paper. Also, the micronotes are placed adjacent to the content, so no space conflicts between users arise. Also, no direct communication among users is enabled by the tool, such as answering another user's question or correcting a peer's notes. Simple search features are implemented, but no handwriting recognition algorithm is used to parse and search within the micronotes.

Group Scribbles

Another different example illustrates how micronotes can be used for collaborative capture and computation, but does not explicitly provide support for traditional note-taking activities. Group Scribbles [RTC+07], developed at SRI International, is designed for improvised and interactive learning environments, where each student has a tablet PC. The system provides each student with a private board for composing and storing micronotes and a public board for sharing and collaborating with micronotes. A student can write a micronote in the private board and drag it to the public board to share. Likewise, a student may take any micronote in the public board, drag it to the personal area, modify it as pleased, and may drag it back to the public board. The tool is designed to provide no explicit support for management or coordination among users, but rather to leave it entirely up to social interactions. The only thing that the tool guarantees is that only one copy of each micronote exists, even if two people click to move a given public micronote into their private board at the same time. Recordings of Group Scribbles sessions and the content of private micronotes may be used for note-taking.

3.5 Four Main Aspects

The activity of student note-taking in college lectures was decomposed into its constituent parts using activity theory in Section 2.4, and the tools component of the activity was further investigated (in the previous four sections of this chapter) to determine the various ways in which computing technologies can enhance the overall activity. These computing tools enable note-taking on visual content, during audio content, in small groups, and on micronotes. From the analysis of note-taking and the review of computer-enabled tools emerge four main sub-activities of note-taking: capture, access, manipulation, and collaboration.

Capture

The capture sub-activity of note-taking is also referred to as the encoding process by educational psychologists. It involves exposure to new information, whether in visual form such as a textbook, in audio form such as the speech of a lecturer, or both, and the recording of that information. The interest of this research is on recording interfaces that support handwritten interactions. The medium for these interactions varies widely, from physical, digital, and electronic pen and paper to PDAs and tablet PCs. The DigitalDesk system uses a projector and camera pointed at a physical desk, whereas the Tivoli system is deployed on an electronic whiteboard. Despite the diverse recording media, these tools provide support for background content. In some systems, request for the background content occurs once at the beginning of the interaction. For example, PADDs, XLibris, StuPad, Tivoli, Livenotes, and NotePals all provide mechanisms for associating the notes to follow with a specific document or set of slides. Other systems, such as PapierCraft, ButterflyNet, InkSeine, and EverNote allow multiple documents or artifacts to be brought in at any time as the background content. For example, various photographs can be brought in from papers on the local machine and from websites as background content when note-taking with InkSeine, in contrast to a set of micronotes taken with the NotePals system, which are associated with a specific document.

Access

The access sub-activity of note-taking is also referred to as the storage product by educational psychologists and typically occurs after the capture activity. It involves the review of written material in preparation for examinations and for learning in general. The interface for this sub-activity can be the same or different from the capture activity. For example, StuPad and NotePals provide completely different interfaces for capture and for review, whereas InkSeine and Livenotes provide exactly the same interface. The most salient feature of a note-taking tool for the access sub-activity is navigation. Tools that only support linear navigation tend to be too slow for usage because students want to be able to quickly jump to portions of the material that are difficult. Simple time-based navigation of synchronized streams, such as in the Filochat and StuPad systems, allow for access of the desired information, but tend to be more tedious to use. Some novel navigation techniques include tactile navigation in the ButterflyNet system and phrase detection in the Audio Notebook system. Navigation can also be supported with underlying structure in the notes, whether is user-provided or automatically inferred. User structuring is required in systems such as Dynomite, Livenotes, Notepals, and OneNote. Acoustic structuring of data to determine topic suggestions in the Audio Notebook system or the gathering of clippings derived from the user's annotations in the XLibris system are examples of automatic, inferred structure. These structures aid the user in rapidly accessing relevant content.

Manipulation

The manipulation sub-activity of note-taking is completely orthogonal to the previous two activities. This manipulation occurs during both the capture and access sub-activities. Manipulation involves adding new notes, deleting notes, editing existing notes, creating links, etc. An important aspect of manipulation commands is receiving feedback on whether or not the command was executed as the user had expected. Systems such as InkSeine and Livenotes provide immediate feedback on all manipulation commands, whereas systems such as NotePals and PapierCraft can not provide immediate feedback for some commands. In NotePals, the PDA interface does not give feedback regarding which digital document the newly created micronote was attached to. In PapierCraft, adding and editing handwritten notes have immediate feedback, but commands to copy and paste or to add a link do not take effect until synchronization with the computer.

Another important aspect of manipulation commands is finding and organizing relevant material. The purpose of manipulating notes, especially during review, is to organize the various thoughts in a way that they make sense. Searching for relevant content in notes can either be based on keywords, tags, or properties, as in XLibris, Dynomite and NotePals, or can be based on handwriting recognition, as in InkSeine, OneNote, and EverNote. Searching for relevant content outside of the notes can either be explicit, as in InkSeine, or serendipitous, as in XLibris. This relevant content can either be organized manually, as in NotePals, or automatically with tags and properties.

Collaboration

The collaboration sub-activity of note-taking is also orthogonal to the capture and access sub-activities, but heavily involves the manipulation activity. Tivoli, Livenotes, and Group Scribbles support collaboration during capture, whereas Notepals mostly supports collaboration during access. The two main components of collaboration are time and location. Collaboration at the same time involves synchronous communication, as in Livenotes, but at different times involves asynchronous communications, as in emailing EverNote micronotes. Collaborative note-taking in the same place involves colocation of users, and this colocation can be during capture, as in Tivoli or StuPad, or during access, as in NotePals. On the other hand, collaborative note-taking where all the users are not in the same location might occur in distance learning programs or online courses. DigitalDesk proposed a mechanism for the local user to view the remote users' drawings and Tivoli developed a mechanism for multiple whiteboards in different places to communicate and collaborate. Both of these projects are from 1993, and no recent work has pursued this area of collaborative handwritten note-taking at disjoint locations.

Chapter 4

NoteBlogs

4.1 Introduction

To explore one way public digital notes can be utilized during lecture, we deployed a Tablet PC tool for NoteBlogging in a large introductory computer science (CS1) course. NoteBlogs are real-time, publicly-viewable notes, captured by a select handful of students in the context of lecture slides and live instructor annotations. A blog is a personal reflection on a shared experience, often providing commentary or news on a particular subject. It is a popular way to support an online community.

The lecture setting, and the activities conducted during lecture, are important to study, because students perceive to be "paying for" it as part of their university experience. Lecture, by its one-to-many nature, is most often instructor-led rather than student-led. While the instructor may engage students in performing activities, the instructor, for the most part, sets the agenda of learning for the day.

Furthermore, introductory computer science lectures face special challenges in that they often must support students with varying backgrounds in programming. The rate and depth of instruction needs to support novices, but hopefully does not bore completely those with some programming background. Additionally, instructors often feel there is much material to cover and students may be reluctant to pose or answer questions where there are definite "right" and "wrong" answers.

In contrast to lecture, activities such as programming assignments, laboratories, exams, and other assessments are primarily student-driven. In such scenarios an instructor may set a goal, but it is the responsibility of the students to decide how to start, what resources to engage, and to make progress towards a solution of their own creation. The distinction between who leads the activity may have a significant impact on students' understandings of programming concepts. This work focuses on the lecture setting, complementing previous work on strategies or abilities in student-generated scenarios.

To document students' understandings of CS concepts in the fleeting environment of lecture, we engage students in the act of NoteBlogging. The blog-based nature serves to focus students' efforts on providing information useful to their peers and on conveying the their personal reflection of lecture concepts. In this context we seek to explore the potential for "blogging" in the classroom.

In this study we use a Grounded Theory-based approach to analyze how students grasp CS concepts through their blogs. We describe and provide examples of 31 categories of "blog events" that we observed, where a blog event refers to a logical unit of annotations for some purpose. We analyze the styles, techniques, and tactics that blogger students employed to explain course content and engage their audience of peers in learning. Student work contained 31 distinct categories of blog events. We further analyze the data using a card sort process to map these categories to common educational theories, such as Bloom's Taxonomy, the SOLO Taxonomy, and a variant of Piaget's Cognitive Development Theory. We find that blog events span from superficial to advanced pedagogical levels. These results describe and highlight the diversity of experiences students have in the lecture setting.

We also sought to better understand the motivations, desires, and potential negative side-effects of blogging in the classroom. From interviews, we find that the more advanced students who served as bloggers found a new and engaging role in the classroom. Bloggers enjoyed the ambient communication medium of blogging, described as being able to "say things that I want to without having to say it to anyone in particular [and without] interrupt[ing] the class to say it" (B1). They sought to provide clarity, emphasis on important concepts, a student perspective, alternate explanations, and provide peer instruction.

From a survey of students on their blog-watching habits and interviews with selected watchers, we find that blog watchers watch in order to get a different viewpoint on classroom materials or to divert themselves when, for whatever reason, the classroom material is not engaging them thoroughly. Students feel it has a positive impact on their learning experience.

4.2 Related Work

Some prior work has focused on students' abilities on programming tasks [MAD+01] and their skills in reading and understanding code [LAF+04, FST05, LST+06], while other work has tried to enlighten us by documenting what questions students have in performing these types of tasks [GHR05]. However, little work has focused on how students experience the learning of introductory CS concepts during lecture.

Also, this work, as part of applied educational research, utilizes some educational methodologies and theories. We provide a brief discussion of the theories that we apply in this study and provide references to some of the relevant work in CS education research that has also engaged these theories.

Understanding Novice Programming Skills

Recent research efforts have used a variety of approaches to understand novice programmers' skill levels and deficiencies. McCracken et. al. [MAD+01] engaged students in a program creation task and found that programming skills of novices were very weak. Work by Lister et. al. [LAF+04] used multiple choice exams to determine that code-reading ability is a key weakness of novice programmers. In addition, by analyzing think-aloud transcripts from these exams, Fitzgerald et. al. [FST05] identified strategies that novices use to read and understand code, but could not correlate any particular strategy or set of strategies with success. In other work by Lister et. al. [LST+06] students' abilities to match expert level English descriptions of "what code does" were measured on a final exam. Garner et. al. [GHR05] moved the "time of assessment" of CS1 learning from a post-hoc assessment period to one closer to the time of instruction. They identified the most common types of questions that novice students performing programming tasks asked of instructional staff in a closed lab section. A commonality of these studies is the student-directed nature of the activities: students are engaged in completing a task in which they direct the application of knowledge or seeking of information. The results of these studies inform us about students' understandings when applying concepts on their own and for a specific task. In this study, we describe student learning and understanding in the context of the lecture environment, which is a more instructor-led scenario and often exhibits students' first exposure to a topic.

Techniques for analyzing novice students' understandings of programming concepts have also varied. In McCracken et. al. [MAD+01] programming assignments were graded for correctness, but also rated on a "Degree of Closeness" ranking, which subjectively determined if programs seemed to be on the right track. Lister et. al.'s [LAF+04] post-hoc evaluation scored multi-choice questions and identified that "fill in the code segment" questions were more difficult for novices than "trace the execution of the given code" questions. Garner et. al.'s [GHR05] analysis counted the frequency of question types. They reported that the most frequent questions were those relating to basic mechanics (minor errors). Surprisingly, this category (a) remained a strong source of errors throughout all the labs in the course rather than decreasing in frequency as the term progressed and (b) was a dominating category for students of all ability levels (based on final grade).

Fitzgerald, et. al. [FST05] performed a qualitative analysis of think-alouds from the Lister study [LAF+04] using a Grounded Theory-based approach to identify strategies that novices used in reading and understanding code. Our work also take a qualitative, Grounded Theory-based approach, but our data consists of noteblogs instead of think-alouds. Where Fitzgerald's data allowed them to identify strategies students use in reading code, we seek to identify students' understandings, questions, and experiences in learning CS1 concepts in lecture.

Bloom's Taxonomy

Bloom's Taxonomy of Educational Objectives seeks to classify the goals of an educational endeavor in an order that indicates depth of understanding [BK56]. Since it is one of the most commonly known educational taxonomies (especially in the U.S.), a number of works on computing and computing education have been based in or structured by Bloom's Taxonomy. Bloom identified six taxonomic levels: Knowledge (recognition or recall), Comprehension (literal understanding), Application (use of abstractions in concrete situations), Analysis (breakdown into parts/recognition of relationship of parts), Synthesis (putting together elements to form whole), and Evaluation (making judgments of value).

Buck and Stucki [BS00] mapped Bloom's taxonomic levels to CS abilities as a whole, but did not focus in depth on any one course, such as CS1. In earlier work, Lister suggests a teaching approach to CS1 that steps through Bloom's taxonomic levels [Lis00]. In our work, noteblogging events, as much as they reveal students' understandings of the lecture material as they unfold, are often reflective of students' depths of understanding. However, an ordered evaluation of the movement of blog events from one taxonomic level to another as the term progresses is beyond the scope of this work.

SOLO Taxonomy

John Biggs [Big03] sought to classify learning outcomes in terms of their complexity. Thus, he developed a Structure of the Observed Learning Outcomes (SOLO) to measure student understanding as the material became increasingly complex. The ultimate goal, according to Biggs, is constructive alignment: the instructor's declared, intended learning outcomes must be aligned with the learning activities and the assessment tasks. SOLO identifies five stages of student understanding: Pre-structural (bits of unconnected information), Uni-structural (simple connections made), Multi-structural (a number of connections made), Relational (significance of the parts in relation to whole), and Extended Abstract (connect beyond given subject/generalize).

Lister, et. al [LST+06] analyzed "respond in plain English" questions on CS1 exams based on the SOLO Taxonomy to determine how expert-like CS1 students' analyses of code fragments are. Fitzgerald et. al. [FST05] also categorize their strategies based on SOLO. In our work, due to the preponderance of active learning exercises presented in lecture, we often see assessment-type responses in noteblogging events. Additionally, this "application focus" of the class seemed to cause many students to seek and express understandings on many lecture slides. Such responses are naturally categorizable within the SOLO Taxonomy.

Piaget's Cognitive Development Theory

Jean Piaget is most well-known for his constructivist theory of knowing and his theory of the cognitive development of children. He divided the cognitive development of children into four stages, that roughly correspond to the cognitive structures found in infancy (Sensorimotor stage), pre-school (Pre-operational stage), childhood (Concrete Operations), and adolescence (Formal operations). Piaget believes as knowledge is constructed within an individual, they move from one stage to the next.

We adopt the constructivist viewpoint of Piaget and adapt his development stages to a constructivist development of skills and understandings in CS1. For example, the Sensorimotor phase involves development of reflexes and habit. We find noteblogging events that evidence habit through discussion of IDE environments and through highlighting of new concepts. In the Concrete Operational stage, we see blog events involving code tracing, drawing memory and connecting code to output.

4.3 Data

Reviewing the content of students' noteblogs revealed 31 categories. For each category, we give a name, an explanation and an example in Tables 4.1, 4.2, 4.3, and 4.4. Keeping with the Grounded Theory approach, categories are described to reflect what was *seen* in the blogs rather than what could fall into each category. For example, Highlighting New Concepts did not simply involve circling a new keyword, but rather annotations around the new concept emphasized its meaning, purpose, or relationship with other concepts. It is also important to note that some blog events fell into multiple categories. In Table 4.2 under Introducing Terms, the example shows that the blogger not only introduced the term “overloading” but did it as a question. This content is also an example of Asking Questions because the blogger was unsure that he was correctly introducing the term.

The 31 categories we found naturally broke into four groups for ease of discussion. The groupings are purely syntactic and do not correspond to any of the theories discussed in Section 4.2. In the following subsections, we explain categories that are blog events *about programming concepts* (4.3.1), blog events *within code* (4.3.2), events that are *code or code execution* (4.3.3), and events that are only *related to programming* (4.3.4). We discuss several categories further either to provide additional clarity or to focus on particularly interesting blog events in that category.

4.3.1 Blog Events about Programming Concepts

When students blogged about programming concepts, they employed a variety of techniques. Among the categories that the authors find most interesting are the Hints to Start and Hints (other) categories. Blogger B1 made extensive and explicit use of hints, more so than the other bloggers. In an interview he explained that he tried not to give away the answers and instead tried to provide information that would help students complete the in-class problem even if they were having difficulty in the course. The example given in Table 4.1 for Hints (other) is shown in Figure 4.1. Notice that the second hint B1 gave “where does the println (or enter) happen?” is also a question so this blog event could be cross-categorized into Teaching with Questions as well.

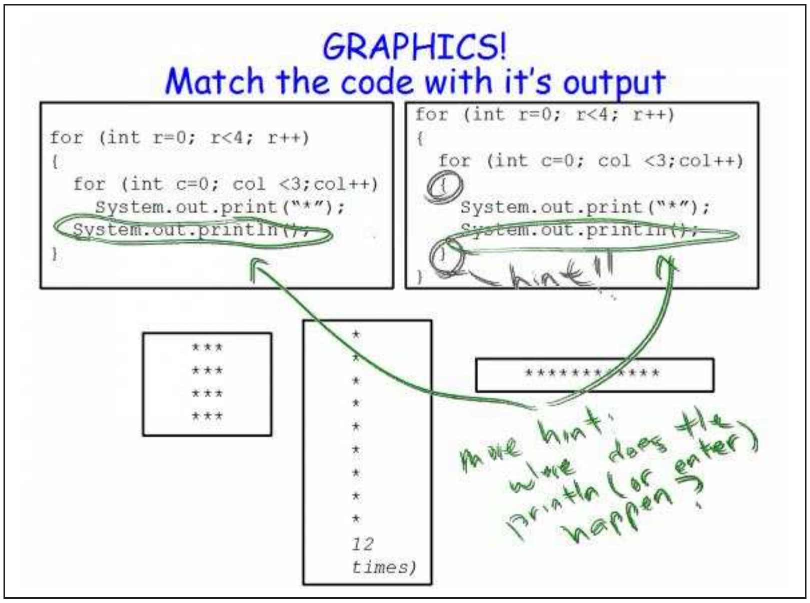

Figure 4.1: Example of Hints (other) and Teaching with Questions categories from B1's blog.

Table 4.1: Categories of blog events about programming concepts

Category	Explanation	Example
Defining Terms	Bloggers write out an English description of CS terms.	For an example with a loop that terminates with a sentinel value, blogger B3 wrote out "sentinel values - entering this will make the loop stop."
Analogies	Bloggers analogize a CS term or concept to something familiar.	When instances of classes were introduced, B1 analogized them to "instances" in massively multiplayer online games (MMOs). In MMOs such as WoW, instances are areas that can have multiple concurrent copies which do not interfere with one another.

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Table 4.1 – Continued

Category	Explanation	Example
Comparing Conventions	Bloggers compare a CS-specific conventions to other conventions.	B3 reminded her audience that JAVA graphics classes use a coordinate plain with the origin at the top left, unlike the standard first quadrant in math.
Comparing to Outside Resources	Bloggers highlight and point out another resource that covers the same concept (such the course text book).	On the same lecture slide that B3 defined sentinel values (see example for category Defining Terms), she also noted the pages from the text that cover the concept.
Asking Questions	Bloggers ask questions when they do not know the solution.	In a sample code segment, two subpackages of a package "acm" are imported using ".*" notation, B1 asked "Or just acm.*?" He doesn't understand that packages are not recursively imported.
Teaching with Questions	Bloggers pose questions so that thinking about the answer may teach their peers.	B1 asked "what if i type in 51 sentences?" about a code segment which filled an array of size 50 with user input.
Explanation	Bloggers write out an expanded English explanation of an explanation already on the lecture slide.	One slide asked students how much memory is required to store Class types to emphasize that the size varies. B1 expanded by clarifying that "it stores ADDRESS" instead of the data like primitives.
Hints to Start	Bloggers provide a hint about how to start an in-class problem.	On a code tracing exercise, B1 blogged "*hint deal with inner loop until it finishes."

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Table 4.1 – Continued

Category	Explanation	Example
Hints (other)	Bloggers provide hints to in-class problems *other than* how to get started.	When students were asked to match code segments with output, B1 offers two hints. In one, he circled curly braces to emphasize the nested structure of the loops and wrote "hint!!". He later added "More hint: where does the println (or enter) happen?" The second hint is also in the Teaching with Questions category.
Admonishments	Bloggers warn their audience of potential bugs or other problems.	B1 warned "*watch for OBOs!" (Off By One errors) on an in-class problem.
Style Comments	Bloggers write out explanations or suggestions for coding styles	On example code that calculated an average, B3 suggested that the variable "y would be better called sum".

4.3.2 Blog Events within Code

Since bloggers were given Tablet PCs to use for the course, they had significant freedom of expression, particularly to embed elements of their blog in or around code segments. A great example of a blogger taking advantage of digital ink is the Pictorial Annotations category. Figure 4.2 shows the blog event of the example for Pictorial Annotations given in Table 4.2. This example is from B3's blog on the same lecture slide as the example of B1's blog in Figure 4.1. B3 chose to emphasize the scope of the loops in a very different way from B1's hints: this blogger chose to use different ink colors (red and black) to connect related chunks of code visually and clearly.

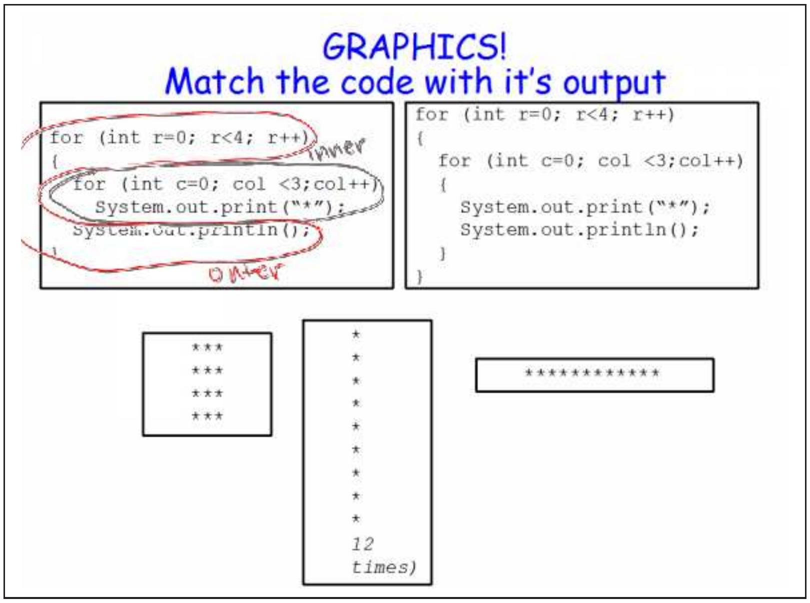

Figure 4.2: Example of Pictorial Annotations category from B3's blog.

Table 4.2: Categories of blog events within code

Category	Explanation	Example
Introducing Terms	Bloggers introduce a new CS term for a concept before the instructor mention it.	The first time a lecture slide showed two methods with the same name and different method signatures, B1 wrote "overloading?" and pointed to the two methods.
New Concepts	Bloggers expand on and apply a new concept.	Sentinel values were introduced only with numbers. When a slide used a text string ("stop"), B3 noted that "sentinel values don't have to be NUMBERS ONLY".

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Table 4.2 – Continued

Category	Explanation	Example
Highlighting New Concepts	Bloggers highlight parts of code that are new concepts in a way that emphasizes the meaning, purpose, or relationships of such concepts.	On the first example of mutators and accessors, B3 circled "set" in a method called `setRadius`, underlined the method, and labeled it "mutator" to show her audience how to identify mutators.
Highlighting Peers' Errors	When the instructor displays a student's work, bloggers highlight the location of an error.	Blogger B4 pointed to an incorrect `if` condition on a peer's submission and noted "does not work".
Pictorial Annotations	Bloggers draw on top of code to give additional meaning.	To emphasize the structure of nested loops, B3 drew a circle around the inner loop, and a C-shaped region around the outer loop.
Explanation of Peers' Work	Bloggers write out an expanded English explanation of an explanation written by their peers.	A student submitted correct work, but missed the main point of the exercise. When the work was shown in class, blogger B1 noted that it was "also a valid point. note starting from 0, <5 & 1 <= 5". (B1 also drew a smiley face next to his note.)

4.3.3 Blog Events that are Code

The CS1 course from which the data was gathered focused on teaching programming as a skill. Since lectures were done in an active learning style, students had many opportunities to write, alter, trace, and translate code. The example discussed in Table 4.3 for the Connecting Output to Code category is in the context of the same lecture slide from examples in Figures 4.1 and 4.2. We repeat this same lecture slide, not for consistency,

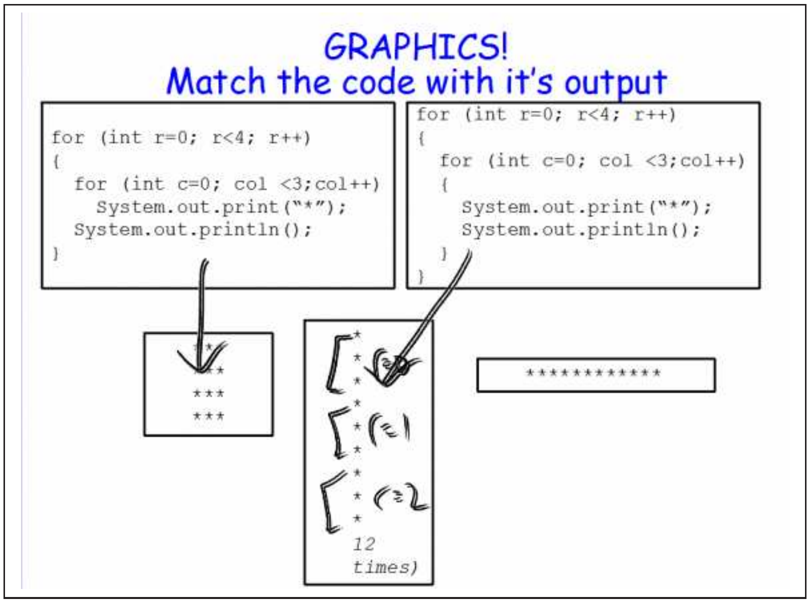

Figure 4.3: Example of Connecting Output to Code category from B2's blog. The writing on the right-hand side of the output refers to the loop variable in the outer loop.

but instead because it is an in-class problem for which each of the three bloggers took a different and interesting approach. Figure 4.3 shows B2's blog event in the category Connecting Output to Code. Like B1 and B3, he is also trying to show scope of the inner and outer loops. In an interview with B2, he reported that he would keep a web browser open on his tablet and actively watch the other blogs to ensure that his was unique. We cannot be certain if that is the reason his blog is distinct from his fellow bloggers, but it is an interesting approach to noteblogging nonetheless.

Table 4.3: Categories of blog events that are code

Category	Explanation	Example
Correcting Code	Bloggers explicitly fix an error in code.	To motivate the need for `else if`, the instructor showed a slide with incorrect code using only `if`. B3 created a new blank slide associated with the lecture slide and rewrote the code to produce with correct result by altering the `if` conditions (rather than using the yet-to-be-introduced concept of `else if`).
Connecting Output to Code	Bloggers draw explicit connections between output and code segments.	When the output of nested loops was shown, blogger B2 drew brackets left of the inner loop's output, and labeled which iteration produced that section of output on the other side.
Code Tracing	Bloggers trace through code and show the output.	B2 traced the values of two variable for a code segment and labeled explicitly the sentinel value which terminated the loop.
Drawing Memory	Bloggers draw pictorial representations of the state of objects and variables in memory.	B4 filled in labeled boxes for variable values, crossing out old values and writing new ones below when the variable were updated. She also filled in an array-like structure with an object's instance variables, labeling each with its name.
Code to English	Bloggers write out an English description of code or pseudocode	On the same sample code for which B2 traced the output, he also annotated the variables' values to explain the error: "this code is bad because it adds the sentinel value".
English to Code	Bloggers write code from an English description.	When instructed to "Write a loop to print out multiples of 3 from [3,33]," B2 wrote a correct code segment.

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Table 4.3 – Continued

Category	Explanation	Example
Providing Solutions	Bloggers write explicit answers or solutions to in-class problems. This category has significant overlap with several others since in many cases the blog event is also a solution to an in-class problem.	B2's solution to printing multiples of 3 (see English to Code) provided his audience with an explicit answer to the problem.
Multiple Solutions	Bloggers provide multiple possible solutions to in-class problems.	For the same problem mentioned as examples in the previous two categories (English to Code and Providing Solutions), a different blogger, B3, produced three distinct solutions (all correct).

4.3.4 Blog Events that are Related to Programming

Bloggers also included content that was not specifically programming, but related to programming. This type of content was either embedded in the lecture slides (such as the Mental State category) or put on a separate *note* slides. Note slides are additional blank slides associated with a particular slide in the lecture. Figure 4.4 shows B3's blog (on a note slide) for the example of Shell Commands in Table 4.4. On this note slide, she was addressing the programming assignment due the next week. While this example is not used for the Advice category, her suggestion of testing on multiple inputs falls into that category as well.

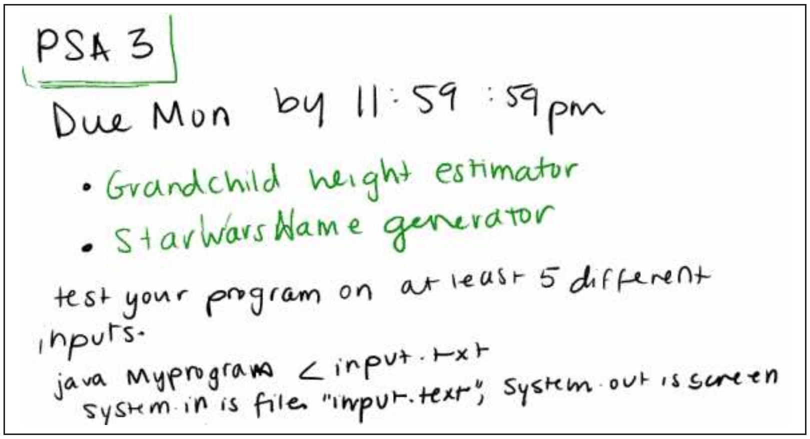

Figure 4.4: Example of Shell Commands and Advice categories from B3's blog on an extra note slide.

Table 4.4: Categories of blog events that are related to programming

Category	Explanation	Example
Shell Commands	Bloggers provide context-relevant information about Shell commands.	B3 created a blank slide to blog about the programming assignment. "test your program on at least 5 different inputs." "java Myprogram <input.txt" "system.in is file 'input.text,' System.out is screen"
IDE Hints	Bloggers provide context-relevant hints for IDEs.	B3 blogged an ordered list of emacs commands and annotated the commands with an explanation of what each does.
Additional Practice	Bloggers suggest additional problems for practice, either from the text book, or writing out the extra problem.	B3 annotated on top of the week's reading list to suggest that the problems were worth working through.

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Table 4.4 – Continued

Category	Explanation	Example
Advice	Bloggers give general life advice that's relevant to lecture.	On a slide about CS courses and other requirements, B5 suggests that students "take programming every quarter."
Mental State	Bloggers express how they feel about lecture content. Often, these are statements or drawings.	B3 labeled correct but (intentionally) poorly written sample code "really confusing!". Additionally, B1 labeled incorrect code by drawing an ascii angry face ">=(" (he drew the face right-side-up).
Empathy	Bloggers express empathy on their peers' work.	When the instructor correct a student's work, B1 pointed to it and wrote "Genius..!! i didn't think of that =(." (Like in the example for Mental State, B1 drew the ascii face right-side-up.)

4.4 Blog Content Analysis

As part of our multi-pronged analysis of the impact of noteblogging, we perform a content-analysis examination of the blog content from a 10-week course introducing programming in Java. Since we are interested in the educational impact and import of blogging, we analyze the content in the framework of Bloom's Taxonomy of Educational Objectives [BK56] the SOLO Taxonomy, and a variant of Piaget's Cognitive Development Theory. We also discuss emergent theories through an unconstrained card sort by the course instructor (author Simon). We sought to find out if blogs simply made low-level comments on content (e.g. knowledge level) or if blog content reached into higher levels such as application, analysis, synthesis, or evaluation.

4.4.1 Methodology

We study the artifacts from author Simon's CS1 in Fall 2006. The final enrollment was 119 students. The students had a variety of programming backgrounds: some had no prior experience, others had minimal formal training (perhaps in a different language), and others had explored computing on their own. However, students with significant prior programming experience (including a pass-ing AP grade) were placed in a different class. Most of the students were Computer Science majors. The instructor made a determined effort to foster active learning in her classroom: she encouraged students to read the textbook before each lecture and she carried out at least three active learning exercises in each 80-minute lecture (supported by UP). Approximately 50 students brought web-enabled personal computing devices (almost exclusively laptops) to class to participate in the exercises. Four note-bloggers were selected by application and instructor review. Half way through the course, a re-election process occurred: all the students in the class could vote to keep a particular blogger or elect a new one. As a result, two of the bloggers remained while the other two were replaced by new bloggers.

4.4.2 Bloom's Taxonomy Analysis

Reviewing the content of students' noteblogs revealed 31 different blog event types. Due to lack of space, we cannot provide examples of all event types, but samples of interesting events will be discussed. We apply Bloom's Taxonomy of Educational Objectives [BK56] to analyze the perceived understanding expressed by various noteblog events. Table 4.5 shows our categorization. It should be noted that the meta-descriptions of some blog events seem to belong to several categories. In these cases, we categorized based on actual content from observed blog events.

Table 4.5: Blog event categories according to Bloom's Taxonomy

Taxonomic Level	Descriptive Verbs	Categories of Blog Events
Knowledge: recognition or recall, of ideas, material, or phenomena	defines, describes, identifies, matches, recalls, states	Defining Terms, Shell Commands, Comparing to Outside Resources
Comprehension: understanding of the literal message contained in a communication	comprehends, converts, distinguishes, explains, extends, interprets, translates	Code Tracing, Highlighting New Concepts, Connecting Output to Code, Asking Questions, Introducing Terms, Drawing Memory, Mental State
Application: use of abstractions in particular and concrete situations	applies, changes, constructs, demonstrates, modifies, produces, relates, shows, solves	Providing Solutions, IDE Hints, Additional Practice, New Concepts, Correcting Code, English to Code
Analysis: breakdown of the material into its constituent parts and detection of the relationships of the parts	analyzes, breaks down, compares, contrasts, differentiates, discriminates, distinguishes, identifies, illustrates, infers, outlines, relates, selects	Teaching with Questions, Highlighting Peers' Errors, Hints (other), Comparing Conventions, Explanation, Explanation of Peer's Work
Synthesis: putting together of elements and parts so as to form a whole	categorizes, combines, compiles, composes, creates, generates, organizes, reorganizes, rewrites, summarizes	Multiple Solutions, Pictorial Annotations, Code to English, Analogies
Evaluation: making of judgments about the value of ideas, works, solutions, methods, material, etc	appraises, contrasts, criticizes, critiques, discriminates, evaluates, justifies, relates	Advice, Admonishments, Hints to Start, Empathy, Style Comments

Knowledge

At this level, we placed Defining Terms, Shell Commands, and Comparing to Outside Resources. While Comparing to Outside Resources sounds more advanced (for example, at the analysis level), the examples in the blogs did not make inferences. Rather they *recalled* and noted difference between lecture material and the material in the text.

Comprehension

Since bloggers could make any kind of annotations in their blogs, we expanded this level to include acknowledgment of a lack of understanding or questioning. Blog events that introduced terminology showed a level of comprehension beyond simple knowledge recall (like Defining Terms). The instructor began the section on overloading by showing sample overloaded methods and without using the term until later in the lecture. On the first slide where overloaded methods are shown side-by-side, blogger B1 wrote “overloading?”. In this case, the blogger did more than note the term and its definition: he understood the context enough to recognize the concept. Similarly, Connecting Output to Code and Code Tracing are placed in comprehension because they demonstrate a knowledge of what the code is doing, but not a higher level because they are not applying the coding concepts themselves.

Application

A good example occurs when a blogger translates a problem from English to code, they are not told which concepts to use (e.g. `if` or `for-loop`). Correcting Code is another example of Application because the bloggers first identify a misused concept and replace it with the correct one. A particularly valuable application blog event is suggesting Additional Practice. This includes blog content like “can you write code to print the even numbers” (on an example which required printing odds). Sometimes bloggers expand upon and apply a New Concept. For example, in class, sentinel values were introduced only with numbers. B3 noted that “sentinel values don’t have to be NUMBERS ONLY”.

Analysis

Both Explanation and Explanation of Peers' Work fall into Analysis because bloggers are able to analyze a concept or proposed solution and provide additional information. In some cases, blog events in the Explanation category may only show comprehension; however, many such cases, including our primary example for Explanation (see Table 4.1), bloggers are extending another explanation in a way that shows a higher level of understanding than just comprehension. The Hints (other) category shows a level of distinction that is a hallmark of the Analysis level. In part of one hint, blogger B1 circled curly braces, distinguishing the scope of the inner loop as key to solving the problem. In this same slide we also see an example of B1 Teaching with Questions when he asks "where does the println (or enter) happen?". This is a critical element of analysis we hope students can perform with this example.

Synthesis

Analogizing new concepts to those familiar is an exemplar for Synthesis. When students notice parallels between pre-existing concepts and one newly introduced, they construct an understanding of the new concept based on the ways in which it is similar to familiar ideas. An example of an analogy provided by B1 shows his deep grasp of a new concept. When instances of classes were introduced, B1 analogized them to "instances" in massively multi-player online games (MMOs). In MMOs such as World of War-craft, instances are areas that can have multiple concurrent copies which do not interfere with one another. Pictorial Annotations show synthesis since bloggers are quite literally putting together parts (e.g. lines of code) to form a whole (e.g. the concepts of inner and outer loops), as shown in B3's blog in Figure 4.2. Blog content based on describing Code to English was specifically taught in the class. Students were told that one should always seek to find English-definable meaning in a code segment, and bloggers took this to heart even when not prompted.

Evaluation

Among others, the events Hints to Start and Style Comments belong in Evaluation. When bloggers give hints about how to start an in-class problem, they are assessing the value of different potential approaches and picking the one they think will be best. Blog events about different coding styles (Style Comments) show evaluation since the bloggers identify what they believe to be good and bad styles (even though their comments may be based on limited experience). Admonishments included notes like "Watch out for OBOs!" (off by one errors). Statements of empathy include comments like "Genius! I didn't think of that :(" when commenting on another students' work.

While there is some degree of flexibility regarding to which taxonomic level each category belongs, including that some could arguably span multiple levels, it is interesting to notice that the techniques employed by CS1 students span the entire range of Bloom's Taxonomy. Moreover, anecdotally we see usage spanning the levels throughout the chronological delivery of the course. While these students' familiarity with CS1 concepts may be limited, they still think about these concepts at the Analysis, Synthesis, and Evaluation levels.

4.4.3 SOLO Taxonomy Analysis

To further understand the relationships between the categories of blog events and theoretical levels of understanding, we mapped our data into the SOLO Taxonomy [Big03]. Table 4.6 shows at which taxonomic level each of our categories falls.

Table 4.6: Blog event categories according to the SOLO Taxonomy

Taxonomic Level	Descriptive Verbs	Categories of Blog Events
Pre-structural: students acquire simple bits of unconnected, unorganized information	misses the point	Defining Terms, Comparing Conventions, Shell Commands, IDE Hints, Mental State, Empathy (overlap w/ relational)
Uni-structural: students make simple and obvious connections, but their significance is not grasped	identify, naming, do simple procedure	Introducing Terms, Comparing to Outside Resources, Highlighting New Concepts, Correcting Code, Code Tracing (overlap w/ multi), Drawing Memory (overlap w/ multi), Asking Questions (overlap w/ multi)
Multi-structural: students make a number of connections, but miss the meta-connections and the overall significance	enumerate, describe, list, combine, do algorithms, find out more about	Highlighting Peers' Errors, Pictorial Annotations, Connecting Output to Code, Code Tracing (overlap w/ uni), Drawing Memory (overlap w/ uni), Providing Solutions, Asking Questions (overlap w/ uni)
Relational: students can appreciate the significance of the parts in relation to the whole	compare/contrast, explain causes, analyze, relate, apply,	New Concepts, Code to English, English to Code, Teaching with Questions Explanation, Explanation of Peers' Work, Hints (other), Empathy (overlap w/ pre)
Extended Abstract: students make connections beyond the given subject area by generalizing and transferring principles and ideas	theorize, generalize, hypothesize, metacognitive understanding by reflecting,	Analogies, Multiple Solutions, Hints to Start, Admonishments, Style Comments, Additional Practice, Advice

Pre-structural

Blog events that demonstrated this level of understanding included Defining Terms, Comparing Conventions, Shell Commands, IDE Hints, and Mental State. Empathy also contained blog events at this level, but also events in the Relational level. In sample code that incremented a variable, `c++`, a student submitted work that joked that it was "advertising a dif. language". Blogger B1 expressed what we categorize as empathy on the student's work by commenting "LoL...good find...." In this case, the blog event fits Pre-structural in that it "misses the point" (the descriptive verb phrase for SOLO at this level). Arguably, one can imagine Empathy events occurring at any level in the SOLO Taxonomy, though we did not observe them.

Uni-structural

At this level, we placed Introducing Terms, Comparing to Outside Resources, Highlighting New Concepts, and Correcting Code. Some categories, such as Code Tracing, Drawing Memory, and Asking Questions, had blog events in the Uni-structural level and also the Multi-structural level. We describe these categories as overlapping since they varied among blog events due to background context. For example, Code Tracing a single `for-loop` belongs a this level, whereas a nested loop is more advanced.

Multi-structural

As mentioned above, this level includes overlap with Uni-structural for the categories of Code Tracing, Drawing Memory, and Asking Questions. Categories we placed only at this level include Highlighting Peers' Errors, Pictorial Annotations, Connecting Output to Code, and Providing Solutions. While Connecting Output to Code seems to require the same overlap as Code Tracing since the tasks are somewhat inverses of one another, cases where the bloggers made the connections between printed output and a code segment were all in the context of more interesting, multi-structured code. An example of Connecting Output to Code is shown in Figure 4.3.

Relational

Since this level includes applying concepts to new situations within the same domain, it follows naturally that translating Code to English and English to Code as well as the New Concepts category are Relational. The categories Teaching with Questions, Explanation, Explanation of Peers' Work, and Hints (other) all require a Multi-structural understanding and take that understanding to the Relational level by analyzing and evaluating. Empathy events which are Relational are more relevant to the lecture material. They are evident of evaluative thinking, as in the Empathy example given in Table 4.4.

Extended Abstract

This level includes the categories Hints to Start, Admonishments, Additional Practice, and Advice because they are all evident of metacognitive, reflective understanding. Transferring concepts outside the of the domain is a characteristic of this level, thus the Analogies category is placed in Extended Abstract. Style Comments, and Multiple Solutions are at this level because they are evidence that bloggers were generalizing CS concepts.

Hence, noteblogs demonstrated understanding at all levels of the SOLO Taxonomy, much like they did with Bloom's Taxonomy. Unlike Bloom's, some of our categories were split between levels of SOLO. However, the general trend of spanning the entire range still holds.

4.4.4 Piaget's Cognitive Development Theory Analysis

We adopted the general definitions of Piaget's Cognitive Development Theory [PI69] and adapted them to our beliefs about the incremental development of programming ability. Table 4.7 defines the four stages in the cognitive development of children and provides a mapping to the blog events that we found to be characteristic of each stage.

Table 4.7: Blog event categories according to Piaget's Theory

Taxonomic Level	Descriptive Verbs	Categories of Blog Events
Sensorimotor Stage: children experience the world through movement and senses and learn object permanence	development of reflexes, habits, coordination between vision and prehension, goal orientation, new means to achieve ends, and creativity	Defining Terms, Introducing Terms, Comparing Conventions, Comparing to Outside Resources, Highlighting New Concepts, Shell Commands, IDE Hints, Mental State
Pre-Operational Stage: children acquire motor skills (mentally acting on objects)	symbolic functioning, centration, intuitive thought, egocentrism, serialization, classification, inability to conserve	Highlighting Peers' Errors (overlap w/ concrete), Correcting Code, Asking Questions, Teaching with Questions (overlap w/ concrete)
Concrete Operational Stage: children begin to think logically about concrete events	decentering, reversability, conservation, elimination of egocentrism	Highlight Peers' Errors (overlap w/ pre-operational), Pictorial Annotations, Connecting output to Code, Code Tracing, Drawing Memory, English to Code, Providing Solutions, Teaching with Questions (overlap w/ pre-operational), Explanation (overlap w/ abstract), Explanation of Peers' Work, Hints (other), Empathy
Formal Operational Stage: children develop abstract reasoning	understanding of 'shades of gray,' physiology, love, cognition, and moral judgment	Analogies, New Concepts, Code to English, Multiple Solutions, Explanation (overlap w/ concrete), Hints to Start, Admonishments, Style Comments, Additional Practice, Advice

Sensorimotor Stage

CS1 students at this stage are using their sensations and perceptions to become familiar with the development environment, to differentiate between source code and executables, and to recognize some basic CS terminology. For example, blogger B2 defines what an "iteration" of a `for-loop` is. Other categories of blog events that are representative of this stage include Comparing Conventions, Defining Terms, and IDE Hints. The expressions of mental state, such as confusion or frustration, also exemplify this stage of sensation, perception, and simple reflexes.

Pre-Operational Stage

Examples of basic motor skills in CS1 involve infrequent, inadequate mental thought about programming concepts. Some intuition for how programs work is developed, but the focus is very narrow. CS1 students at this stage grasp ideas at the basic syntactic level. They have a naïve understanding of how computers work, but are still questioning their own understanding of the material. For example, B1 asked "does this work?" when referring to some code segment. They are able to correct simple mistakes in code, often involving some sort of syntax error.

Concrete Operational Stage

CS1 students at this stage begin to use logic to understand the semantically correct ways in which syntactically correct code can be put together to achieve some objective. Evidence in noteblogs of understanding program control flow (Code Tracing) and the current state of memory (Drawing Memory) is presented via Pictorial Annotations next to or on top of code traces. Students are Connect Output to Code and providing an Explanation of what a small code segment does in English sentences. Advanced students provide Hints (other) for active learning exercises and attempt to instruct their peers by Teaching with Questions and Highlighting Peers' Errors.

Formal Operational Stage

This stage is marked by abstract reasoning, the ability to draw conclusions from observations, and the realization that there is not always a single right or wrong answer. Computer science is filled with many layers of abstractions, and there is always more than one way to program the same thing. Evidence of different levels of abstract reasoning in the noteblogs included Analogies between CS concepts and other real-world phenomena, transcribing Code to English, providing Hints to Start a problem, giving Admonishments to avoid common mistakes, suggesting Additional Practice, and supplying life Advice relevant to the topic.

The noteblogs are filled with blog events at all stages of Piaget's Cognitive Development Theory. Many blog events are at the concrete operational stage, but many others are at all the different stages.

4.4.5 Instructor Evaluation

Additionally, we sought to understand the types of blog events that occurred from the point of view of the instructor's goals for and experience with the course. Author Simon, who taught the course, performed an unconstrained card sort of the blog event categories keeping in mind the learning goals for the course, the classroom presentation and activities designed, and the desired classroom interaction.

Overall, there were blog events that spanned the range of materials and learning events presented in the course. Additionally, blog events existed which exemplified new communication modes or content that appeared novel or uncommon in the instructor's experience with large CS1 classrooms. A summary of the results of the unconstrained card sort can be found in Table 4.8.

Table 4.8: Blog event categories according to instructor

Learning Events and Skills	Characteristic Blog Events
Singular events: basic identification, paying attention	Defining Terms, Introducing Terms, Comparing Conventions, Comparing to Outside Resources, Highlighting New Concepts, Highlighting Peers' Errors, Correcting Code, Asking Questions, Shell Commands, IDE Hints
First skill level: basic programming language and program execution concepts	Connecting Output to Code, Code Tracing, Drawing Memory
Second skill level: construction of code to perform a specific task	English to Code, Providing Solutions
Third skill level: comparison of code, recognition of common structure, description in English terms	Pictorial Annotations, Multiple Solutions, Explanation of Peers' Work
Fourth skill level: coherent expression of program execution in English	Code to English
Abstraction Events: identification of overarching meaning	Analogies, New Concepts, Explanation, Admonishments, Style Comments
New communication modes: interesting content that is beneficial to students	Teaching with Questions, Hints to Start, Hints (other), Additional Practice, Advice, Mental State, Empathy

The first, and lowest-ranked learning events level identified is *singular events* which reflect basic identification of terms, concepts, or code. These blog events reflected students paying attention or following along in class. Some were attentional in nature, and some reflected simple identification of terms or concepts that may have been read in the textbook.

Next were an ordered series of four levels of skills identified through blog events. These categories reflected levels of learning goals that the instructor emphasizes in the classroom and which are reflected in assessments.

The *first level of skills* is the most basic, involving basic programming language and program execution concepts. These involve recognizing the function of programming language terms, tracing given code, and identifying output from code execution. This skill level requires basic development of a mental model of program execution as exercised by Java code - that is code reading.

The *second level of skills* is the construction of code to perform certain tasks. This skill ranks higher in that it requires the creative application of a programming concept into programming language terms and in conjunction with an understanding of a program execution model. Essentially, this skill set gets at basic problem solving and code writing.

The *third level of skills* involves a higher level of abstraction, comparison, or description of concepts or programming terms in English words. Here we may see code related or compared to other code, or notations that identify or comment on common structures.

The *fourth level of skills* involves a coherent expression in English words of an understanding of what a code does (or at least an attempt to do so). This level of blog event recognizes that code has a meaning, in that it solves a problem, and that one can communicate about that problem in English.

A further category of blog events which falls less into specifically targeted and assessed CS1 skills is *abstraction events* and identification of overarching meaning. This category is not identified as a fifth level of skill, perhaps because it was not scaffolded specifically in classroom activities, but arises impromptu from blog events. As such, though its analytical level seems quite high, it can be hard to tell at times due to the unscripted nature of the blog events in this category. We see identification of overarching themes or meaning and going beyond in terms of higher levels of code description.

Finally, more unrelated to specific learning goals for CS1 a number of new *communication modes and content*. These involve types of reminders and questioning that often do not happen in large lecture settings but which may be beneficial (either factually or socially) to students.

4.4.6 Comparisons

The card sorts presented above help us see how our categories align with existing educational theories or form new theories. What can commonalities and differences between the card sorts tell us about students' learning experiences in CS1 lectures?

All of the theories examined have a clear "lower" level: the Knowledge and Comprehension levels of Bloom's Taxonomy, the Pre-structural and Uni-structural levels of learning in the SOLO Taxonomy, the Sensorimotor and Pre-Operational stages of Piaget's Cognitive Development Theory, and the Singular Events in the instructor's evaluation. Only rudimentary, unsophisticated thought processes are present in the blog events at these levels across all the taxonomies. Basic recognition of terminology, either through definition, highlighting, or mentioning the name, are all elementary levels of understanding. Another example of this level of thinking is referring to alternative sources of information during lecture, such as the textbook, or bringing in prior knowledge about shell commands and IDE suggestions. Somewhat more advanced students might be able to make minor syntactic corrections to code or ask some pertinent questions. And, most students at this level are able to express their mental state, even if as emoticons. The nine categories in the lower levels, Defining Terms, Introducing Terms, Comparing to Outside Resources, Highlighting New Concepts, Correcting Code, Asking Questions, Shell Commands, IDE Hints, and Mental State, are evidence that CS1 students believe it is sometimes important and relevant to think at a rudimentary level when learning to program.

Similarly, all of the theories also have an evident "higher" level of understanding as well: the Analysis, Synthesis, and Evaluation levels of Bloom's Taxonomy, the Relational and Extended Abstract levels of learning in the SOLO Taxonomy, Piaget's Concrete Operational and Formal Operational cognitive development stages, and the instructor's third and fourth skill levels and abstraction events. Categories that consistently appeared at these higher levels of understanding involved a theoretical or conceptual grasp of the material with the ability to transfer knowledge outside of the immediate context. Blog events that provide hints, analogies, expanded explanations, or multiple solutions are all evidence of "higher" levels of understanding. The ability to translate code segments into an accurate English description involves a thorough understanding of the material. And note blogs warning other students of common mistakes or giving life advice also demonstrate a comprehensive grasp of the material as well as metacognitive processes. Ten categories consistently mapped into higher levels of the four theories, Analogies, Code to English, Multiple Solutions, Explanation, Explanation of Peers' Work, Hints to Start, Hints (other), Style Comments, Admonishments, and Advice. This is evidence that during lecture, students think and take notes conveying theoretical and conceptual understandings of the material. They find using higher levels to be helpful even when learning basic concepts.

Between these two extremes is a "middle" ground, where concrete applications of theoretical concepts to practical situations occur. At this intermediate point, students demonstrate basic programming abilities: tracing of code, annotating code segments, drawing the state of memory, and connecting output to code. Mastery at this level involves providing a correct solution or translating an English specification into a program.

A few of the categories of blog events do not conform to the three generalized levels of understanding. Blog events that compared conventions, applied new concepts, or suggested additional practice were found at very different levels in all of the four theories studied in this paper. The reason for this is unclear although a possible explanation is ambiguities in our understandings of the theoretical levels. Another category of blog events that does not fit this trend is highlighting peers' errors, mostly because blog events in this category varied dramatically depending on the type of error detected and whether or not it was corrected. Also, blog events that attempt to teach by asking questions or demonstrating empathy did not provide a clear way of gauging the bloggers' level of understanding.

A generalized trend of "lower," "middle," and "higher" levels of understanding is evident from the blogs and confirmed by four different educational theories. This shows that CS1 students learn programming concepts through a range of levels from superficial to advanced. Furthermore, they appear to believe that notes at each level are valuable (based on the fact that they bothered to blog them) in a CS1 course.

4.5 Interviews of Bloggers and Watchers

4.5.1 Methodology

We conducted and recorded interviews of three bloggers and two watchers, using a semi-structured protocol. The interviews were transcribed, broken into quotes, and analyzed to find emerging patterns. Also, a survey about NB was given midterm in the course. We discuss the behavioral and perceptual changes, evident from the data, of the bloggers and then of the watchers in the sections below. This data is reported in more detail in an earlier publication [DKM$^+$].

4.5.2 Changes in Bloggers

Overall, bloggers actively thought about their note taking behavior as “bloggers”. They focused on the clarity and organization of material as well as providing alternative explanations and problem solving hints. As they took on a more active role in the classroom, the blogs became a medium for self-expression and individuation. We elaborate on these changes below.

Blogger B1, “signed up to noteblog because [he] could kind of give tips or ideas that [he] thought would help the learning process” for his peers. He explained that NB “kind of forced [him] to take [...] good notes, because other people are relying on them in some way or another.” Later, he emphasized that he “tr[ied] to make things clearer for other people.” B3 claimed that her noteblogs were “more like a student’s point of view of what the content is rather than the instructor’s point of view,” in that they might “stress a point” that the professor might not because she didn’t have sufficient background knowledge. Thus, with her noteblogs, “the content becomes more detailed and easier to understand for the other students.” B2 described the content of his blogs: “if [the professor] said something out loud important that she didn’t write down, [he] would write that down, [...] or just like if [he] had a question about like a program, [he]’d write that, and maybe like someone would ask it or something like that, and [he]’d like underline, circle important stuff.” Thus, bloggers clearly had their audience in mind and tried to please them by taking clear, complete notes with an emphasis on important concepts.

Providing alternative explanations and different perspectives was a goal for some of the bloggers. For example, B2 explained that “people don’t want to look at the same exact thing for each blogger, they want to read different stuff.” So, he “tried to write as much helpful stuff as [he] could, and keep it interesting.” He actually “looked at, like, the other people [blogging] and tried to, you know, write different kinds of stuff, [he] didn’t want to write the same stuff everyone else’s writing.” B3 also agreed that “if more people [blog], then yeah there is more variety of like watching some point that [she] might not think is important but some other people think that part is important.”

In addition, bloggers also tried to give hints or suggestions for solving the problems. B1 explained that for “some of the in-class problems, like, if you’re completely new to computer science, like it would take you way longer than the professor gave you time for in order to solve the problem, and then by then the professor would have told you the answer, so then, [he] think[s] if, just the few hints of from, like, where to start, like, what to focus on, could help them write the program a little faster, if they choose to read it.” This blogger concluded that NB was “most efficient if the person that’s blogging has [...] his own ideas of tips and ways to learn the material,” describing his blogs as “more like during class, just like an extra self-tutor kind of deal” for the watchers.”

In general, bloggers valued NB as a means for self-expression and communication. As already noted above, B2 strived to differentiate himself from other bloggers, to form his own persona. He also expressed how “everyone gets to see what I write [...] and it’s just like a cool way to get your opinion out there for everyone to see.” Later, he expanded more about the nature of the communication: “it’s a cool way to you know, if you don’t understand something or something makes you angry [...] you could write like an angry face or something without having to you know shout it in front of the whole class and everyone having to hear it, so it’s a cool way to express yourself.” B3 explained that she “can like point out and write what [she] thinks is important,” “what she found difficult, or which other students should stress more on” as a response to what the instructor thought was important in the lecture. B1 compared noteblogging to traditional weblogging, and found that both allow him to “say things that [he] wanted to say without having to say it to anyone in particular [and without] interrupt[ing] the class to say it." However, the note blogs were not personal to him in the same way as traditional weblogs or journals were. This blogger de-scribed the flow of communication in the classroom as a "downward hierarchy, like, there's a professor, there's the bloggers, and there's the students, and then, you can see everything that the person above you writes, but you can't write back to them." Thus, he concluded that "it's a forum that happens during class as op-posed to after class [and that makes a big difference] 'cuz a lot of times, like [he]'ll have like questions during class, um [he] won't bother to ask like or find the answer, and then when [he] goes out of class, [he]'ll forget about it because it's not on [his] mind at that time, [...] but it feels like if [he] could write it down, [...] then it's as easy as that."

Hence, qualities that notebloggers endeavored to achieve included clarity, emphasis on important concepts, a student perspective, various explanations, and suggestions for starting to solve a problem. These were achieved through attempts at self-expression and individuation in an ambient peer-to-peer communication medium.

4.5.3 Changes in Watchers

Two-thirds (n=48) of students who participated in the mid-course survey reported they watched blogs during class (with varying frequencies), while lack of a laptop in class was a common deterrent for non-watchers. Clearly, a change in student behavior in the classroom has occurred: students bring laptops and use them to class-related activity. Our interviews indicate that watchers valued blogs as a source of assistance, encouragement, and reassurance.

Watchers changed their in-class habits by turning to blogs to keep themselves engaged or amused. Watcher W1 commented that "the questions, like the, the input they have is really helpful," and that he "would be a little more lost" if the blogs weren't there. He explains that "since it's [his] major class, [he] should try taking notes, and then, [... he] didn't find [him]self like looking over them, rather like, [he found himself...] going to the blogs." W2 indicated that he used classroom idle time, such as when the professor was "writing something," to "look over to the other blogs to see what they have to say."

What did the watchers want to see in the blogs? According to W1, he "would look at notes if [the bloggers] outlined stuff... or if they like provided like their own like content." What did the watchers actually see? W1 indicated that when an in-class activity was underway, he would "scroll down like through [all the bloggers]" and he found that "they won't like give you like the answer directly, as much as they'll [...] give you [...] hints or like how to solve it or the logic behind like solving it." This watcher noted that a blogger was "a student too, but just [one who] helps the students learn, and to I guess like complement [the professor's] teaching." W2 also "look[s] for solutions, for how to figure out how to do this" and for "ideas on ways to attack the problem." He explained "when [he tries] to solve a problem, [he's] not sure if [he's] doing it right, not sure if the blogger is [...] either, but it gives you a feeling that you're probably going the right way."

4.6 Conclusion

Blogging, as a form of public digital note-taking, has a significant and potentially useful impact on the computing classroom. Our work shows that blogging can support a sense of community in the classroom (perhaps especially in large classes) through an ambient communication channel. But we also suggest important recommendations for instructors to engage blogging positively in their classes. Bloggers should be self-selected advanced and confident students, so that they can (and are likely to) contribute meaningful content. Additionally, the bloggers were engaged based on their perceived social responsibility to the class, in this case supported by the midterm blogger reelections.

In a study of blogging in CS1, we find that blog content spans a range of educational complexity, as evidenced by an analysis based on Bloom's Taxonomy of Educational Objectives. Student bloggers produce a range of interesting content which spans from the lower Knowledge level to the Synthesis and Evaluation levels. Importantly, blogging has reported positive impact on the student classroom experience. Bloggers report conscious note-taking changes to support clarity, multiple explanations, and peer instruction. Blog watchers appreciate the alternate viewpoints and gain confidence from seeing the efforts of their peers.

We find that student expressions of understandings of CS1 concepts as evidenced through qualitative analysis of noteblogs shows:

1. Students experience and reflect a diversity of explanations and experiences with lecture-based materials in the classroom.

2. Student blog events can be categorized within descriptions of existing educational theories and can span a range of pedagogical levels from rudimentary to advanced.

3. This evidence is reinforced by the fact that categories of blog events map to similar (high or low) levels of pedagogical taxonomies; novice student do experience CS1 material from both low and high levels of understanding.

4.7 Acknowledgements

Chapter 4, in part, is a reprint of the material as it appears in NoteBlogging: Taking Note Taking Public. Roshni Malani, Beth Simon, K. M. Davis, William G. Griswold, and Michael Kelly. In SIGCSE 2008: Proceedings of the Special Interest Group on Computer Science Education Technical Symposium, pages 417–421, ACM press, March 2008. The dissertation author was the primary investigator and author of this paper.

Chapter 5

Collaborative SearchNotes

5.1 Introduction

Many students in conventional university lectures perceive individual, private note-taking as the key to understanding lecture content, and reviewing these notes as well as the assigned reading and homework problems as the key to succeeding on the exams. However, most educators agree that students learn more through collaboration with their peers and that higher levels of learning occur when discovering and synthesizing information from various sources. We hypothesize that the Web provides relevant and useful supplementary material as well as an easy way for students to gather and synthesize these search notes collaboratively.

We developed a system that allows students to search the Web easily using terms from lecture materials, that automatically saves and shares these results in the lecture context, and that provides a simple way to review the anonymous results of their peers. We hypothesize that minimizing the time and effort required to search will encourage inquiry-based learning, that storing the search results in the context of lecture materials will provide easy access to related information when reviewing for exams, and that viewing other students' work will not only result in easily discoverable related content, but also help students learn how to refine search terms. This paper presents a thorough investigation of a preliminary deployment of the system in an active learning physics course and a social research methods course. Some students heavily used the system to search for relevant material, but all students viewed the results found. The instructor benefited from the flexibility added to preparing lecture content, whereas the students benefited from another source of reliable explanations.

5.2 System Design

The search interface operates as follows: highlight any text on the lecture slide by clicking and dragging across the characters. A small menu pops up that provides several default search engines, such as Google, Answers, Wikipedia, and Dictionary, as seen in Figure 5.1. Some instructor-customizable search engines can also be provided, such as those for physics displayed in the figure. Upon choosing a search engine, the result is displayed where the larger view of the slide was displayed, as seen in Figure 5.2. However, the thumbnail filmstrip is maintained to provide easy navigation back to the lecture content. The search term forms a new tab along the top of the main display area. Search tabs are divided into results from "my" searches and results from "their" searches, and in each category are displayed chronologically. The search tabs accumulate per lecture, because initial evaluations found that per slide search tabs are too granular and displaying all the search terms for the entire course is too much information and difficult to process.

5.3 Methodology

To explore our hypothesis regarding collaborative, inquiry-based note-taking, the system was deployed in the middle of a semester-long course on Modern Physics in Spring 2008 at a small public state university. The course covered topics such as statistical mechanics, thermodynamics, quantum mechanics, and special relativity. In addition to being a required course for physics majors, this course is second in a sequence of four courses required for a minor physics for those students who are majoring in computer science. The total enrollment for the course was fifteen students, all of whom were male. The instructor strongly promotes active learning in his classes, and is very comfortable using new tech-

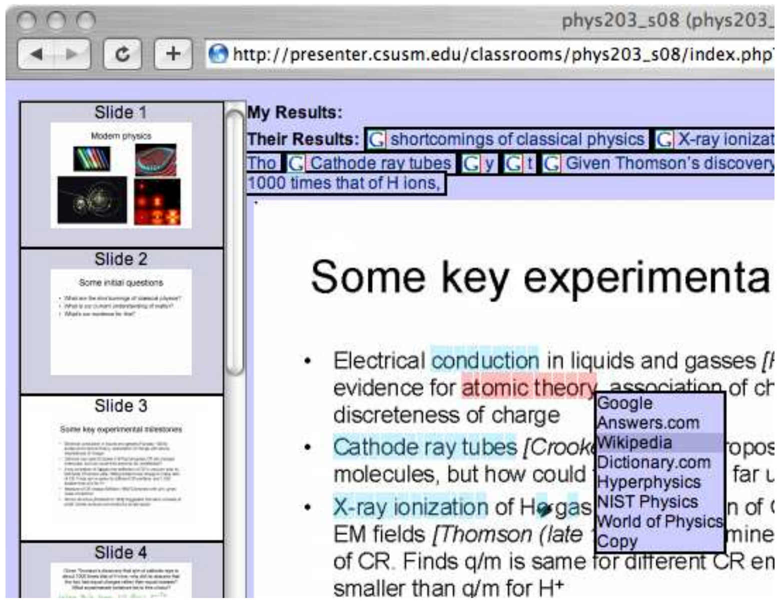

Figure 5.1: An example of searching a term

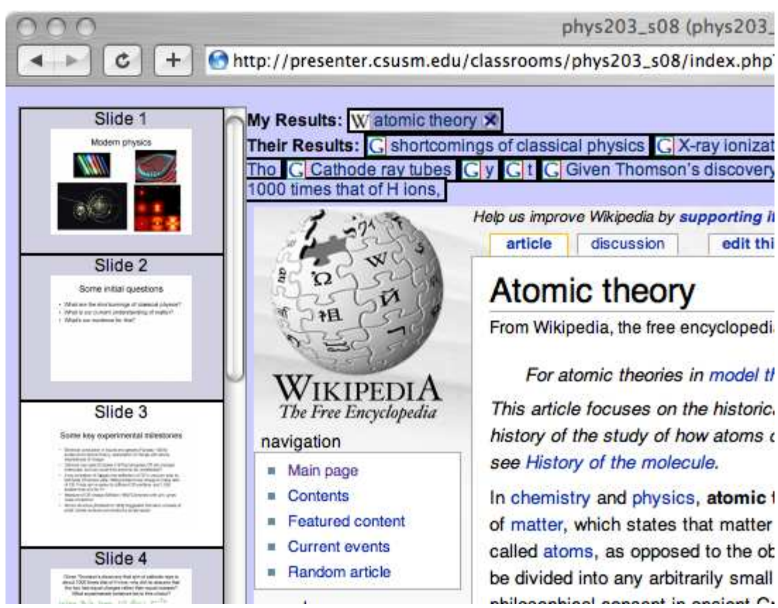

Figure 5.2: An example of viewing a search result

nologies. All students were required to purchase the course textbook as well as a clicker, and the instructor provided tablet PCs during lecture. The lectures were in a laboratory setting with six large tables, each of which could comfortably seat four students. The course consisted of twenty-five lectures, all of which were given using the Ubiquitous Presenter system, and the new collaborative, search-based notes were introduced after the thirteenth lecture.

5.4 Data

The multi-pronged methodology to explore the use of collaborative, inquiry notes in this course includes surveys, server log data, ethnographic observations, and interviews. An online survey was administered to the students, both before the system was introduced to the class and at the end of the quarter. Also, detailed logs of which queries were searched and viewed were also recorded. With the instructor's permission, author Malani conducted ethnography in half of the lectures in the second half of the course when the new functionality was enabled. And, the instructor as well as one of the students provided some useful feedback via an informal interview format.

5.4.1 Surveys

The pre-survey data provides some background information about the students, including their prior knowledge and career goals, their typical habits regarding finding content on the Web, their abilities to select and refine search queries, and their attitudes towards online collaboration. Of the eleven students who responded, more than half the students were computer science majors and two were physics major. The students represented a wide range of prior education, from second year students to fifth year students and beyond, as well as a wide range of ages, from 19 to greater than 30. More than half of the students reported that they bring their laptops to class and open the laptop and use it during class. This self-reported claim was verified in the ethnographic observations, where approximately half the students were using their own laptops and the other half either using the provided tablet PCs or not using a computer at all.

In the pre-survey, students reported using the Web to "search for more in depth info" or "for homework." Another student said that "I look up topics that are unclear or topics that require more material than was presented in class." A different student recognized the efficiency of searching the Web in contrast to searching printed materials: "I look up topics that the book doesn't cover well, or I'm too lazy to look at the book and Google gives me a quick short answer." Most students claimed to use the Web to search for relevant information, but one student highlighted the tendency to be distracted: "Every time I use the internet to lookup something physics related I end up bird-walking all over Wikipedia from liquid helium, to metallic hydrogen and just waste time."

Ninety percent of the respondents to the pre-survey believed that the Internet is a reliable source of information when studying for this class, and reported using search engines to help find information on the Web. All of those who use search engines claimed to find what they are looking for on the first page of results at least 75% of the time. If the desired information is not on the first page of results, eighty percent of search engine users are able to refine their search terms. One student said that he might rarely view the second page, another student suggested trying a different search engine, and one student would try to search the textbook or ask classmates. When asked about how they collaborate electronically with their peers, email was the most popular answer, and only one student suggested other collaborative media, such as "instant messages, message boards, and also google groups."

Most of the data in the post-survey is corroborated by the server log data provided below. Reflections about the collaborative search process is provided more in-depth in the interview data below.

5.4.2 Server Logs

The server logs provide a very accurate and detailed summary of system usage. These logs record time-stamped data about the lecture, the slide, the login name, the search query, the search engine, and whether the search action was to create a new search, to view an existing search (in which case the original searcher's login is also recorded), or to delete a search. In the three months of data gathering, there were 184 entries in the log, 97 of which were by students, not administrators and instructors. The remaining of the statistics below are for log entries by students, not administrators or instructors, and exclude search queries that can be ignored, such as terms that are less than four characters or off-topic queries. There were four off-topic queries: "scooby doo", "Price's SSN" (Price was the professor's last name), "secret easter egg", and "wakawaka."

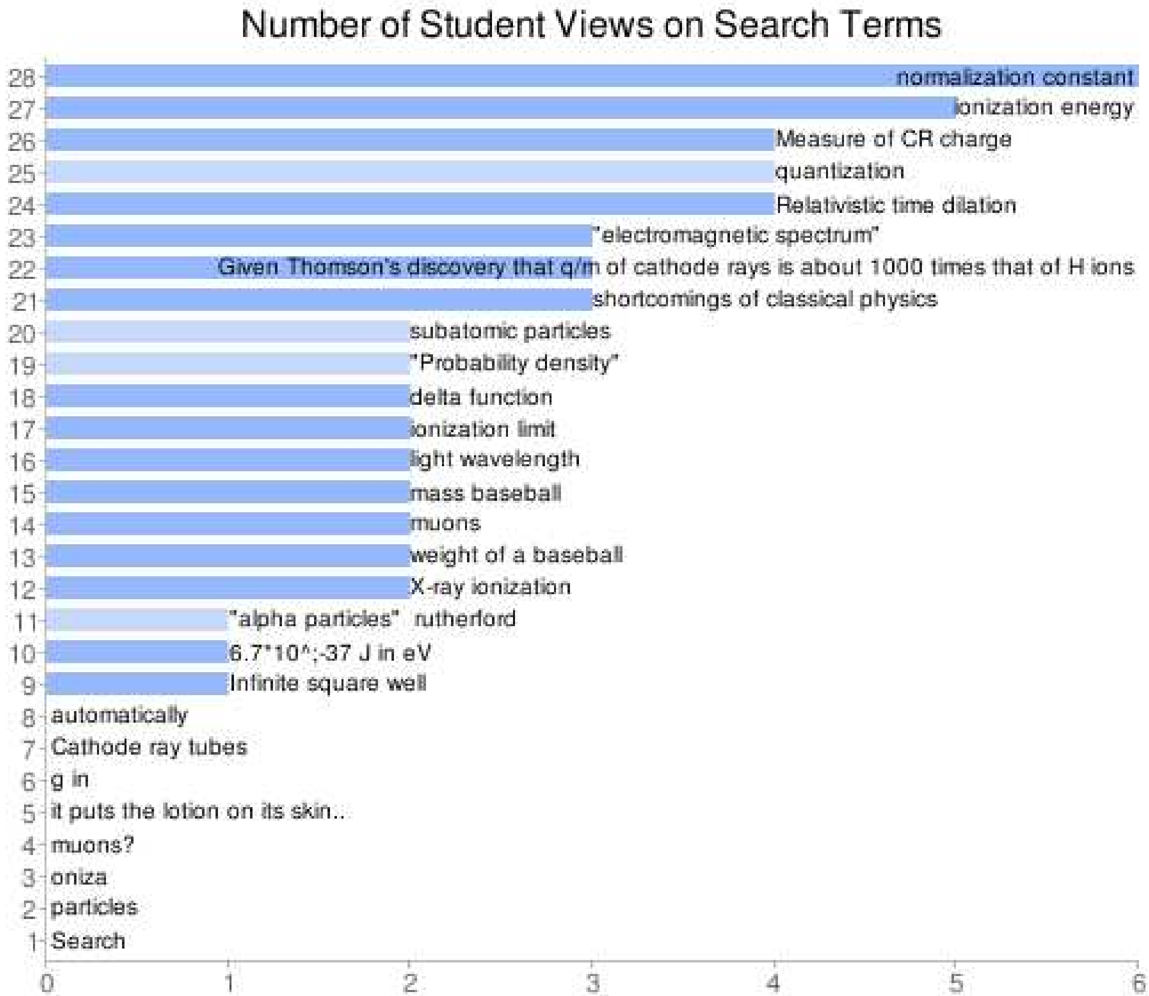

Figure 5.3: Search queries and the number of result views by students

The logs show that searches were made in the context of 10 different lectures. All of these lectures were after the search feature was introduced, and thus students did not search on previous lecture material. Thirteen different users logged in and used the search features, and ten different users actually created relevant search queries.

Comparing the time-stamps on the log entries with the actual lecture time shows that of the 97 search actions (searches, views, and deletes), 86% were performed during lecture. Of the 97 student search actions, 36% were new search actions, 53% were view results actions, and 11% were delete search term actions. Of the 35 new search actions, 69% of the queries used Google's search engine and 23% used Wikipedia's search tools. Other physics-specific search engines were also provided to the students, such as Science-World, Physics at NIST, and HyperPhysics. One query to each of these physics-specific search engines was also made by students.

Of the 10 searcher logins, did they all create an equal number of searches, or did one person do most of the searching? The server logs indicate that a few students did many searches, and most students did fewer students. To be precise, different students performed the following number of new search actions, in decreasing order: 11, 7, 5, 4, 2, 2, 1, 1, 1 and 1.

Throughout the course, there were 28 unique queries, 21 of which were open and not deleted at the end of the course. The text of these 28 queries and the number of query result views by students is shown in Figure 5.3. The lighter color indicates that the query was later deleted by the user.

5.4.3 Ethnographic Observations

The primary author conducted ethnographic observations for five lectures after collaborative inquiry-based note-taking was introduced to the class. For each lecture, the ethnographer noted the layout of the classroom using shorthand notation, as shown in Figure 5.4. In this layout, each person is indicated with a small dot, and students are numbered for ease of reference in future notes. The technology available to each student is also noted.

In each of the observed lectures, the instructor set up a tablet PC in the front of the room, connected to the projector. Each lecture often began with the instructor providing some information at the front of the room, and then assigning some active learning exercises. During these exercises, the instructor would walk around the classroom, providing scratch paper or tablet PCs to the students who needed them, talking to the students, discussing their solutions, providing starting points, etc. The ethnographer would silently wander the edges of the classroom in a similar manner, but for the most part did not interact with the students in any way. Thus, students were accustomed to people wandering around the classroom, and were not particularly distracted by it.

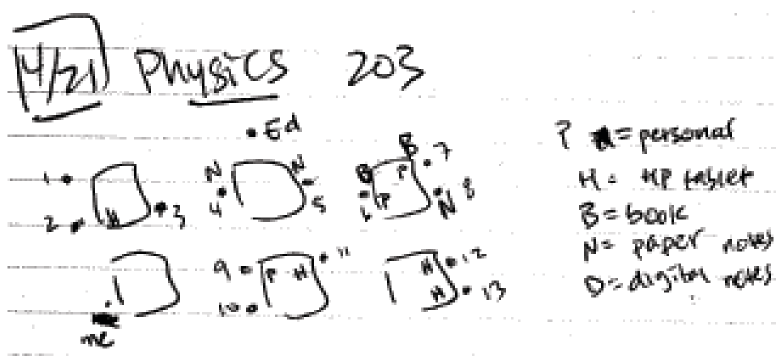

Figure 5.4: Example of ethnographic notation

The instructor made a conscious decision to encourage his students to use the Web. For example, after a demonstration of a cathode ray tubes, he said during lecture “there’s actually a good explanation of that [how cathode ray tubes in monitors work] on Wikipedia.” The server logs show that one student did indeed search the term “Cathode ray tubes.” However, interestingly, the student chose to search using the Google search engine rather than the Wikipedia one. As another example, the instructor asked the students to approximate the wavelength of a 100 mph fastball using quantum mechanics perspective. To solve this exercise, students need to know the mass of a baseball, and the server logs indicate that both “mass baseball” and “weight of a baseball” were searched on the Web using the integrated search functionality. In addition, the ethnographer saw other students using external Web sites to also look for this information.

5.4.4 Informal Interviews

Informal interviews with the instructor before, during, and after the collaborative, inquiry-based search features were introduced to the class lead to several insights, the most important of which relates to active learning classrooms. The instructor said that "the problems we do in class often have more to do with knowing *how* to do something, rather than knowing *about* something." Using this approach to lecture content, the instructor often does not provide key searchable terms in the text of his lecture slides. Rather than introducing a concept by its formal name, he provides everyday examples of the concept first. Thus, the instructor claims that "I usually don't do that [include terms in slides] because I want them to think about what phenomena are involved." This key observation lead to a slight redesign of the collaborative search feature, and a search text box was added in addition to the text selection on the slide feature.

Another insight from the interviews was about the cumulative result of student work in the classroom. Not only does the collaborative search feature allow the instructor to "ask more open ended and under-specified problems," but also the "students' work in class becomes less contrived and more realistic – a supervisor or client will expect you to use the Web, etc., to figure out info you need to solve a problem." Also, the instructor realized that "the search options are much more open – so one student may search on something that another student never thought to search on." A student in the class acknowledged this benefit of collaboration and said that "I do look at what others have searched. It's quite possible that they are searching for something I had not thought of and this would be information that I may not have ever found out about."

5.5 Analysis

The data indicates that all students can participate in the collaborative, inquiry-based note-taking. Some students are more confident in their abilities to find related content on the Web, whereas other students are not. Those students with pre-existing knowledge in search and in refining search queries will tend to excel in creating new search terms. However, most students are confident in their abilities to read related material and thus, most students will browse the results of their peers' search queries.

5.5.1 Searches in Lecture Context

Search notes on the lecture slides is a new behavior that students need to learn how to use in order for it to be effective. There is a learning curve for this behavior, even for those experienced in searching. Most students use browser toolbars or home pages of search engines as their default behavior when searching for content on the Web. Automatically saving the results in the context of the lecture prevents the results of their searches from being lost amongst their other unrelated browser history.

5.5.2 Automatically Saved Results

However, students in this class did not find the automatically saving the results in context as useful as anticipated, because the majority of the student usage of this system was during class. Very few students reviewed the results of their search notes outside of lecture, for example, when reviewing for their exams or preparing homework assignments.

5.5.3 Automatically Shared Results

The benefit of automatically sharing the results with the rest of the class definitely kept the students focused on the course material when searching the Web through this interface. The ethnographer observed that some students were distracted during some parts of lectures, especially if the student had brought his own personal laptop. However, these distractions were mostly email or instant messaging, and once, a student was observed completing a programming assignment for a different course. However, over 80% of the search queries were on topic and very related to the course. Thus, this tool minimizes distraction and helps retain student attention.

From the data gathered, no conclusions can be made about the length of time students spent looking at the search results or why students did not use the system outside of the lecture very much. Also, the small laboratory environment in which this lecture was held is not very representative of traditional lecture halls with fixed chairs in rows and small tables. Thus, this preliminary evaluation provides a good starting point in understanding how students use collaborative search notes, but further investigation is needed to determine how the system will scale. The system has been deployed in two other computer science courses, but that data is still being gathered.

5.6 Conclusion

The most important lesson learned is that collaborative search is a new mode of interaction for the students that must be learned. The new search behaviors must be acquired, practiced, and refined. The instructor may choose to model good search behavior to encourage students to use it. However, starting with the functionality from the beginning of the course will also likely encourage its use.

Another important lesson is that not all students will be comfortable executing search queries and that not all queries will result in relevant information. However, some students who feel comfortable in their search abilities will use the system extensively to search for related content. Most students will review the pertinent findings of others. Thus, exploratory and discovery learning is enabled for all by the selfish work of the few.

The instructor of the physics course summarized this collaborative inquiry-based note-taking tool as "a *productive* thing the [students] can do on the Web." Collaborative search-based note-taking has the potential to encourage students to address gaps in prior knowledge, to find alternative explanations, to explore additional examples, and to discover multimedia content related to lecture material. Embedded searching of terms from lecture materials and seamless sharing of results allows students at all levels of abilities and skills to learn various methods of inquiry. Future work is needed to explore the effects of this tool in a more conventional large university lecture.

Chapter 6

Integrative Notes

6.1 Introduction

Students attending university lectures perceive note-taking as a key to academic success and have developed their own habits and practices. Technologies aimed at enhancing the activity of student note-taking, in order to be widely adopted and used, must strive to minimize changes to existing behavior while providing pedagogical benefits. SearchNotes (presented in Chapter 5) radically changed the style and content of the notes, and thus required instructor-driven incentives for participation and use. NoteBlogs (presented in Chapter 4) relied on the metaphor of live blogging to ease the transition to a different flavor of note-taking. The goal of this study is to determine how closely technology can emulate traditional note-taking, while still encouraging peer learning with minimal distraction.

The main idea of Integrative Notes is that a few students take handwritten notes in a very natural manner, which are then published online after lecture, embedded in the instructor prepared slides. To save development time and answer the research questions without delay, Integrative Notes were evaluated with a *Wizard of Oz experiment* [Kel83]. In this research methodology, subjects interact with a computer system that they believe is autonomous, but the system is actually being partially operated by an unseen human being. This research methodology is commonly used in human-computer interaction [KSC+00, PFS+95] as well as fields of experimental psychology and linguistics. In this study, the human operations could just as easily have been implemented programmatically given more time.

The immediate purposes of the study are to understand the following qualities of the form factor: (1) to determine the value of public digital notes when shared asynchronously after lecture, as compared to live during lecture like NoteBlogs, (2) to discover the benefits of high resolution digital notes, and (3) to evaluate whether juxtaposed or superimposed notes are more valuable to students. We believe that these questions can be answered with a Wizard of Oz style study, though automatic clipping and publishing of notes would be preferable.

6.2 Experimental Design

Integrative notes are captured using Livescribe technology (see Figure 6.1 from http://www.livescribe.com), which is a revolutionary paper-based computing platform. Livescribe mimics regular pen and notepaper, and the interactions are very natural. The ballpoint smartpen, called the Pulse, is an embedded computer with a high speed infrared camera to record the location of pen strokes, a force sensing resistor to detect pen down, a small OLED display to provide feedback, a microphone to record audio, a speaker for playback, and an internal flash memory to store the handwritten notes and drawings. The pen must be used with special dot paper, which is regular paper printed with very small infrared dots, which enables the pen's camera to track the pen strokes. Connecting the pen to a computer using a USB dock after lecture allows the handwritten notes and audio recording to be transferred, organized, searched, and shared. Even though the Livescribe Desktop software provides a mechanism to publish the notes and audio online, these notes are not shared in the context of the instructor prepared materials and are not shared automatically with all of the students in the course.

In the Integrative notes system, students were given the choice either to take freeform notes on blank sheets of paper or to make annotations on top of the prepared lecture slides. The freeform notes were recorded in the single subject lined notebook that

Figure 6.1: Livescribe Pulse smartpen, dot paper, and desktop software

comes with the Livescribe system, which mimics very directly the notebooks sold in the campus bookstore. The annotation notes mimic the behavior of printing out the slides before attending lecture, to reduce the amount of effort in duplicating what the instructor has already prepared. Normal paper must first be printed with the dot pattern and then the lecture slides, before annotated notes can be captured digitally using the Livescribe technology.

The digital notes, captured using the Livescribe technology, are then shared automatically with all of the students in the course, embedded in the lecturer's prepared slides using the Ubiquitous Presenter (UP) system. At the end of lecture, the researchers collected the pens and let the students take the paper version of the notes with them. The notes were then transferred to the computer by docking the pen in a USB cradle and then uploaded to the UP website. The freeform notes were split according to what content was most relevant to which slide, and appended below that slide online, as seen in Figure 6.2.

The notes that annotated the prepared lecture slides were clipped to the relevant content and then superimposed digitally on the corresponding lecture slide on the UP website. The superimposing used the same interaction features as the NoteBlogs, as demonstrated in Figure 6.3. The screen shot in the background shows the instructor's annotations, and the screen shot in the foreground shows the students notes. The student notes for a given slide are visible temporarily by hovering over the student's login name in the

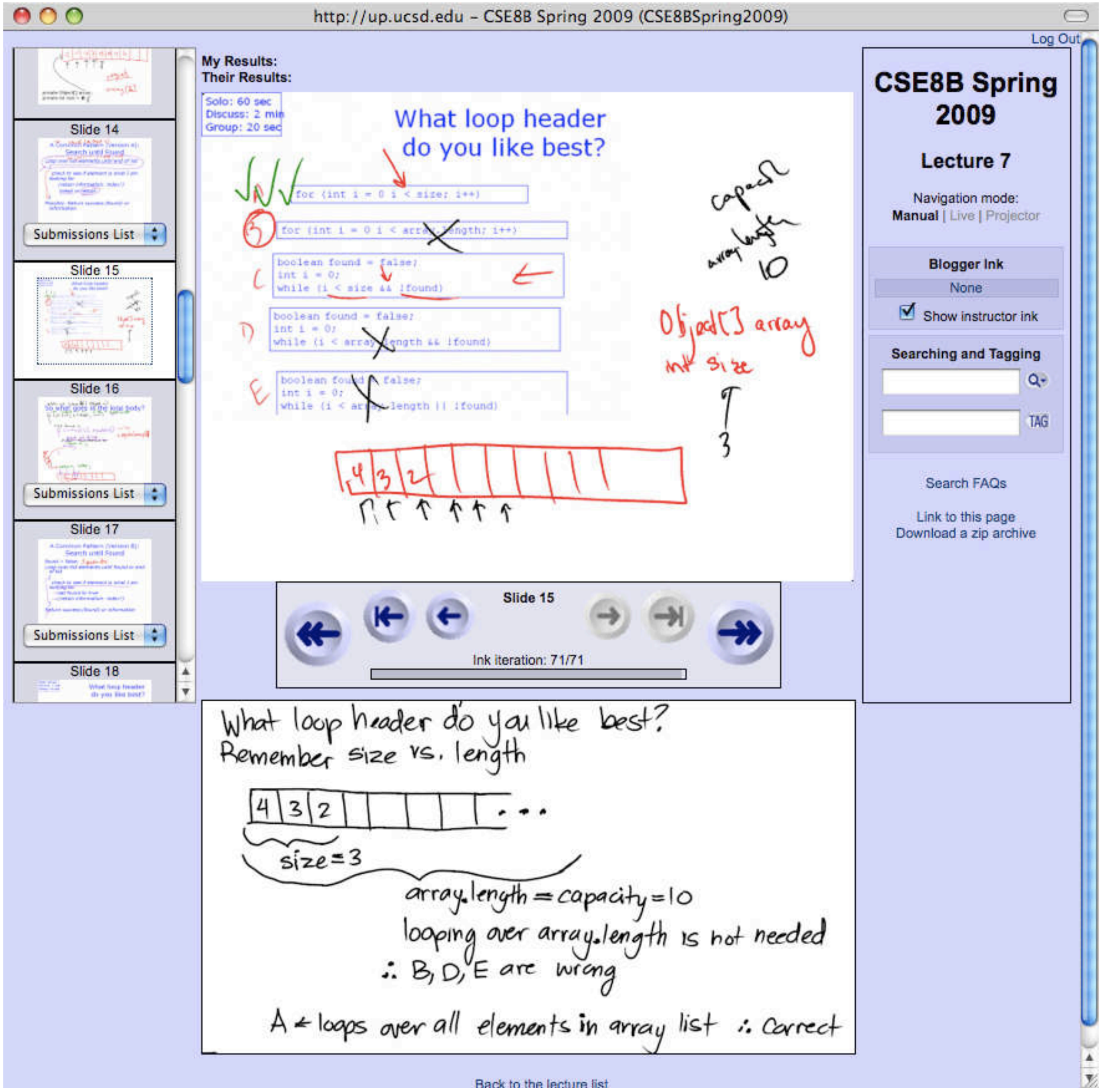

Figure 6.2: Example of juxtaposed integrative notes

right-hand panel or more permanently by clicking on it (making it filled with a darker background as seen). Note that the instructor has easy access to different pen colors on the tablet PC, and thus, emphasizes the difference between the multiple choices using color. The student only has one color in the Livescribe Pulse pen, and thus uses space indicators (such as arrows and large square brackets) to differentiate the choices.

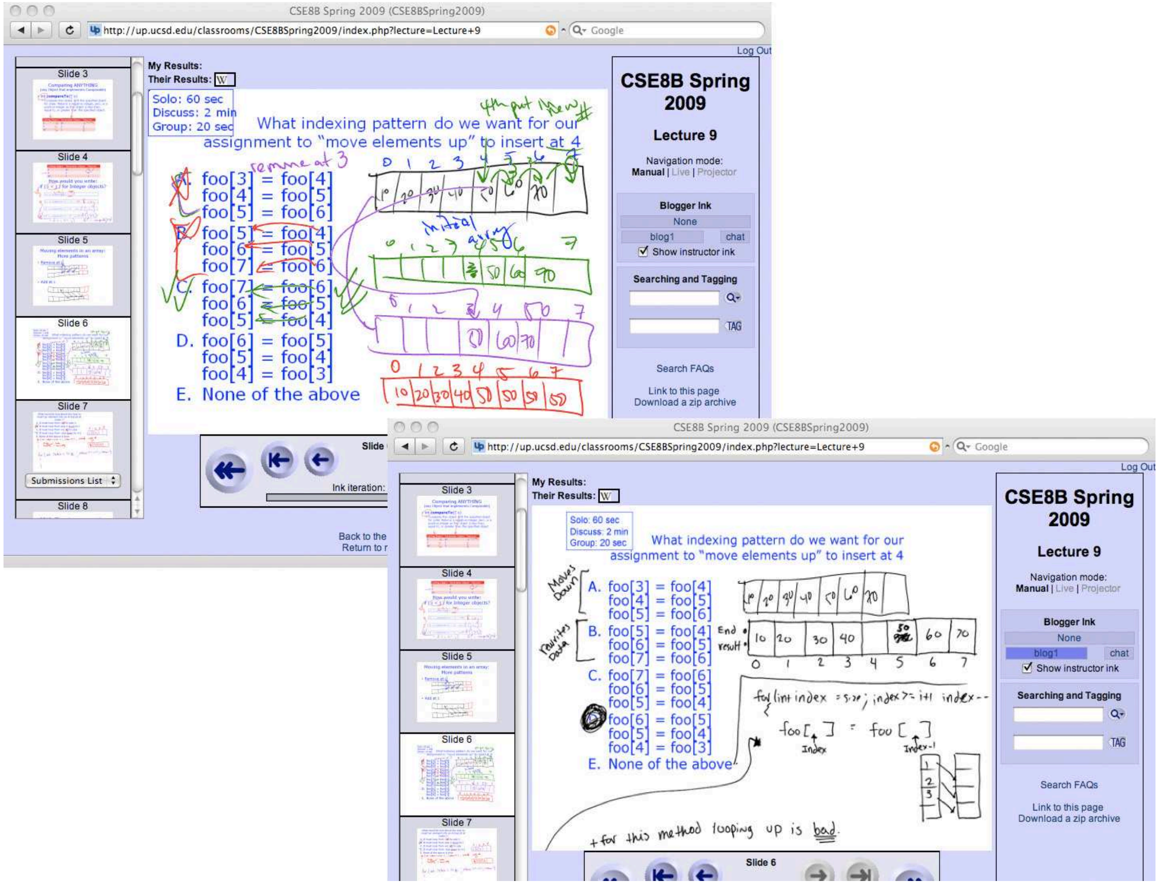

Figure 6.3: Example of superimposed integrative notes

Thus, students perceived that the handwritten notes captured during lecture were automatically being published on the Web. Because of the time limitations of this study, the notes were manually clipped by the researchers, thus creating a Wizard of Oz style experiment. Given more time, automatic clipping of notes and posting to the appropriate slide online would be feasible. Automatically determining which portion of notes is relevant to which slide can be determined by eliminating whitespace, interpreting some sort of next slide gesture from the student, and using timestamp information of both the note-taking pen strokes and the next slide action from the instructor.

6.3 Data

The Integrative Notes system was deployed in a second quarter introductory programming course (CS2) in Java, which covers topics including arrays, recursion, and basic searching and sorting algorithms. The system was studied over two quarters (Winter and Spring of 2009) in two different offerings of the same course by the same instructor. For both quarters, the instructor elected to use the Ubiquitous Presenter (UP) system to present lecture slides, to conduct active learning exercises, and to make lecture materials available to students for later review. Active learning exercises were a focal point of lecture, and the instructor asked an average of 10 different multiple choice questions during lecture. Students first answered each question individually, submitting their responses using the i>clicker system (see http://www.iclicker.com). If one answer did not receive a majority of the votes, then the students were given two minutes to discuss the solution with their neighbors and then each student answered the question again. Then, the instructor would discuss all of the choices as well as the correct answer before moving on to the next topic or question.

In each offering of the course, three students volunteered to take Integrative notes with the Livescribe pens. In the Winter quarter, the system was introduced in the last three weeks of the course, and all of the students were surveyed in the last class meeting before the final using the i>clicker system that they were required to bring to class everyday. In the Spring quarter, the system was introduced near the beginning of the quarter, ethnographic observations were recorded every lecture, and the students filled out a paper survey on the day of the midterm. Also, interviews via email were conducted with the Integrative note-takers.

6.3.1 Surveys

In the Winter quarter, a total of 78 students were enrolled. In the last class meeting before the final exam, a survey was conducted by projecting questions in the front of the classroom and the results were gathered using the Clicker system that students employed during every lecture. Of the 78 students enrolled, 56 students participated in the survey.

In the Spring quarter, a total of 69 students were enrolled. The survey was conducted on the day of the midterm. A single sheet of paper was handed out at the beginning of class, and students could work on it while other papers were being passed out. The survey was collected again at the end of the midterm. The sheet of paper had an open response question at the bottom. Of the 69 students enrolled, 55 students participated in the survey.

The first two questions on the survey asked students whether they used the Ubiquitous Presenter system to prepare for the exam and how much of the handwritten student notes did they read. Of the 111 students total that responded to the survey in both quarters, a total of 55 students used the system and read any of the Integrative Notes. Approximately 20% of the students did not use the Ubiquitous Presenter system to study before the exam. In the open response portion, one student reported “I downloaded the slides” and another student said “I’ll check them out next time, I was too busy this time.” Many students, especially in the Winter quarter, were not aware of the availability of student-written notes on the UP website. Thus, the next quarter, we made an announcement in the lecture prior to the midterm and demonstrated how to access the notes online. Despite this announcement, one student commented “We have student notes on UP!?” on the survey.

The next three questions of the survey asked students about how useful, how interesting, and how distracting the handwritten student notes were. The answers to these questions would only be meaningful if students read any of the notes. The results, across both quarters of the same course, for the 55 students who reported that they read any of the notes are summarized in Figure 6.4. More than 80% of the students reported that Integrative Notes were somewhat, mostly or very useful, and a similar percentage reported that the notes were interesting. 22% of the students found the notes to be very useful. 60% of the students indicated that the Integrative Notes were not distracting at all.

In the Spring quarter, one of the students volunteered to take Integrative notes superimposed on the lecturer’s prepared slides. Of the 34 students that quarter who reported having used UP to read any of the notes, approximately 30% preferred these superimposed notes and the rest of the students preferred juxtaposed notes. Two students provided general feedback regarding this feature: “handwritten notes at bottom were good for sum-

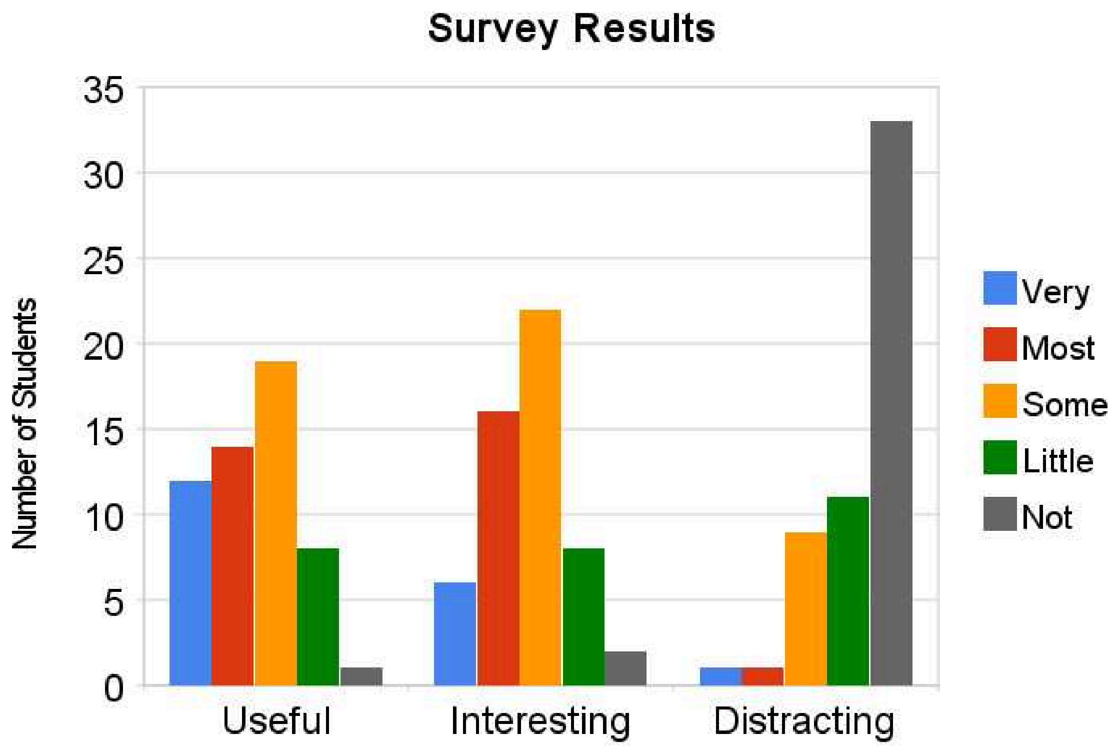

Figure 6.4: Summary of Integrative Notes Survey Results

mary" and notes "below [the lecture slide] is best since they are supplementary to the slides."

The general feedback varied from positive responses such as "cool idea" and "very useful, especially [the] feature that allows me to toggle instructor ink on/off" to mixed responses such as "student notes wasn't that bad" and "the notes were not much different from what was covered in lecture." Students recognized that the Integrative Notes were a "good supplement" because "it came in handy when I couldn't read [the instructor's] slides" and because the Integrative note-takers "were able to write down the important things said in lecture that would take too long for professor to write." Also, one student indicated a learning curve: "I just need to get more familiar with it and I will take more advantage of it."

6.3.2 Ethnographic Observations

In the Spring quarter course, ethnographic observations of note-taking during lecture were recorded. For each lecture, a seating chart was created, describing what kind of notes students took and where they sat. Figure 6.5 is a representative example of how this seating chart was recorded. The chart provides insight into how the ecology of the lecture hall affects the note-taking as well as the discussions during active learning exercises.

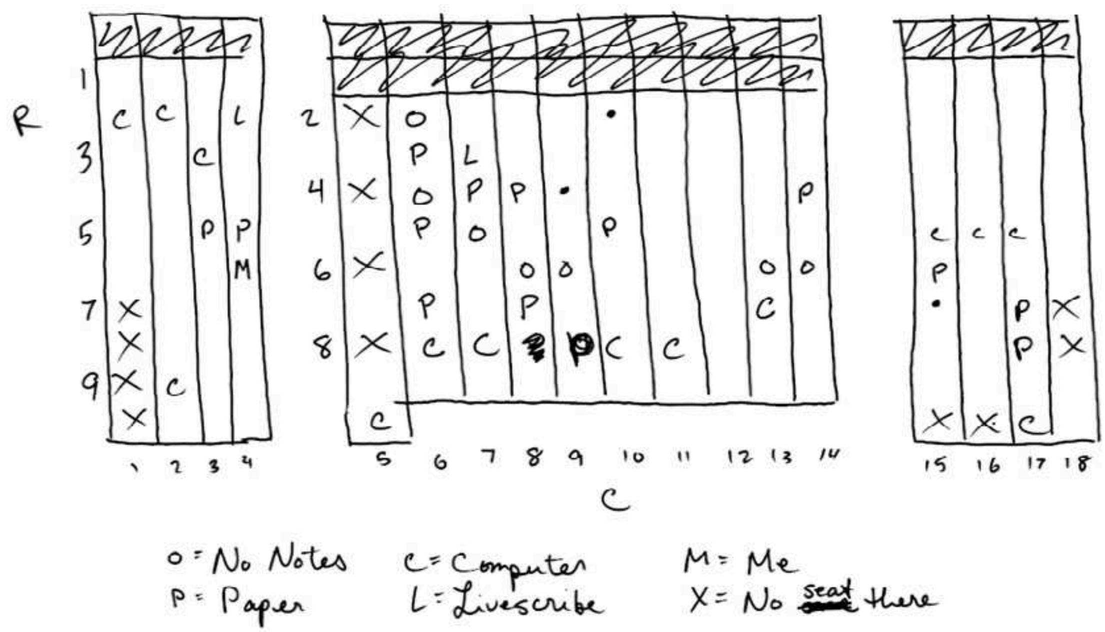

Figure 6.5: Example of seating chart ethnography

On average, 40 students attended lecture. Usually, 10% of the students take Integrative notes, 35% have laptops open on their desk, 40% have paper notebook and pen on their desk, and 15% have no note-taking device open. Students generally tend to sit in the same area of the lecture hall, and certain groups of students tend to sit together. Often, friends and collaborators tend to sit in the same row, because the acoustics of the classroom and the chairs bolted to the floor makes it difficult to hear what people behind you or in front of you are saying. Also, those with laptops tend to sit near outlets, like the one in the middle of the room in row 8.

In addition to the seating chart, the activities of selected computer screens throughout the lecture would be monitored and recorded. An example of such recording is provided in Figure 6.6. Such localized observations provide insight into how much students multitask during lecture as well as how they manage their attention and distraction.

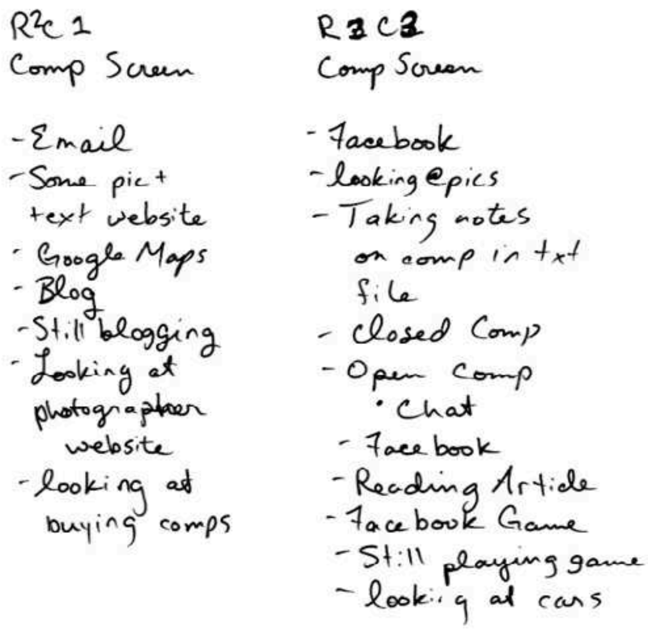

Figure 6.6: Example of laptop activity monitoring ethnography

And finally, a sequential recording of observations during lecture were recorded. Each event identified the student or group of students involved, by referring to a row and column number in the seating chart for that day. A small sample of these sequential recordings in Figure 6.7 demonstrates all of the various things students do during the time allocated by the instructor for discussing an active learning exercise. Even though these observations are not explicitly focused on student note-taking, they demonstrate how students participate at different levels and how students manage their attention during lecture.

Ethnographic observations focused on the Integrative note-takers indicate that they are avid note-takers, often writing notes even if no other student in the class is. For example, the ethnographer observed that both Integrative note-takers were the only students writing notes when the concept of enumerations was introduced. These students are often

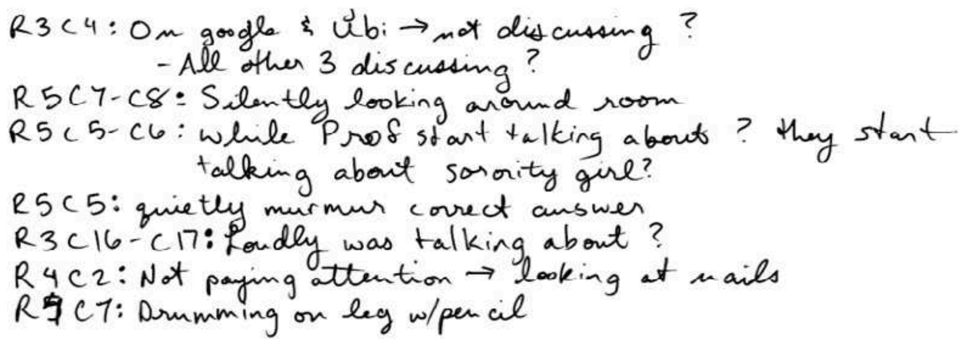
R3C4: On google & Ubi → not discussing ?
- All other 3 discussing ?
R5C7-C8: Silently looking around room
R5C5-C6: while Prof start talking about ? they start
talking about sorority girl?
R5C5: quietly murmur correct answer
R3C16-C17: Loudly was talking about ?
R4C2: Not paying attention → looking at nails
R5C7: Drumming on leg w/pencil

Figure 6.7: Ethnographic notes of student activities during active learning

writing when the instructor is explaining the solution to an active learning exercise, and especially so when the student answered the question incorrectly. The ethnographer also observed that the student who takes Integrative notes superimposed on the lecture slides is often shifting his gaze between the projected slide and his paper notes: “R3C7: taking notes (look back and forth between paper & slide), Prof asked ? & he attended to her, clicked answer & now taking more notes”. Also, these self-selected students are responsible for their own learn, and they bring additional resources to the lecture: “R2C4: looking through book to find answer to clkr ? ”.

The most interesting observation is how the two most active Integrative note-takers would frequently tag-team to make sure all the important content was captured. For example, the ethnographer noted that one day “R2C4: Took break from notes & looked at R3C7 while Prof started talking really fast” and then “R3C7-C8: wrote notes like crazy about new concept”. Another day, at one point: “R3C7: taking notes on what [Prof’s] saying, R2C4: wasn’t taking notes while [R3C7] was → Now both taking notes” and then they switch at another point: “R2C4: Taking notes R3C7 wasn’t, but wrote at end of Prof narrative - Both stop for new [clicker] ? ”.

Observations of students who bring laptops to lecture provide evidence that some can be very attentive while others can be easily distracted. For example, one student focuses on the lecture presentation system “R5C8: Ubi Pres → never veers from this screen”. Another observation is regarding a pair of students who had laptops on their desks: “R5C15 & R8C16: No notes & yet very attentive”. Students are often searching the Web during lecture, and at times this can be distracting: “R8C6: Searching web, not paying attention → until clicker ?”. Sometimes, other students in the course are inadvertently distracted by those with laptops: “R8C10: gets distracted by R8C11 game on screen”. However, students are aware of this issue: “R7C5 & C6: discussed ? & now talking about how R7C5 gets easily distracted on his comp - now both people behind them are involved”.

Observations of students who take notes on paper indicate that students take notes during active learning exercises, during the instructor’s explanation of the exercise, and after the explanation has finished. One observation of a student taking notes during the active learning exercise suggests that students might use the discussion time to catch up on the note-taking from a previous topic. Several students may only focus on the answer, for example “R4C2: Playing w/ nails, not voting on ?s → notes during explanation”. Students especially take notes when an active learning exercise reveals a misconception: “R3C7: Telling guy behing him (group discussing 2 diff answers) → was wrong so wrote notes when find out correct answer”. Another observation evidences how students mimic the instructor after a slight delay: “R3C8: Drawing array like prof, While drawing on screen → student not writing, After main explanation, begins writing again”. This note-taking style carries over to the Integrative note-taking behavior as well: “R3C7: Paying Attention while explaining ? & answer, Began taking notes when new slide + ? came on screen”.

Students are always prepared to take notes, even if they don’t actually take notes or pay attention. For example, one observation is “R7C8: Notebook open but not taking notes (texting)”. Evidence reminds us that students may take nonlinear notes: “R5C3: Went back to add detail to page”. Even though most students take notes in a spiral notebook, there are some students (in addition to the Integrative note-taker) who print out the slides and bring them to class: “R5C4: Taking notes on slide but w/ arrows & circles”.

6.3.3 Content of Integrative Notes

Another source of data is the content of the Integrative Notes. What did students actually write down to share with their peers? As novices in the subject matter, students imitate the more experienced instructor while expressing their own interpretation. Students draw and annotate arrays or other structures in a similar manner to the instructor, and they tend to use the same example, even if the numbers are concocted by the instructor in the moment. For example, in Figure 6.2 the array of size three can have any three numbers in it, but the student writes the same three numbers as the instructor.

In addition to imitating the writing, students' notes also reflect what the instructor says verbally during class but may not have the time to write on the prepared slides. This behavior is evident when multiple students use the similar phrases in their notes. One clear example occurs when students are learning about switch statements. The instructor asks students to write a switch statement: "Given a double grade variable, assign a value to the char letterGrade variable". After students discussed and tried to write a solution, the instructor reviews some of the submitted solutions with the class, providing a verbal explanation and writing "CAN'T DO IT" (emphasis not mine) on the slide. Three students use similar phrasing in their Integrative notes to explain why a switch statement cannot assign a letter grade based on a number between 0 and 100: one student wrote "oops, can't do it, or at least shouldn't use it for this because only checks for equality using ==", another noted "switch statement not good for finding range, only compares using '=="', and a third student wrote "switch statements ONLY check for equality using ==". Thus, students are adept at capturing precise explanations, especially in an exercise where they tried do something and did not succeed.

While copying the instructor's writings and drawings and transcribing the instructor's speech, students are capable of adapting to the affordances of their technology and the resources available to them. For example, students using the Livescribe pens only had one color available to them, whereas the instructor is able to quickly and easily change pen colors. Therefore, the instructor often uses color to disambiguate the possible multiple choices. For example, the instructor drew multiple arrays in different colors in Figure 6.3. The black-colored array on top represents the given array. The green color represents the correct answer, with arrows on the black array describing desired behavior and a green-colored array below showing the result. The purple and red arrays are color-coded to explain why the two other common answers are incorrect. The student note-taker does not have a variety of colors to choose from, and thus captures the resulting arrays in English phrases next to the incorrect answers, using space rather than color. Students commonly use large brackets and arrows instead of colors.

Students usually do not copy gestural ink [PMS07], that is spontaneous ink added to the slide to draw attention to that portion of the screen while talking and explaining a concept. For example, the black arrows under the array in Figure 6.2 are ink gestures to show how the size of an array can change, but not the capacity or length. In the same instructor slide, the red arrows are also ink gestures that highlight specific parts of the code segment that are important to consider in determining the correct answer to this multiple choice question. Gestural ink is an affordance provided by having prepared material to write on top of and refer to. Even though students who take superimposed notes also have this affordance, they rarely use gestural ink. They do use arrows and circles to draw attention to certain places, but these gestures are not standalone like the instructor's. Adjacent to the gestures, students usually provide a written explanation.

Integrative note-takers, especially those who take juxtaposed notes, add their own organization and structure to the given content. For example, one Integrative note-taker often organized the entire lecture's contents in an outline format. Each important concept discussed during lecture is preceded by a roman numeral and starts in the left margin. Examples and code segments are written below and indented. For example, lecture 14 of Spring quarter was outlined by the student as follows: the top level contents were topics on the quiz, learning goals for the lecture (which helped organize what followed), linear search, telephone book search (also known as binary search), and fibonacci numbers. The second level contents of telephone book search were method header, base case, if the element to find comes before the midpoint, and if the element to find comes after the midpoint. Roman numerals, letters, and numbers highlight the important points. When this student's notes were posted online, content relevant to each slide was posted individually, and the overall outline structure was a bit lost. At times, when all the content was too closely related, it would be posted on the initial slide and no notes were juxtaposed to the following slides.

And finally, the Integrative notes were examined not just individually for content

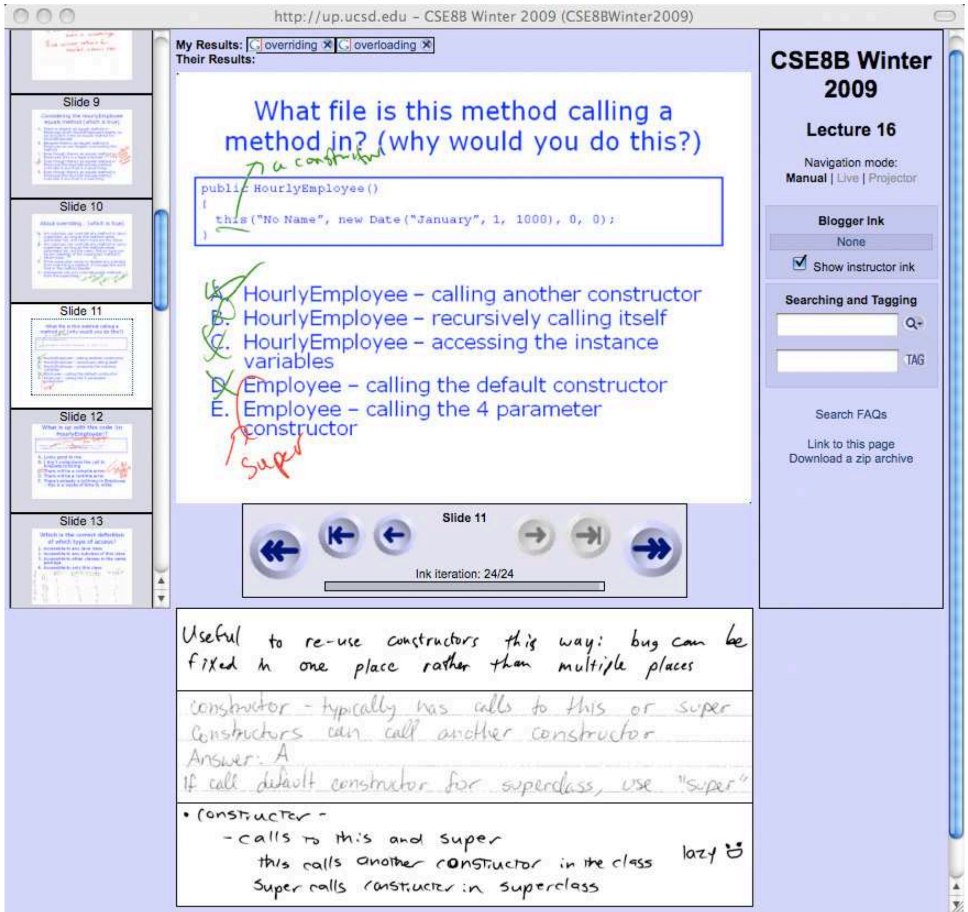

Figure 6.8: Juxtaposed Integrative Notes with different perspectives

and style, but also in context of the lecture slide and each other. Viewing notes about the same topic from different students reveals their different perspectives. Also, when the instructor speaks too fast and present multiple pieces of important information about the same topic, different students pay attention to and understand different aspects of what the instructor said. Their notes then reflect their own perspectives, which can be quite different when examined together. For example, when learning about how to design constructors, especially when considering inheritance, the instructor discusses the keywords `this` and `super`. Figure 6.8 shows the various things students thought was important about the topic, and how each student's notes adds an interesting point to the overall argument. One student explicitly defines the two terms, another discusses what the default is, and a third explains the advantages of the design presented for debugging.

Thus, the content of Integrative notes mirrors the instructor's verbal and written content, while optimizing away unnecessary gestural ink, adding extra explanations, structuring the content into important topics, and capturing different perspectives on the same topic.

6.3.4 Interviews

The Integrative note-takers volunteered to take public notes during class with the Livescribe pens. Besides the opportunity to try an exciting new technology, what other motivations did these students have? Can only overachieving students who are bored during lecture take notes meaningful enough to share with everyone in the class? Do these self-selected students believe that they are paying the cost of laboriously taking notes while everyone else benefits? We asked three note-takers some questions trying to get at these issues.

When asked how do you feel participating in this experiment benefits you, one Integrative note-taker responded, "I feel that since others are going to look at them, I should take good notes which makes it easier for me to study, because my notes are that much better". Thus, the social pressures of performing well in front of others enhanced the quality of his notes, which in turn improved his understanding of the material. On the other hand, another student claimed that "I wouldn't say it helped ME more, (maybe subconsciously), but I hope it helped others" (emphasis not mine). Interestingly, this student professed that he usually does not take notes: "I usually don't take good enough notes to the point where other people can understand them, and on top of that I didn't normally take notes in [this] class, because we were encouraged to bring our computers and participate thru clickers or on UP." Despite his natural inclination not to take notes in this class and his worries about "how atrocious [his] handwriting could be," this student continued to participate in the experiment. Another student who volunteered to participate in the experiment only took notes for one lecture, and then declined to continue participating for similar reasons. He told us that he likes the idea, but would rather spend lecture time discussing verbally with his classmates during the active learning exercises.

We previously found that students are aware consciously of an audience of other students who would be reading their notes in the NoteBlogging study. Is the pressure of other students reading your writing diminished when the sharing is not live but delayed until after the lecture? We asked the Integrative notetakers whether they are consciously aware of an audience when writing notes or if they simply continue to write notes as they normally would. One student responded, “Yes, I consciously took better notes because I knew people would be reading them,” adding that “I tried to write/illustrate concepts in a different way from the teacher to give people a different perspective.” Another student said that, “At first I was just taking notes for myself, things that I thought I need to know, then when I saw that my notes were possibly going to be shown to everyone, I started taking more precise notes, and things that I thought would help them, because it helped me out.” Thus, sharing after lecture only delays the realization of an audience, but does not eliminate it over the duration of the course.

In this study, we also found that the Integrative note-takers appreciated having other students share their notes as well. For one student, it alleviates some of the performance anxiety: “I think its good to have more than one person share notes, I wouldn’t want all that pressure". This student also made an interesting point about number of students sharing notes: “it would be like being a TA if i were the only one providing notes.” Another student modestly recommended that “I just want the best notes to be shown, whether they are mine or one of the other note takers, it does not matter”. Thus, students explicitly recognize that they want high quality Integrative notes.

Are there any costs to the Integrative note-takers in sharing their notes with all the students in the course? The student concerned about his handwriting conjectured that “maybe having to write more legibly made me miss things”. Another student speculated that “the only thing that I imagine losing is shorthand, but even then I don’t use it often enough for it to be a big deal”. We asked these students whether they feel that other students (especially the ones that didn’t show up to class) benefitted from the sharing of their notes more than they did. One student replied, “perhaps they might have, but it’s not something that really bothered me. I’m not competitive to the point of avoiding helping a classmate understand (plus it just solidifies my knowledge when I do)". Another student's response is unexpectedly positive: "I would hope so, I try to write notes as though someone that does not know anything is going to read my notes. This makes it easier for me to understand the notes to a better degree, and also come back to it later on." This student states that "If someone needed my notes, they I would give it to them. I just want everyone to succeed". Thus, this evidence suggests that some computer science students are not competitive and willing to help their fellow peers.

6.4 Analysis

Data from the interviews, examination of their notes, ethnographic observations, and class-wide surveys lead to insights about (1) the impact of the form factor of the technology on note-taking practices, (2) the process of taking Integrative notes, and (3) their benefits and costs.

6.4.1 Form Factor

One of the most important objectives of this project was to understand how the form factor affects public digital note-taking. In comparison to the Tablet PCs used in the NoteBlog study, the Livescribe digital pen and paper technology is approximately one-tenth the cost, has much higher resolution, weighs significantly less, and consumes less power. The Tablet PC, however, has markedly more computational power and provides Internet access. How do these properties affect the digital note-taking? Though no student in our studies used both technologies for note-taking during lecture, a comparison of their note-taking actions reveals the effects of form factor on resolution, the position of the notes, and the time of sharing.

The resolution of the handwriting did not differ significantly. None of the students commented about the illegibility of the handwritten student notes in either study. One Integrative note-taker took advantage of the extra space available to them, for example, by writing between the two slides printed on a single sheet of paper. Another used the large amount of space on a sheet of paper to create her own outline structure juxtaposed to the lecture material. Another advantage of the paper-based platform was that the note-takers did not have to compete for space with the instructor's annotations. In the NoteBlogging study, bloggers complained that the instructor would inadvertently write on top of where they have written or were about to write, resulting in contention for space. Later, a feature was added to turn on or off the instructor's ink. In contrast, Integrative note-takers were not able to view automatically the instructor's annotations on their paper, and as a result, would often shift their gaze back and forth between their paper and the projected slide, as observed by the ethnographer. However, students are already accustomed to this behavior and did not seem to be effected by this limitation.

An affordance of Integrative note-taking is the ability to either take superimposed notes (similar to NoteBlogs) or juxtaposed freeform notes (not directly supported by the NoteBlogging system). The data suggests that having the choice of where to write the notes reflects the note-taking style and preferences of the note-taker, more than the nature or quality of the content. Students in both studies of NoteBlogs and Integrative Notes strove to provide clear, alternative explanations while adding their own organization. More data needs to be collected to determine whether the content of Integrative Notes reflect all levels of the Bloom's or SOLO taxonomy, like NoteBlog content did. Also, the other students in this study had a slight preference for the juxtaposed notes, viewing them as supplementary and summative. This finding also needs to be confirmed by more studies.

A limitation of Integrative note-taking is the lack of wireless access in the digital pens, thus resulting in a delay in the time of sharing of notes as compared to NoteBlogs. Because the Integrative notes were not shared during lecture, the notes did not contain any helpful hints or suggestions like the NoteBlogs did. Furthermore, due to the separation of interfaces for capturing and sharing the notes, Integrative note-takers demonstrated a delayed awareness of an audience. After a couple of lectures, however, these students became aware of the public nature of the notes, and consciously made changes in their note-taking behavior for the benefit of others in the course.

Another aspect of the form-factor is the price of purchasing a Livescribe pen. One Integrative note-taker reported that he "thought about buying a pen" but eventually did not because he perceived that his “handwriting is not that great”. Another Integrative note-taker, who had some familiarity with a friend’s Tablet PC, said that “would pick the pen” because “it would be easier to use and cheaper”. Students are often on a tight budget, and price is an important aspect of the form factor.

6.4.2 Process of Integrative Note-Taking

The process of Integrative note-taking is similar to NoteBlogging in many ways, because self-selected students volunteered to participate and share their notes with the rest of the students. These students tend to be avid note-takers, who endeavor to add organization and to provide different perspectives in their notes. They also adapt quickly to the affordances of the technology, such as color, space, and time of sharing. When students have color available, as in NoteBlogs, they take advantage of it, such as differentiating the two different colors in Figure 4.1. When it is not available, as with the Livescribe pens, students tradeoff color with spatial orientation, using large square brackets and other visual connectors. When NoteBlogs are shared during lecture, students check online what other bloggers are writing (in order to minimize duplication). When the sharing is delayed, an ethnographer observed that Integrative note-takers would still check whether the other Integrative note-taker was also writing. This tag-team effort was achieved with visual eye contact, not based on the content of the notes.

The process of Integrative note-taking is also similar in many ways to widespread, traditional methods of note-taking. Ethnography revealed that clusters of students would engage in similar activities, for example, in a metacognitive discussion of the distractions of bringing laptops to lecture. One possible explanation for this clustering is the concept of social signifiers [Nor]. A signifier is some physical or social indicator, either intentional or accidental, that can be interpreted meaningfully. For example, the sound of typing and the scratching of pencils in a lecture hall may be an indicator that something noteworthy is happening. The actions of one’s peers, especially those within the field of view, may influence one’s activity. The Integrative note-takers, however, were often the only ones writing notes. These observations not only indicate their dedication, but demonstrate how they became a social signifier to others who became reliant upon the shared notes.

6.4.3 Benefits and Costs

The data indicates that Integrative notes were mostly beneficial to all students in the class with minimal cost to the public note-takers. The survey results demonstrated that a majority of the students who read the shared notes regard them as mostly useful and mostly interesting, thus implying that peer learning is occurring. In interviews, the Integrative note-takers also indicated that they benefit from the notes shared by other self-selected students. Integrative note-taking did not cost much, because the technology did not necessitate any change from conventional note-taking practices. A large majority of the students reported that the juxtaposed and superimposed student notes embedded in the lecture material were not distracting.

6.5 Conclusion

Integrating handwritten notes of self-selected students into instructor-prepared slides, which are available for all students to view, is advantageous. Notes can be captured digitally using inexpensive digital pen and paper technology without significantly changing ingrained note-taking practices.

Integrative note-takers strove to provide clear, precise explanations from multiple perspectives, like NoteBloggers. They did not necessarily include hints and suggestions for current problem solving exercises in class, but they captured important information to help prepare for exams. The choice of writing superimposed or juxtaposed notes reflected the personal preference of the note-taker. The advantages of higher resolution and cheaper price offset the drawbacks of not having Internet access. Thus, most of the pedagogical benefits of NoteBlogging, especially peer learning, are achieved even though the sharing is delayed until after the lecture.

Those students who volunteered to take Integrative Notes tended to be avid note-takers and diligent students. They tended to be altruistic and not very competitive in nature. At the same time, they recognized that they have a social responsibility to share high-quality notes with their peers. The pressure to perform well in front of an audience in turn was beneficial to the Integrative note-takers themselves, because they became more focused and engaged during lecture. Thus, even the action of sharing was selfish. The shared notes were useful, interesting, and not distracting to a large majority of the students who read the notes.

Chapter 7

Conclusion

Note-taking during lectures is a pervasive practice amongst university students. An analysis of this practice through the lens of cultural-historical activity theory and social constructivism reveals pedagogical opportunities for cooperative, inquiry-based learning. Emerging Web-based technologies with handwriting interfaces can exploit these opportunities, but must cope with issues of affordability and scale imposed by the ecology of a lecture environment.

The objective of this dissertation has been to exploit the selfish, solitary practice of traditional note-taking to benefit mutually all students in the course without significantly altering the learning ecology. We have demonstrated how notes taken solitarily can be shared with all the students in the context of lecture materials. In particular, we built, deployed, and evaluated three different systems to facilitate public digital note-taking: one based on the metaphor of blogging, another guided by the idea of incorporating lecture-related resources found on the Web, and a third exploring the tradeoff between form factor and time of sharing. Comparing the findings from these user studies indicates that students are more likely to embrace technologies that they perceive minimal changes to their existing practices, such as Integrative Notes and NoteBlogs. Even though students perceived minimal changes, these systems enabled peer learning and enhanced the sense of community amongst students. Those generating public digital notes endeavored to add clarifications, organizational structure, and alternative explanations, while most students found the shared notes to be useful, interesting, reassuring, and not distracting. Technologies perceived by students as more different from existing practices, such as SearchNotes, can be incentivized by instructors to make the long-term benefits of inquiry-based learning appear more immediate.

The public property enabled students to benefit from each other's different perspectives and to improve their metacognitive skills, while the digital property enabled affordable and fast note sharing that extended beyond the classroom. Public digital notes are indeed democratic in nature and motivating to students. Technologies and applications to support public digital notes span the design space specified. Some guidelines for the design of future student-oriented technologies include minimizing the perceived changes to existing practices, encouraging students to participate voluntarily, selecting more than one student to generate public digital notes, providing an outlet for self-expression, and striving to make more immediate the long-term benefits.

7.1 Findings

7.1.1 Rationale

Student note-taking in lecture is a prevailing practice and universally perceived as a key to academic success. Note-taking is a process of encoding information during lecture, and the resultant notes are a product that stores information for later review [Kie87]. Customarily, note-taking and note-reviewing are solitary activities, performed by individual students in intellectual isolation from their peers. Studies by educational psychologists indicate that more than 80% of students do not receive any formal training, that most students record less than half the critical lecture points, and that students are not as good at note-taking as they perceive themselves to be [VYP94, Cra25a, Kie87, PB74]. In addition, students do not trust the note-taking ability of their peers, who are likely also novices, and they may value the opportunity to paraphrase and express their own thoughts.

However, these prevalent student note-taking practices do not align with the contemporary theories of cognition and learning. *Cognition*, according to the cultural-historical theory of activity, emerges from culturally mediated, historically developing, practical activity. Activity, the basic unit of analysis, is the result of subjects (like students) who are motivated toward accomplishing some objective (like academic success) using historically and culturally constructed artifacts (such as paper, pens, book, etc.) [Col96]. Activities are performed in collaboration with a community of others, with some division of labor, specified by a set of norms and conventions [Eng87, Nar95, Col96, Ros98, Mwa02, GH04]. Activity theory provides well-named constructs and explicitly focuses on the motivation of human actions [Hal02]. *Learning*, according to the constructivist theory, is constructed actively by an individual through socially, culturally, and historically situated experiences. Learning is an active and social process, where the learner is an autonomous agent who draws upon previous knowledge to make sense of the current context. The responsibility and motivation for learning resides with the learner [PH91, PI69, Vyg78, Vyg87]. These theories of cognition and learning imply that note-taking should be considered as a collaborative, social, and cultural activity, mediated by cultural historical artifacts. Pedagogical practices advocated by these theories include active learning, peer learning, and inquiry-based learning.

Pedagogical opportunities arise from the discrepancy between what the prevailing student note-taking practices actually are and what the contemporary theories of cognition and learning imply that they should be. Using emerging technologies, such as Tablet PCs and digital pens, the solitary activity of note-taking can be digitized. And using Web-enabled technologies, these digital notes can be shared quickly and easily with all students in the course, embedded in the lecture material, and extended beyond the classroom to incorporate information sources found on the Web. The Web is a two-way communication medium, in which users consume information and also produce and publish information. Web-based technologies can leverage the small efforts of the many with the large efforts of the few, making feasible the concept of public, digital notes.

The ecology of a lecture constrains the design of Web-enabled note-taking technologies. The major challenges include (1) enabling all students to participate by employing ubiquitous, inexpensive hardware technologies, (2) making the technology simple to learn and easy to use, and (3) coping with issues of scale. A review of prior work on technologies for active learning, active reading, group note-taking, and mediated collaboration reveal that the four major sub-activities of note-taking are capture, access, manipulation, and collaboration.

7.1.2 Comparative Evaluation of Applications

Three different types of public digital notes were designed, implemented, and evaluated. NoteBlogs are generated by a small percentage of students using a Tablet PC to take notes on top of instructor prepared slides and shared instantaneously during lecture. Collaborative SearchNotes bring outside resources into the lecture. (3) Integrative Notes emulate traditional student note-taking with digital pen and paper, while exploring the benefits of superimposed versus juxtaposed notes shared after lecture. Each of these projects aimed to minimize changes to student note-taking practices and maximize pedagogical benefits.

Changes to Prevailing Practices

Collaborative SearchNotes was the most radical project, in the sense that even if students are accustomed to having access to Web-enabled devices during lecture, they do not perceive gathering resources as a form of note-taking. Students highly value paraphrasing, summarizing, and expressing new ideas in their own words, because this encoding process reinforces their learning. Even though SearchNotes greatly simplified and empowered the storage function of note-taking by automatically archiving resources in the context of lecture, it did not provide much room for encoding and self-expression. Students were able to select the query terms and phrases, but had no opportunity to reflect on what they found. No students abandoned their own note-taking (either on paper or in a text document) to rely solely upon SearchNotes.

In contrast, Integrative Notes was the most similar to conventional note-taking, in that the form factor was natural to all students and the learning curve was negligible. The interface for taking notes during lecture (pen and paper), the interface for sharing notes after lecture (USB dock and email), and the interface for viewing the shared notes (Ubiquitous Presenter website) were all different, but each individual interface was familiar to students. Due to the disconnect in the interfaces and the delay between the time notes were written and shared, the realization of the consequences of shared notes was not as evident to some of the students. Thus, some students did not significantly change their note-taking practices, while those that change their practices focused on providing clear, precise explanations and illustrating concepts in different ways.

Changes required by NoteBlogging lie somewhere between these two extremes. The form factor is mostly familiar: a laptop with a handwriting interface. However, using a pen to navigate the functionalities of the computer (like pressing command or shift keys) and to write (finding the correct angle and pressure, and becoming comfortable with resting a hand on the screen) take a little while to adjust to. After that initial learning curve, the note-taking also differs in that, as a student is writing notes superimposed on the prepared slides, the instructor's annotations also start showing up, sometimes causing space conflicts. Most bloggers resolved this by waiting until the instructor had moved on to the next slide before writing their comments. Finally, since the notes were shared live during lecture, bloggers were aware of an audience of watchers and strove to provide helpful hints and suggestions during active learning exercises.

Pedagogical benefits

The pedagogical benefits of all three forms of public digital note-taking arose primarily from the public aspect. Shared notes allowed students to see what their peers thought was most important during lecture, and encouraged them to learn from each other. Without explicitly being told to do anything different than they normally would during lecture, students determined how to maximize new utility given the new affordances of the technologies.

In Collaborative SearchNotes, many students reviewed the pertinent search results of only a few other students. A few students felt confident in their abilities to search for related content on the Web, and thus, engaged in exploratory and inquiry-based learning. Their selfish actions had a side effect of introducing new material and different explanations to other students and indirectly teaching their peers how to formulate good search queries.

In Integrative Notes, students focused on providing clarity and organization to the material covered in lecture. The most common behavior was to capture the verbal explanations of the active learning exercise given by the instructor. However, since different students paid attention to different aspects of what the instructor said and since they have different prior knowledge, students often wrote different things. One student decided to structure her juxtaposed notes in an outline format, highlighting at a quick glance all of the important concepts covered during that lecture.

NoteBloggers clarified, organized, and explained differently the concepts presented in lecture, and also provided hints and suggestions to active learning exercises live during lecture. The affordances of immediate sharing allowed watchers to get started on and attempt to solve an active learning exercise, where they might not have been able to otherwise.

In addition to motivating those students to generate public digital notes, all three systems created interesting, class-related content for other students to consider. Rather than forgoing an in-class problem solving exercise or becoming distracted, students had a resource such as NoteBlogs to check for hints and suggestions from their fellow students. Rather than opening a new tab to check email or read RSS feeds, students using SearchNotes had search tabs along the top of the lecture slides to read first. If students became frustrated with illegible instructor ink gestures, students could check if their peer bloggers or Integrative note-takers had explained the same concept in a similar manner. All students found assistance and reassurance in the public digital notes.

The addition of public digital notes to the lecture material did not distract the students. In Integrative Notes, 60% of the students in an introductory programming course reported not being distracted by the posting of individual notes of a few students to the lecture slides, where as more than 80% found the public notes to be useful and interesting. Over 80% of the search queries were related to the course, and thus automatically saving and sharing the search results was not distracting to the students. More than 90% of the noteblog content in an introductory programming course was about programming, and even expressions of mental state or empathy were reassuring to the watchers.

7.1.3 Design Space

The design and construction of these diverse public digital note-taking implementations justifies the design space of public digital notes as comprising of at least four major dimensions: (1) form factor, (2) time of sharing relative to lecture, (3) percentage of students generating content, and (4) direction of information flow.

The form factor of public digital notes includes the physical size, shape, and weight of the hardware technology used, and also the electrical power consumption and wireless connectivity. Form factor is important to consider because students must carry the device all day and use it in the confined space of modern lecture chairs with attached desks. Despite the limited computing power, digital pens show the most promise for finding a balance between affordability, weight, and power consumption. In contrast, Tablet PCs are much bulkier and more costly.

The time of sharing, or when the digital notes are made public, may influence the content and nature of the notes themselves. Instantaneous sharing of lecture notes using technologies with easy access to wireless networks, creates a sense of performance in front of an audience, and students strive to add content that would be helpful during class, such as hints or suggestions on in-class exercises. Sharing after lecture is the only option for devices that do not provide wireless access, such as digital pens. Though sharing is delayed, students still strive to provide clear, organized, and useful notes to their peers.

How many students produce public digital notes and how many consume them is an important aspect of how students communicate with each other. Public digital notes, by definition, are available to all students in the course. The content of public digital notes is authored individually, but the relative percentage of students who are authoring the content varies, depending on the affordability and ubiquity of the note-taking platform. This percentage, in turn, affects the design of how the software automatically aggregates and presents the notes.

The final design dimension to consider is the direction of information flow. Traditional note-taking involves the transfer of information from inside lecture to outside: students capture content during lecture and review it later outside of the classroom. Another flow of information may occur from outside the lecture to inside, for example, when students read the textbook prior to lecture and reference it during lecture. Furthermore, information can flow from student to student within lecture, for instance, when students communicate with each other during lecture.

7.1.4 Design Guidelines

The successful design, development, and deployment of student-oriented technologies is not an easy task. Students have a wide variety of skills and capabilities, all of which must be engaged. Students are constantly multi-tasking and overloaded with many activities. Students are quite adept at optimizing their situation, finding maximum benefit with minimal effort. Some guidelines for successful adoption of public digital note-taking in the classroom are:

1. *Minimize perceived changes to existing practices.* Students are already cognitively overloaded during lecture, and the introduction of new technologies into this constrained environment should be perceived by the students as not significantly changing their natural behavior. The interactions supported by the interface should be familiar and easy to learn. For example, students are already familiar with formulating search queries and finding relevant content on the Web and viewing these results as tabs in their browser. SearchNotes simply brought this familiar interaction with one click into the lecture notes, while seamlessly adding automatic archiving and sharing.

2. *Support choice in note-taking styles.* Students have many different learning styles and note-taking habits. Some with fast handwriting may have developed a strong sense of paraphrasing and organizing, while others with slower handwriting might rely on providing clarifications and other useful annotations on top of prepared lecture slides. As Integrative note-taking demonstrated, both juxtaposed and superimposed notes are valuable resources when shared. NoteBlogs appealed to one student who often brought many colored pens to lecture and was accustomed to using color to disambiguate and organize her notes.

3. *Provide outlets for student self-expression.* Students like to express their own thoughts in their own words. Collaborative SearchNotes limited this expression, with only the ability to express search terms, and ultimately was not as valuable to the students as the other forms of public digital notes. Expressions of self, even something as trivial as an expression of hunger during a lunch-time course or as mundane as an admission of making the common novice mistake, are reassuring and valuable to peers who can commiserate.

4. *Encourage voluntary participation.* The process of self-selection automatically filters students to match their interest and abilities with the technology. For example, only those students who felt confident in their search abilities produced SearchNotes, and mostly those students who were comfortable trying new note-taking methods volunteered to NoteBlog and take Integrative Notes. Both NoteBloggers and Integrative note-takers felt a sense of social responsibility to their peers. All three public digital note-taking tools have the potential to engage high performing students, taking advantage of this selection bias to aid all students in the course.

5. *Select more than one student to participate.* From the pool of volunteers, select a small group of students to participate in public digital notes. As one Integrative note-taker said, there is too much pressure to be thorough and correct if he is the only one sharing notes. A small group of students sharing allows everyone to benefit, including those generating content. The more students generating public digital notes, the greater the variety of viewpoints and alternate explanations. For example, the bloggers in one course clarified the difference between `static` and `final` keywords in Java in two distinct yet complementary ways. Similarly, of the three Integrative note-takers in another course, one explicitly defined the terms `this` and `super` in a class constructor, another discussed the default behavior, and the third explained the debugging advantage of the design presented. A large number of student producers may result in an overwhelming amount of data, which could be repetitive and would require filtering.

6. *Offer immediate rewards to help students achieve long-term pedagogical benefits.*

Students may not recognize the long-term benefits of peer learning and inquiry-based learning, especially if the note-taking tool is perceived as altering current practices. Incentives, such as a negligible amount of bonus points toward their grades or contests with free T-shirt giveaways, motivate students to try the novel application for perhaps enough time to get accustomed to and eventually adopt it. In the NoteBlog study, a re-election of bloggers halfway through the course bolstered spirit and pride in the bloggers and encouraged excellent note-taking.

7.2 Outlook

The potential of public digital note-taking in lectures has not yet fully been realized. Pedagogical opportunities to promote active, peer, and inquiry learning abound. Technological challenges, such as affordability and scale, remain but are not insurmountable. The next major hurdle for public digital notes, and indeed for the design, implementation, and deployment of student-oriented technologies, is understanding what really motivates students. The overall objective for most students is academic success, with the eventual outcome of a successful career. But, what drives their day-to-day choices and their actions in the moment? And how can we design software that appeals to students, does not change existing practices significantly, does provide pedagogical benefits, and does not distract?

Some aspects of motivation have been addressed by this dissertation. For example, making the notes of diligent students public recognizes their hard work. As a blogger, being re-elected is socially rewarding. At the same time, a certain level of error tolerance is already built into the system: students are aware that the public digital notes are generated by their peers, who are fellow students and novices to the material. Public note-takers feel a sense of social responsibility, but are fairly comfortable making mistakes. Participating in creating a search query or reading the search results of peers creates a sense of belongingness in a community.

An important aspect of student motivation that has only begun to be explored is choice, that is providing the learner as much control as possible and increasing their comfort with the new technology. Since all of the projects described here are extensions of the Ubiquitous Presenter system, they form a suite of public digital note-taking options, and students can choose to engage in whichever manner they prefer. Curiosity motivates students to capture SearchNotes, which are automatically shared, but students can choose to not share the result by closing the search result tab. One integrative note-taker who doodles frequently did not want to share her drawings, and would switch between a pencil and the digital pen. What are some innovative ways to provide more fine-grained control over which content is shared with the rest of the students and when?

Other aspects of student motivation yet to be explored include feedback and challenge. The forms of public digital note-taking presented in this work involve indirect collaboration, where the actions of one student are visible to others and the others in turn may or may not react to it. How can public notes support direct collaboration and immediate feedback from other students? A chat application was embedded in the NoteBlogging application and deployed with limited success. The main challenge for the blogger was switching between handwriting notes and typing chat responses. Some of the other students struggled to follow the asynchronous medium during the synchronous lecture environment. And, finally how can students use public digital notes to challenge and engage their peers in the learning environment?

The activity of student note-taking, in one form or another, has been practiced for over 6,000 years and will likely continue for as many years. Students are self-regulated learners who strive to be motivationally and metacognitively active participants in their own learning. They exhibit volition, the tendency to maintain focus and effort towards goals despite potential distractions. Their learning is mediated by technologies that are constantly emerging and evolving. These technologies are tools and artifacts that must be constructed in a social, cultural, and historical context. We must endeavor to devise technologies that mediate our own cognition and learning.

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