Patterns of Collaboration in Design Courses: Team dynamics affect technology appropriation, artifact creation, and course performance

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Abstract: In a collaborative task, group dynamics have been shown to affect students' grades, motivation to pursue a topic or subject, documentation of the experience, learning, enjoyment of a project, and relationships with their classmates. The results presented in this paper illustrate the effect team dynamics also have upon technology appropriation, by combining proven data-collection strategies and the use of a system that augments paper sketchbooks with multimedia capture and sharing capabilities. We analyze the relationships between students' design notebooks, questionnaires, and interview responses, class observations, and course performance. Our study found that students' use of collaborative tools increases when they believe their teammates to be equally engaged and involved in the project. Moreover, students engaged in successful collaborations are likely to take fewer notes than those involved in conflict-filled collaborations, and students with considerable experience working in groups may bypass critical steps in creating joint problem-solving spaces with each new group.

Introduction

Team collaboration and innovation in design are emerging as decisive factors in determining and maintaining global competitiveness for firms and countries (Agustine, 2005). Yet design education has been considered "the top drawer of Pandora's box of controversial curriculum matters" (Evans *et al*., 1990), perhaps because of the challenges in establishing hallmarks of good design across situations and contexts. Or perhaps, as a group of engineering design professors suggest, because the collaborative, open-ended, creative nature of design collides often with the convergence required of engineering departments in which it is taught (Dym *et al*., 2005). While some firms have succeeded at instructing recruits in their design process and tenets (*e.g*., Kelley, 2001; 2005), academia seems to lag behind in replicating the success of these small corporations (Dym *et al*., 2005). Recently, however, an interest in evaluations of design education at the collegiate level has begun to percolate (*e.g.* Song *et al*., 2004; Mabogunje, 2003).

Meanwhile, research on collaboration in educational settings traditionally has focused on short-term collaborative episodes and concrete tasks, where there are a limited number of acceptable solutions (*e.g.*, Barron, 2003); and collaboration scripts, where roles are predefined and structured (*e.g.*, O'Donnell, 1999; Dillenbourg *et al*., 2006). Recently, there has been an increased interest towards considering longer-term collaborations (*e.g.,* Goldman *et al*., 2004, Mercier *et al*., 2006). The research we report in this paper is at the confluence of these two developments: we focus on longer-term collaborations where students engage in creative, open-ended projects. Our findings are drawn from analyzing weeks-long collaborative projects in two courses on interaction design: an undergraduate introductory course, and a design studio.

Our evaluation methods similarly combine strategies from collaboration and design research. A significant fraction of the collaboration literature centers on video analysis of students' utterances and gestures, (*e.g.* Barron, 2003; Mabogunje, 2003); others consider the unit of analysis to be the students' use of representations (*e.g.* Yang, 2003; Song *et al*., 2004). Collaborations have traditionally been considered successful according to the groups' performance, measured in terms of grades or number of solutions reached. In contrast, some studies consider what students *themselves* value in collaborative endeavors (Mercier *et al*., 2003; Gillies, 2004; Levesque *et al*., 2001) – which may not correlate with their instructors' assessment. Our analysis for this paper draws insights from class and group *observations*; *interviews* of selected students; as well as pre- and post-experience *questionnaires* measuring attitudinal, self-reported behaviors, and experiences within the groups. We also discuss findings from *quantitative analysis of each student's design notebook*, associated coursework, and performance metrics.

Design notebooks are deeply embedded in the discipline and teaching of design (Verplank & Kim, 1986; Klemmer *et al*., 2005; Chen *et al*., 2005). In the design studio course we analyzed, these notebooks typically account for 30% of the students' final grade. Their importance is also reflected in the professional field, where they are considered valid sources for patent disputes. Also known as Idea Logs, the design notebooks provide a space for individual ideation and documentation, reflection, and organization of any project's elements: students take class notes, record team meetings, and sketch, write down, and paste in observations, ideas, and inspiration (typical Idea Logs appear in Figures 1 and 2).

This paper begins by summarizing the implementation framework of the Ideas learning ecology, for which Idea Logs are the starting point, barriers to adoption of such an augmented paper system, and usage and performance metrics. We concentrate on the effects of group dynamics on the appropriation (Pea, 1992; Leontiev, 1981) and usage of the system, as well as the students' enjoyment and performance in the course. Hardware and software can provide incentives and barriers to collaboration, yet our findings indicate that group dynamics may have as powerful an effect — if not more — on both adoption of the collaborative tools and on performance metrics. We find that the type of content and frequency of writing in their Idea Logs, both paper and electronic, correspond with the team's dynamics.

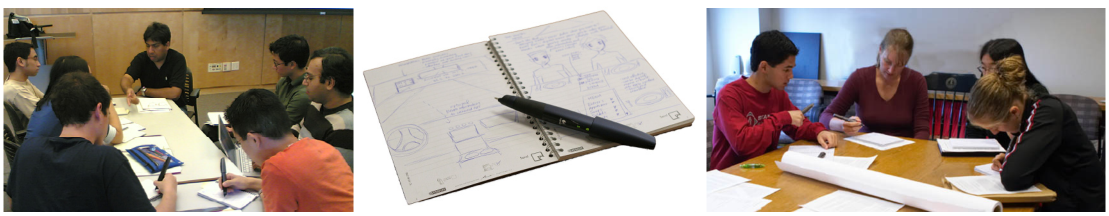


Figure 1. Students during group meetings using the Ideas ecology; the Ideas digital pen and notebook.

The Ideas Learning Ecology

The quantitative analysis of the students' Idea Logs we discuss was made possible by the introduction of the Ideas ecology, which aims to fluidly bridge the digital and physical world of artifacts used and created by design students. We use the term *ecology* (Barron, 2004) to recognize that students actively engage in learning through a wide variety of social resources, practices, and tools. To capture written content, design students use the Anoto digital pen system (http://www.anoto.com). For the study deployments, we used Nokia SU-1B and Logitech io2 digital pens. When used with an Anoto digital notebook, the pens record time-stamped vector graphics of each stroke the students make, along with the page number. Students may upload and view their digitized notes by synchronizing with a PC. Unlike purely digital systems, the Anoto digital pens also act as normal ballpoint pens: should the pen digitizer fail (*e.g.*, if the pen runs out of battery power), users may continue taking notes and sketching as if they were writing with normal pen and paper. Similarly, the digital version provides a backup should the physical notebook become lost or unavailable. Students can import digital images into Ideas, allowing them to document fieldwork with digital cameras or camera phones, as well as material downloaded from the web.

The Ideas ecology has been in use for over six months, by more than 56 design students, authoring over 4,000 pages of content in the course of their class work. Users interact with captured Ideas content through the ButterflyNet browser (Yeh *et al*., 2006), which integrates digitally captured paper notes with photographs and other media through a faceted metadata browser (see Figure 2). Notebook pages currently in focus are displayed in the *content panel* on the left; the browser offers the ability to zoom in/out and display multiple pages at a time via a drop-down menu. The *context panel* on the right automatically presents data related to the pages in focus, such as images taken around the time the page was written. At the top of the browser, a *timeline visualization* allows the students to jump to content by date. The height of each bar represents the amount of content written on that date. Flags representing course milestones, indexed by date, provide links to course web pages while simultaneously providing a visual aid for students searching for content related to a given milestone. Exporting notebook pages as images to other programs allows students to complete common tasks such as pasting sketches into documents or sharing their design content through email without the burden of scanning.

The Ideas system supports collaboration among teammates by enabling users to create, join, and leave groups. Members of a group can directly view the notebook pages of other users in the group through the digital browser. Group members can comment on each other's work via highlighting and annotating interesting pages through *tags* (text labels of pages) and *annotations* (text or image labels of page areas). These tags and annotations are indexed and searchable for later retrieval. As the Idea Logs are collected, reviewed, and evaluated several times throughout the quarter, we also added features to facilitate these tasks for the course instructors and teaching assistants, such that they have access to aggregate views of the entire class, as well as the ability to view and annotate any notebook. In addition to supporting design practice, the Ideas ecology is a powerful instrument for studying the practices and behaviors of design students. Digitally augmenting paper lowers the threshold for acquiring aggregate metrics of notebook activity, time-stamped ink strokes enable us as researchers to ask finer-grained questions, and the digital copy allows researchers to examine content without taking the notebooks away from the students at any time.

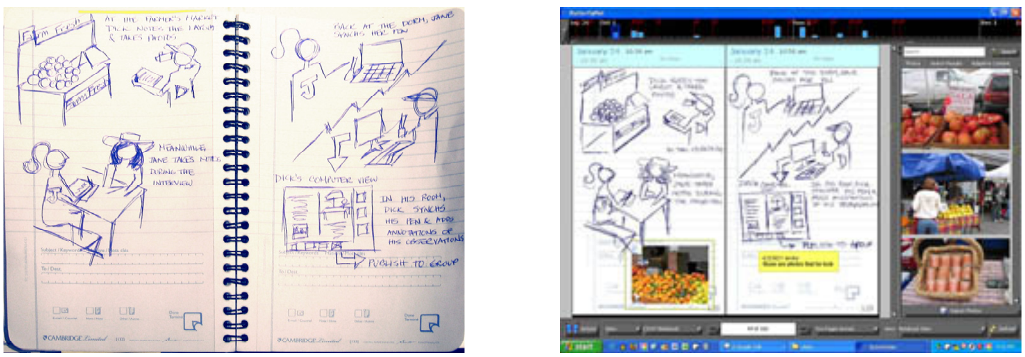


Figure 2. *Left*: Pages 1 and 2 from an Idea Log recoding observations during a Farmer's Market. *Right:* The same pages viewed in the ButterflyNet browser. Notebook pages with their photo and text annotations are presented in the left-hand content panel, while contextual data (*e.g.*, related images,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

Study Method

We review the different methods and evaluations strategies employed, in both the pilot and central study reported, the students' positive evaluation of the technology, and their usage of the Ideas system. In the next section we concentrate on the educational and collaboration findings, and their relationship to the usage metrics.

Technology Probe

The pilot study ran during the fall quarter of 2005, when we deployed parts of the Ideas ecology to selected sections of the undergraduate introductory HCI design course at our university. Eighteen students used the pens, notebooks and browser, authoring a total of 550 pages over 10 weeks. In the post-experience questionnaire, participants rated the Ideas system as significantly useful, easy to understand, and easy to learn (median 4, 5-point scale). For exporting and sharing design content, students preferred using Ideas to traditional means such as copiers and scanners (median 6, 7-point scale), and commented on the value of the ability to share notebook content quickly and fluidly (exporting the page image to office productivity and email applications), the browser's capacity to display multiple pages, visualize a timeline of when pages were created, and view pages within a calendar.

One of our concerns was the added weight and encumbrance of the pen introduced by the digital capture instrumentation, which could discourage usage. We did not discover an impact of the pen's form factor on content production: the students using Ideas filled an equivalent number of pages to those using traditional pen and paper (40 full pages on average, when accounting for notebook size differences). . Notably, several students used Ideas for classes in addition to the one under study; we hypothesize this is because they found a digital mirror to be useful.

The HCI Design Studio Experience

Informed by these findings, we conducted a whole-class deployment the subsequent quarter. As with the pilot, we chose this studio course, for its focus on collaborative project work: students' grades are based on their group projects and individual Idea Logs. Moreover, both courses employ the studio critique method for formative assessments.

All 48 students enrolled in the HCI Design Studio course (Klemmer *et al.*, 2005) during winter quarter were asked to participate in the evaluation of the Ideas ecology; of these, 38 (10 female, 28 male) agreed. Participating students were provided with the study's consent form, a pre-experience questionnaire, Anoto digital pens, and A5-sized notebooks (approximately 137 mm × 203 mm). At the end of the quarter, students were asked to fill in a post-experience questionnaire and return the filled notebooks and pens. Paper copies of their notes were provided for the students who requested them. An additional eight students chose to participate in the surveys without using the technology. The survey questions were drawn from earlier studies' findings about collaboration, feelings of belonging to a group, interpersonal closeness, friendships among teammates, satisfaction with project outcomes, group interactions and learning, among others (*e.g.*, Hinds *et al.*, 2004; Bailenson, 2006; Mercier *et al.*, 2003). Questions about technological proficiency, experience with the Ideas tools, and prior workgroup experience or experience in maintaining logbooks—including Idea Logs, blogs, and journals—were also included.

Participants were predominantly engineering students, the majority pursuing degrees in Computer Science and Symbolic Systems, and evenly split between undergraduate and graduate programs. As was the case with the technology probe, no explicit remuneration—whether monetary or in terms of grades—was given to encourage the use of the system, although the Idea Logs themselves were graded for the courses. Students were free to use the technology as much or as little as they desired. The electronic versions of the students' notebooks were not used for grading unless the students requested it.

Results and Discussion

We evaluate the results of the study by first covering a general overview of the experience and reported barriers to adoption of the Ideas system, the content analysis of the Idea Logs, and the findings on collaboration illuminated through the survey instruments. We then analyze the ways in which the team's interactions moderate usage of the Ideas learning ecology: the type of content and frequency of writing in their Idea Logs, both paper and electronic are impacted by the group's dynamics.

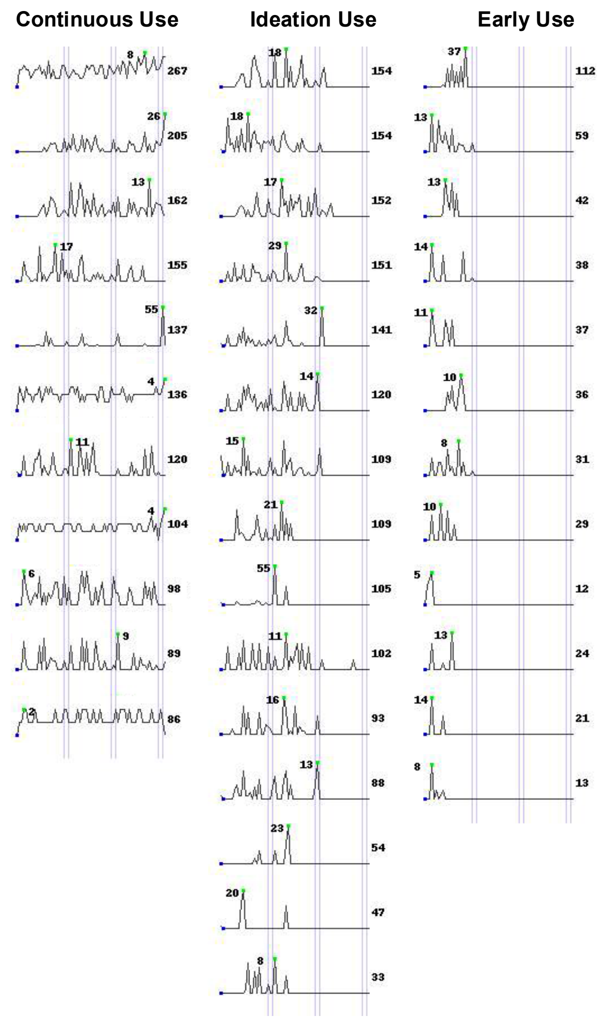
During the 10 weeks of the quarter in the second study, the 38 students using the Ideas system entered 3,637 pages, predominantly working on them during weekdays outside of class. Each student contributed approximately 1.4 pages per day, although students varied greatly in the frequency and amount with which they wrote into their Idea Logs: one student wrote as many as 267 pages (an average of 5.3 pages per day!). Students cited as particularly welcome the automatic digital copy with the additional information of the *timestamp*, as well as the ability to quickly and fluidly insert excerpts from paper notebooks into digital documents. The timeline and the ability to annotate and import related images were also mentioned favorably.

Idea Logs

We analyzed both the server-logged *timestamp data* for the 38 students who participated in the study and the *content* of the 46 students' Idea Logs (including those that did not use the Ideas system). Idea Logs accounted for 30% in each student's final grade for the HCI Design Studio course; their evaluation by the course instructors and teaching assistant emphasizes the need to ideate and iterate frequently, thus rewarding quantity and scope of ideas. Therefore, it is not surprising to find a large and significant correlation between the students' performance in the class and the quantity of their Idea Log entries (Pearson $r=0.589$, $n=46$, $p<0.01$). Figure 3 shows the appropriation pattern using the server-logged *timestamp* data through sparklines representing the number of pages each of the 38 students filled daily. The trend towards a decrease in note-taking that Figure 3 highlights at the end of the 10-week period may stem from the better fit of notebooks and pens to the ideation and iteration that characterize the early parts of the course, as the last weeks of the quarter are focused on implementation (programming).

Our results indicate a clear need for a digital repository of design content for students; the Ideas system seems to have at least partially addressed that need. Seven of the most frequent and prolific users of Ideas were invited to interview, and they repeatedly mentioned the high value in quickly sharing information among teammates. The perceived value proposition for the students was twofold: the ease of sharing visual ideas; and the lessening of the need to document the same materials as their teammates, particularly during meetings. Earlier we discussed other benefits that students perceived in continued usage of the Ideas ecology; now we address the system's shortcomings that may further account for the differential patterns of usage.

Figure 3. Sparklines showing the number of pages each student completed each day during Study 2, with the values for each student's maximum daily pages, and total number of pages filled throughout the quarter. Note that three groups are easily distinguishable: those that quickly adopted and continued using the technology throughout the quarter (approximately 11 students), those that stopped in the weeks when programming demands took over (10 to 15 students), and those that only gave the technology an early try (approximately 12 students). The paired vertical lines correspond to deadlines for projects and, two days later, for turning in the Idea Logs.



Some of the barriers to adoption of the Ideas ecology are intrinsic to the current incarnations of the technology in the available pen, notebook, and synchronizing interface. The girth of the pen (23mm × 20mm), battery life, and lack of ink color variety were mentioned throughout the interviews and free-form survey responses. It seems likely that future versions of augmented paper technology will overcome these limitations, and in fact new pen models (such as the Magicomm model http://www.originote.com/) seem to be addressing the size and girth concerns. To determine whether the digital pen was primarily responsible for the barriers encountered in these studies, we compared the number of pages written in the notebook to the number of pages synchronized to the computer. Not all pages students wrote were transferred to the browser via synchronization: an average of 186 pages written to 98 synchronized (some were not written with the Anoto pen – perhaps due to its form-factor or qualities, to the students' preference or forgetfulness; others were not recorded, because the pen ran out of battery during note-taking or meetings). The sheer quantity of pages synchronized – almost 4,000 in the three months under consideration – would seem to indicate that most students are able to get beyond the ergonomic shortcomings of the pen. We are interested in exploring this gap further, as the categorization of the content of the notebooks may lead us to determine whether the students preferred the pens for note-taking and related tasks, and a different set of instruments (markers, colored pencils) for tasks requiring greater line control (such as artistic renderings of their interfaces).

Other barriers for our audience are not solvable through off-the-shelf components; for example, the Anoto notebooks also drew a few complaints. Videotaped interviews with students and teaching assistants suggest that lined paper discourages freeform content in favor of textual content. To see if this anecdotal frustration was pervasive, we used the pilot data to compare the number of drawings present in unlined notebooks to those in lined notebooks, finding only a small correlation (Pearson $r=0.153$, $n=79$). As the heft and quality of the paper of the commercially available Anoto notebooks also proved disappointing, we are currently purchasing custom-printed, unlined Anoto sketchbooks with better quality paper.

Analyzing Team Variables and their Interactions

Analysis of the survey data highlights some characteristics that correlate with these differential usage patters. What other factors influence students' decision to record their thought processes in their Idea Logs? From the survey analysis, we found the number of total pages written in each student's Idea Log to be negatively correlated with the students' reported satisfaction in their current team interactions (Pearson $r = -0.32$, $p < 0.05$). Besides providing an enjoyable working environment, satisfaction with team interactions correlated with the team's project grade ($r = 0.376$, $p < 0.05$). From the perspective of curriculum development, given the equal importance in the final grade measurements of the individual Idea Logs and group project grades, the link between unhappy or conflicted groups and additional contributions to their individual Idea Log raises concerns on the potential causes of such a relationship.

Barron (2003) points out that "research on motivation suggests that the more competitive the environment, the more students focus on finding ways to document and protect their individual competences". It is plausible that fear of not receiving credit for their contributions when working among strangers, or in a competitive environment, motivates students in these teams to document their ideas frequently. This conjecture may also explain, why we found that friendship with teammates negatively correlated with the number of pages each student synched to the Ideas system ($r = -0.326$, $p < 0.05$). From these findings, it would seem that those teams where teammates were satisfied in their interactions and/or were friends before the experience felt less of a need or urgency in recording and documenting their thought process. On the other hand, it may be that friends met more often synchronously, and saw less of a need to share their documents asynchronously. An alternative explanation comes from comprehension theorists, who suggest friends have more "shared semantic fields" and therefore feel less of a need to document these shared perspectives and understandings (Sabelli & Pea, 2004).

The interesting dynamic of working with friends deserves further attention and evaluation. Research has shown that "friends are used to building joint problem-solving spaces and are consequently more familiar with the prior knowledge, communicative strategies, and thinking styles of their partners" (Barron, 2003). Establishing joint problem-solving spaces and creating shared meanings are behaviors that have been shown to be at the center of successful collaborations (Roschelle, 1992). We were particularly interested in evaluating the impact that working with friends had on the students' graphical output, since graphical representations have been linked to the construction of a joint problem-solving space (Brown *et al*., 1989) and making the students' thinking visible (Barron, 2003). Moreover, quantity and type of graphical content in Idea Logs has been shown to correlate with product and process outcome measures (Song *et al*., 2004; Yang, 2003).

We set out to code the graphical output of the students, which proved particularly challenging. We experimented with coding the diagrams and sketches as units, reducing human error by involving four coders working independently. As interpretations of the boundaries between sketches led to inaccuracies, we evolved to considering the quantity of the pages that the diagrams covered as the unit of analysis. Two coders, working independently, analyzed the Idea Logs for their graphical content, counting an average of 62 pages filled with sketches and diagrams during the 66 days of the quarter. The class does not require drawing proficiency, yet some students had as many as 134 pages filled with sketches and diagrams, and no student had fewer than 11 pages devoted to graphical content. This measure, however, is biased towards large size sketches and heavily correlated with the number of pages written by the students. To address this potential imperfection in our measurements, we are developing an "ink counter" for the electronic versions. We hope this tool will compensate for differences in detail and size across students' sketches, although accounting for paper-only sketches will, by necessity, remain challenging and prone to human error.

Using pages filled with graphical content as a measure, we found a negative correlation between prior friendship with teammates and the graphs in students' Idea Logs ($r = -0.30$, $p < 0.05$). Then, given the measuring challenges mentioned above, we calculated the frequency of graphical content as a fraction of all pages written by each group. We contrasted this frequency with a team identity measure, obtained through a seven-point pictorial scale of interpersonal closeness. This scale has been shown in earlier studies to correlate with feelings and behaviors reflecting interconnectedness (Hinds *et al*., 2004). We validated the scale using six items from Bailenson (2006) on group cohesiveness ("entitativity" items with a Cronbach's alpha of 0.81), and found the two measures to be positively correlated ($r = 0.489$; $p < 0.01$). Individual ratings for interpersonal closeness were averaged across the team, and a large negative correlation emerged once again between the team's interpersonal closeness and the frequency of graphical content aggregated across the team's Idea Logs ($r = -0.581$, $p < 0.01$). These findings seem to indicate that ease of establishing joint problem-solving spaces translates into a decreased dependency on graphical representations to convey meaning and strategies. As working with friends or in a highly interconnected group facilitates the creation of shared meaning, the survey responses suggest that the need for technological and pedagogical support for creating a shared space, such as that fostered by the Ideas ecology, would be stronger in groups where the teammates are not friends at the beginning of the project.

Lastly, as part of the post-experience questionnaire, students were asked to rate on a 5-point Likert scale their agreement or disagreement with 45 statements (divided in five sections) on their feelings about group interactions, group goals, common group challenges, learning outcomes and their satisfaction with the final product design, their learning experience throughout the project, and their collaboration. The number of pages individual students synchronized to the browser correlated negatively with their agreement to the survey question about group members "that did not take the work as seriously as everyone else" ($r = -0.33$, $p < 0.05$). A likely explanation for the disjoint between written and synched pages emerges when we consider that students in unsatisfying collaborations are more likely to individually record and reflect in their Idea Log. Yet these same students may remain reticent to synch and use the Ideas system, because of the potential sharing of their insights with their conflictive teammates. Support for this differential pattern in documenting vs. sharing also appears in the other direction: the total number of pages synched by each group correlates with the project grade ($r = 0.363$, $p < 0.05$) which, as mentioned, correlates with satisfaction with team interactions ($r = 0.376$, $p < 0.05$). Consequently, it would seem that although students in a successful collaboration – or in a team with friends – are likely to take *fewer* notes than those involved in conflict-filled collaborations, students are more likely to *share* and synchronize their notes when they believe that their teammates are equally engaged and involved in the project.

Friendship may not be the only factor influencing students' ability to quickly establish joint problem spaces and create shared meaning; our survey results suggest that this ability may be developed through continued collaborations across teams and courses. Colbeck's interviews of college students (2000) suggested that interdependence (Johnson *et al*., 1998) seemed to develop more in project teams that included students with prior group experiences than in teams whose members had little or no prior group experiences. We had expected the differences in usage patterns to be related to expertise and prior experience with regularly documenting and recording thought processes. However, our analysis showed a relationship to the students' prior experience with groupwork in related activities ("Outside of this class, how often have you participated in technology-based or design group projects, whether for courses or as part of your job (group projects involve 3 to 5 persons working together)?"), rather than to their prior experience in maintaining notebooks, journals or blogs ("Outside of this class, have you ever kept a journal or diary, whether private or public? Please include blogging experience in answering this question.").

Students' answers to the frequency with which they have worked in technology-based or design group projects were negatively correlated to both the number of graphs in students' Idea Logs as well as the number of pages synched with the system (respectively $r = -0.317$, $p < 0.05$; and $r = -0.576$, $p < 0.01$). It would seem that expertise in the domain and with group interactions could have as large an effect as that of prior friendships among teammates on a group's ability to quickly create shared meaning. Colbeck *et al.*, (2000) found that prior experience with collaborative teamwork both in and outside school contributed to the degree of positive interdependence developed within teams. We would have expected this interdependence to manifest itself in performance gains, yet this high frequency of prior experience in group projects may be misleading, as the same questionnaire item was negatively correlated with the group's grade in the project itself ($r = -0.304$, medium strength non-significant correlation), unlike prior friendship with teammates. We can speculate that familiarity with groupwork practices could lead students to underestimate the need for crafting a shared problem space with every new project. Further research is needed to clarify this complex relationship between prior experience with collaborations and success at a new collaborative project.

We should discuss the suitability of using performance metrics in a design course, where objective evaluations of projects tend to be difficult to validate, as the appropriateness of the design may be best appreciated by the audience for which the product is intended. The HCI Studio course we followed resolves this challenge by inviting a panel of expert judges (instructors of design courses in related disciplines and professionals, among others) to the final project presentations, and adding their evaluation to that of the course's staff. Yet the question remained as to whether the team's perception of a successful project would match the views and criteria of the course staff and expert judges. Several studies have suggested that grades may not accurately represent a successful collaboration (Song *et al*., 2004) and raised concerns that performance metrics may be out of place, both in collaboration studies and courses based on collaboration. Students in our study filled-in the post-experience questionnaire after their final project presentations and demonstrations, after hearing the experts' verbal feedback on their project, and before receiving their project's grade. Yet students' belief that their project turned out well correlates highly with their project grade ($r = 0.404$, $p < 0.01$) and their satisfaction with the project ($r = 0.531$, $p < 0.01$). Similarly, students' satisfaction with their team interactions also correlated highly with the students' reported satisfaction with the final product ($r = 0.636$, $p < 0.01$) and as mentioned earlier, with their project grades ($r = 0.376$, $p < 0.05$). We can therefore conclude that the students' perception of quality accurately reflects that of the judging panel and course staff, and that performance metrics are acceptable dimensions of evaluation for this course. Moreover, it is clear that a successful collaboration and a successful product were intricately linked for this course, even if the multicollinearity between these constructs prevents us from establishing statistical regressions. The approach of evaluating projects through peer, expert and course staff comments seems to both encode an objective assessment, and reflect the students' own criteria.

Conclusion and Future Directions

In this paper, we described the Ideas learning ecology, and its appropriation during both a ten-week technology probe, and during the HCI design studio course. We analyzed students' design notebooks, class observations, questionnaire and interview responses, then discussed how collaboration patterns affect technology appropriation, artifact creation and sharing, and course performance. We found that students' use of collaborative tools increases when they believe their teammates to be equally engaged and involved in the project. Students in a successful collaboration – or in a team with friends – are likely to take fewer notes than those involved in conflict-filled collaborations, and students with considerable experience working in groups may bypass critical steps in creating joint-problem solving spaces with each new group. Further research would be needed to explore the relationship between groupwork experience and documentation strategies.

Analysis of the content of these students' Idea Logs beyond the scope of this paper continues in three directions: we are interested in replicating the findings regarding graphical content type that other researchers in the area of engineering education have found (Song *et al*., 2004; Yang, 2003), and extending these existing graphical content taxonomies to categorize textual content. Simultaneously, we are evaluating strategies to analyze and make visible the apprenticeship process (Lave & Wenger, 1991) by which students go from novices to expert designers through the lens of their Idea Logs and their progress through the college level curriculum, following the practices of Scribner (1986) and Pea (1993). We are also looking forward to developing (and testing) effective interaction strategies for taking formative assessments of evolving patterns of use of the Idea Logs, and for guiding students towards those patterns of most productive use: perhaps there are forms of collaborative scripts (O'Donnell, 1999; Dillenbourg *et al*., 2006) that may yield replicable improvements to team processes and outcomes in design settings.

From an application development perspective, we are designing several innovations for the Ideas system, including incorporating some of the students' existing digital practices and requests. One of these efforts is leading us to take advantage of the ease and fluidity of online photo sharing applications such as Flickr (http://www.flickr.com). We are also moving towards an implementation that would incorporate display and capture of information on digital whiteboards, as well as the design of group notebooks. Group notebooks are of particular relevance as they seek to provide an intermediate step for students to highlight content for sharing asynchronously before, or synchronously during meetings. Integrating physical and digital tools also opens up new avenues for knowledge building and reflective activities (Scardamalia, 2002). In addition to providing persistent common ground for groups in the midst of projects, we seek to create an ecology of augmented tools that facilitates the creation of status updates, project reports, and electronic portfolios by highlighting vital content gathered over the course of a project. Such an ecology can provide the ability both to *capture* design activity more effectively using physical tools and to better *organize* and *share* design content using digital tools.

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