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A DESIGN COLLABORATORY FOR ENGINEERING STUDENTS

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Abstract

Rapid advances in web-based communication and mobile computing present opportunities for fundamental changes in engineering education, particularly in team-based project courses for which collaborative learning is a common pedagogical model. Research on collaborative learning suggests that it is more effective than competitive and individualistic learning in promoting academic, social, psychological and attitudinal student outcomes, leading to a higher quality of academic experience. What we need, however, are tools that can support collaborative learning. We present preliminary findings on a computer environment, the Kiva, that supports the activities of group collaboration for engineering design teams. We have employed methods from human-computer interaction to iterate on the design in the context of use. In this paper, we discuss the implications for both student design teams and professional design teams.

Keywords: engineering design, group collaboration; learning; design education

1 Introduction

For both student and professional design teams, the design and development process requires that collaborators build and retain knowledge through discussions, sharing artefacts, and creating documents. The team design process also requires coordination of schedules, artefacts, documents, deadlines, and deliverables. Teams need to develop a shared language in order to communicate well. However, collaborators often have pressures that undermine coordination. Team members come and go, even in academic settings. Team members deal with competing priorities from work, school, and personal demands. Finally, for both student and professional collaborators, dedicated project space is at a premium. Meeting spaces need to be cleared at the end of a meeting, and each team member leaves a meeting with pieces of a puzzle that needs to be reconstructed at the beginning of the next meeting. Often critical pieces are missing, so the team is either unable to proceed or revisits decisions they have already made.

The differences between engineering design teams in universities and those in industry are numerous. Students are novices both in their domain knowledge and in their knowledge of the design process. Students work in unstructured teams of peers, even if roles such as team leader have been assigned. They often judge their success by the grade they earn or by the artefacts they produce. The client, whether it is a professor or a company, rarely plans to use the team's design directly. Rather, the goal of the university design activity is to learn about the design process and to master new domain knowledge. On the other hand, professionals are expected to be domain experts, assigned to projects based on their skills, producing a product that the company can profit from. Learning, and the accumulation of shared knowledge, is rarely an explicit goal for industrial teams. For all these reasons, collaboration tools designed for teams in industry rarely work well for student teams. In response, design faculty on many campuses have begun to work on collaboration tools for student design teams, particularly for teams that are not collocated. Those working in this area include [1, 2, 3, 4, 5].

Through an iterative, user-centred design process, we have designed and built tools to support students learning through collaboration. We have been conducting empirical studies to evaluate their usability and their contribution to learning. We have designed the tools to facilitate learning through co-construction and reflection. Co-construction is the successful activity of knowledge building and problem solving between individuals [6]. Reflection and discussion promote critical thinking [7]. This paper reviews the iterative design and development process of these tools. The environment is called the Kiva[1], a gathering place.

2 Design motivation

Typical academic environments can undermine the learning goals of collaborative design projects. Scheduling and attending meetings are often difficult for students from different majors with different schedules and priorities. Because not all team members can attend all meetings, some team members miss key information and activities. They may be unaware that certain decisions have been made or that critical information has been presented and discussed. In addition, students do not usually have dedicated project space. Team meetings take place in conference rooms, personal offices, and open spaces. At the end of a meeting, the various artefacts – including notes, action lists, timelines, digital files, paper sketches, and prototypes – that have been produced must be distributed among the members; the white board gets erased, and no one person can reconstruct the meeting.

Finally, individuals rely on the personal recall of these distributed items when formulating new information. Without a central repository for both physical and electronic artefacts, the necessary co-construction of knowledge is lost during the project cycle. Team members lose the opportunity to build on each other's work and, more importantly, to learn from one another. Unstructured by nature, student teams manage their workload under-equipped with tools and technologies that could compensate for these conditions. Computer support can provide mobility, flexibility, and the persistence of information to meet the demands of individual and collaborative work at, and between, meetings.

3 The Kiva

In spring 2003, we challenged a team of 25 students in the Rapid Prototyping of Computer Systems class to create a visionary scenario for a mobile and physical meeting space for student design teams that would support their own design activities. This course draws students from engineering, computer science, and fine arts. The students spent one semester designing, developing, integrating, and testing the multimodal environment that we now call the Kiva.

The Kiva is an interactive physical and digital workspace that addresses the requirements of interdisciplinary teams. It is the digital equivalent of a dedicated project room. Teams share non-dedicated physical spaces and restore their group's project work at the flip of a switch. Walls become interactive surfaces that display work in progress. (See Figure 1.)

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[1] Kivas, built by both North American (Pueblo) and South American (Aztec) native Americans, are large underground circular chamber used for communal and religious purposes.

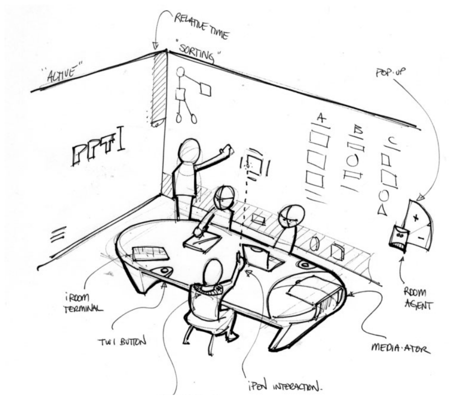

Figure 1. Sketch of Kiva activity

The *Thinking Surface* is an interactive whiteboard designed to support group brainstorming and continuity of work between group sessions. Groups can use it to generate and organize information to build shared arguments. Content, in the form of electronic artefacts, originates from four sources: files or images loaded to the surface, notes that are posted to the surface, annotations to the surface itself, and the web [10]. Users can interact during or between meetings. They can save and restore their workspace using any web browser, and they can meet in any classroom with a projector.

The *Kiva Web* provides a place to capture all group artefacts and discussions. It allows team members to build on each other's work and to draw relevant relationships between information according to time and circumstance. The portal can be projected to a *Meeting Surface* to share information in custom visualizations during the group session.

The Kiva's interoperable set of tools support student learning. Its interface promotes the natural activity of its users, thus keep meetings fluid and energy sustained. The physical Kiva room is enhanced with digital tools and interactive devices that support collocated group collaboration. Mobile extensions facilitate remote collaboration, as well as individual work outside the context of group meetings. Together, these tools support the rapid generation, organization, group construction, and archival of ideas.

To date, we have focused our research attention on the Kiva Web, because it supports group organization and process, as well as content organization and construction. Hence, it has the greatest potential to support individual learning through collaboration.

4 Evolution of the Kiva Web

The students designed the Kiva Web to extend their ability to share information. Each team member contributes to the content, centralizing the discussion that surrounds the various artefacts or information.

4.1 First design iteration

In the initial design of the Kiva, the students on the development team believed that supporting novices in unstructured teams called for a coordination solution. The initial prototype was adapted from an open source software application called MimerDesk. The initial design used highly structured modules to impart good habits, thus good process. These modules included: a meeting scheduler with note-taker that was called the Meeting Minder, an Actions list, an Outstanding Issues tracker, a work log for students to track their contributions, and a file repository. (See Figure 2.) Tools were interoperable so that students could use some or all of them. Meetings were regarded as the essential building blocks of coordination, and various structured modules for managing and coordinating information were provided. The Meeting Minder prompted students to plan and schedule meetings. During a meeting, students could follow the set agenda and add notes to the items as they were discussed. If tasks were assigned or outstanding issues identified, students could populate the Actions or Outstanding Issues modules. With a mix and match design, actions, and issues could also be entered directly into the dedicated modules. All information was visible to all project members, opening channels for monitoring activities and exchanging information between groups.

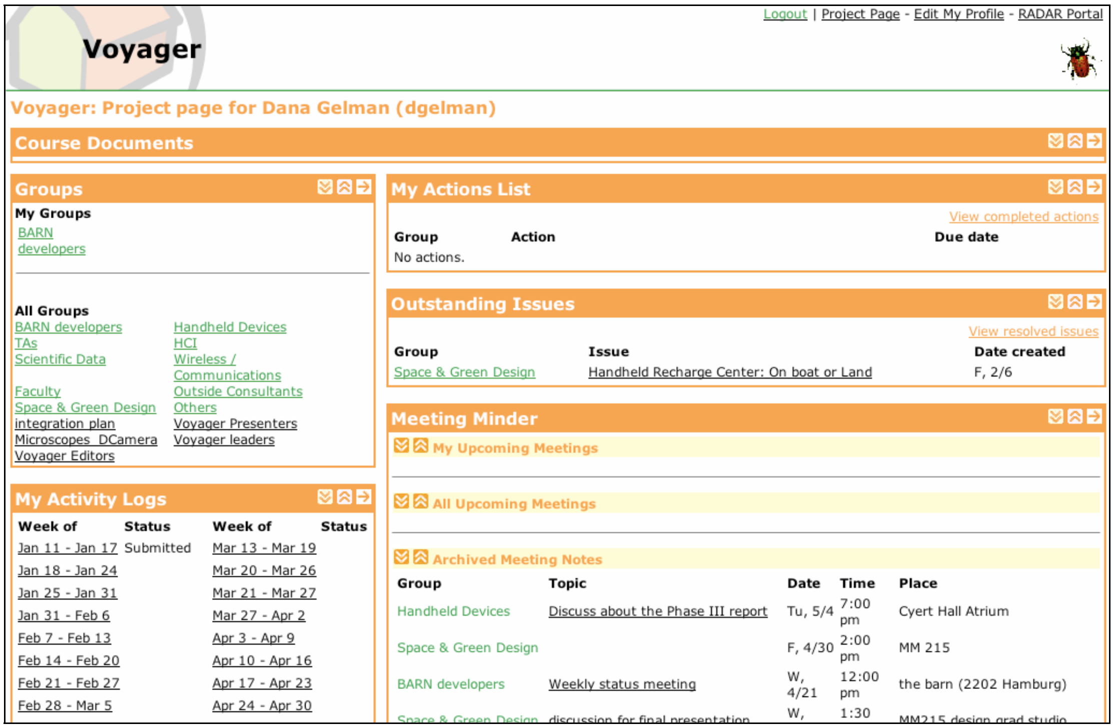

Figure 2. Modularized first design iteration

These tools were deployed in the Rapid Prototyping of Computer Systems class in spring 2004. The class project involved 5 teams designing mobile applications for Pittsburgh Voyager, a non-profit organization dedicated to educating children and adults about the Three Rivers of the Pittsburgh area. Web usage was not mandatory, but teaching assistants posted project documents to the site to encourage students to check with some regularity. The multi-pronged study relied on convergence of data. It included:

1. A survey designed to identify group processes and personal satisfaction with group process. The survey was administered at the beginning of the semester to record past group experiences and two more times to measure any changes.

2. Pre-and-post course essays, in which students described how they would design a particular product. The essays were designed to reveal if an understanding of process developed during the course, and if it was attributable to the collaboration tools.

3. Student focus groups were conducted at the end of the semester focusing on personal experiences and tool use.

4. Site usage was monitored for the patterns of usage.

5. Anecdotal information was gathered from teacher assistants and from a weekly meeting for group leaders.

The open source software was somewhat unstable and the tools lost the trust of many students and the teaching assistants during the first few weeks of use. The web tool did not get the critical mass of users necessary to be an effective group memory or organization tool. Still, we were able to collect important group and individual data that changed our approach in the second iteration. The results highlighted that rigid structures (e.g. Outstanding Issues, File Repository) did not map to student team organizations. Students in the class applied organizational tools at the point they needed to manage complexity.

The essays revealed that students often view the design process as the division of tasks among roles. By the end of the course, students reflected the *integration between components* in the essay. However, the tools had no impact on the learning because of the light usage.

4.2 Second design iteration

Using the data from the first iteration, we engaged in an affinity diagramming process, a bottom up technique for analyzing contextual data and identified the following key needs: 1) support of emerging structures for information and group organization and 2) user adoption of the tools. We first identified user acceptance or rejection criteria and distilled them into guidelines for redesign: We believed that if we leveraged what students were already doing, they would adopt the tools more readily.

1. Establish one pipeline for communication, and leverage student preference for email;
2. Support emerging structures for groups and individuals by providing multiple ways for users classify, find, and view information;
3. Increase context for meeting notes to clarify fragments of information; and
4. Facilitate comfortable eavesdropping between groups.

The new framework is unstructured – offering few, but rich, choices. The core interaction combines email and a bulletin board to keep threaded discussions intact. For example, meeting announcements, notes, and pre/post meeting discussions are joined in a topic. Everything is submitted to the web via one transaction: *a post*. Students can post documents, diagrams, conversations, meeting notes, notes to self, task assignments, and so on. Posts are made visible to all groups to support eavesdropping, but students can organize their homepage so that their group is prominent. The home page of the second iteration is shown in Figure 3. This homepage illustrates two of the features that students can use to organize their views of information:

1. *Views*, which are private, map to personal organization schema. A user can change how and what they see according to personal preference. Views are created through sorting and querying and can be saved and/or displayed on an individual's front page.
2. *Groups*, which are public, provide infrastructure. In addition to formal group designations, users can form groups to support emerging needs. For example, the report editors from each project team might form a new group to share templates and styles or faculty might create a Course Documents group to post information for the class. Kiva administrators have the ability to set access rights. For example, faculty and teaching assistants can form groups that are hidden from students to support their internal activities, such as grading.

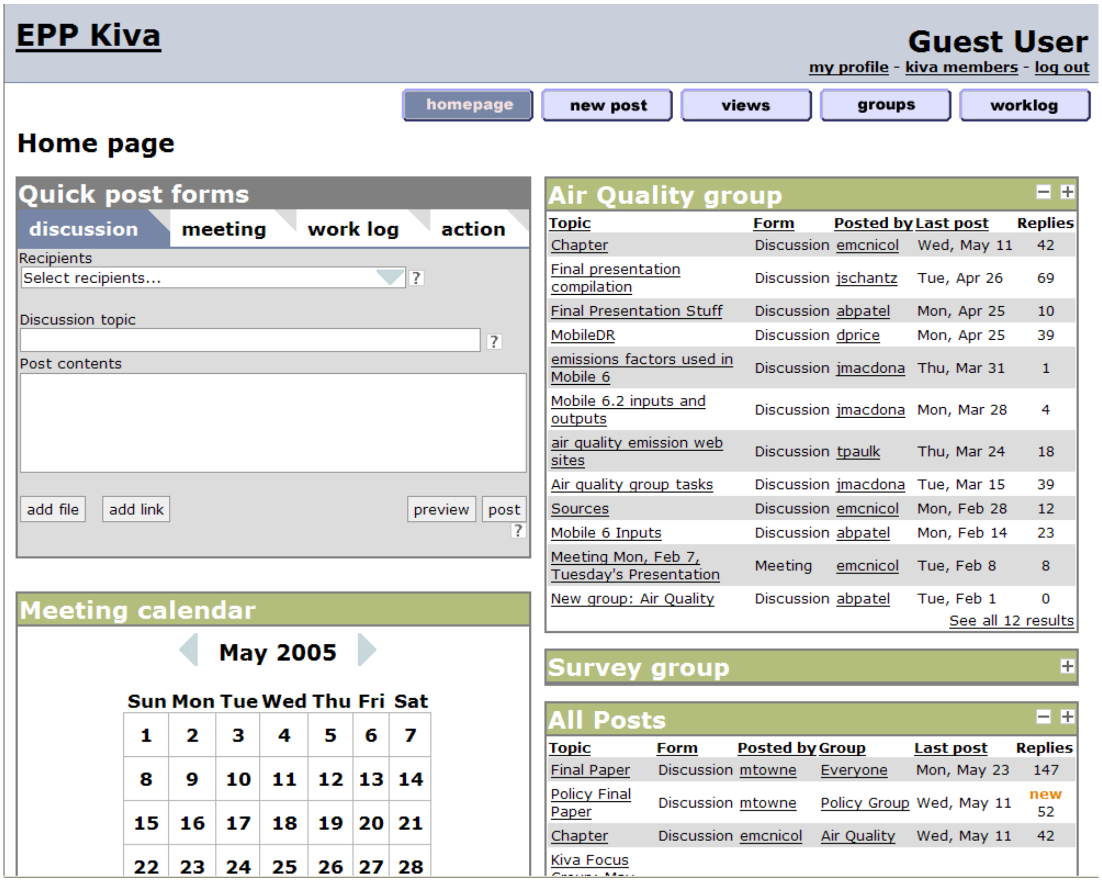

Figure 3. Home page of second iteration

Figure 3 shows the homepage for a student in the Air Quality group. The student has the posts for the Air Quality group first, but also has included a minimized view of the posts from the Survey group, plus a view of all the posts for the class. The view of All Posts enables the student to eavesdrop on other groups, to monitor posts made by the faculty to everyone in the class, and to monitor the creation of new groups, which can be created by any user at any time. Threads with unread posts are always flagged and, by default, new posts are always at the top of the list. Figure 4 shows a typical thread for a student design team.

When a student enters a threaded discussion, the page opens at the first unread post in the thread. The last element in the thread is an empty post box, shown in Figure 5, in which the student can respond to a particular post, using “quote in reply” or can continue the general discussion.

Extending the success of the meeting scheduler from the first iteration, we included forms for assigning actions, tracking time, and general discussion to stimulate co-construction. (See Figure 6 a, b, c). One of the pedagogical benefits of this design is an ability to create forms that support the goals and activities of a particular project course.

Scheduling a meeting puts the meeting on the class calendar and also starts a new thread. Students can post the agenda, meeting minutes, etc in the thread. In addition, if a meeting time or place is changed or the meeting is cancelled, everyone in the relevant group is sent an email message notifying them of the change.

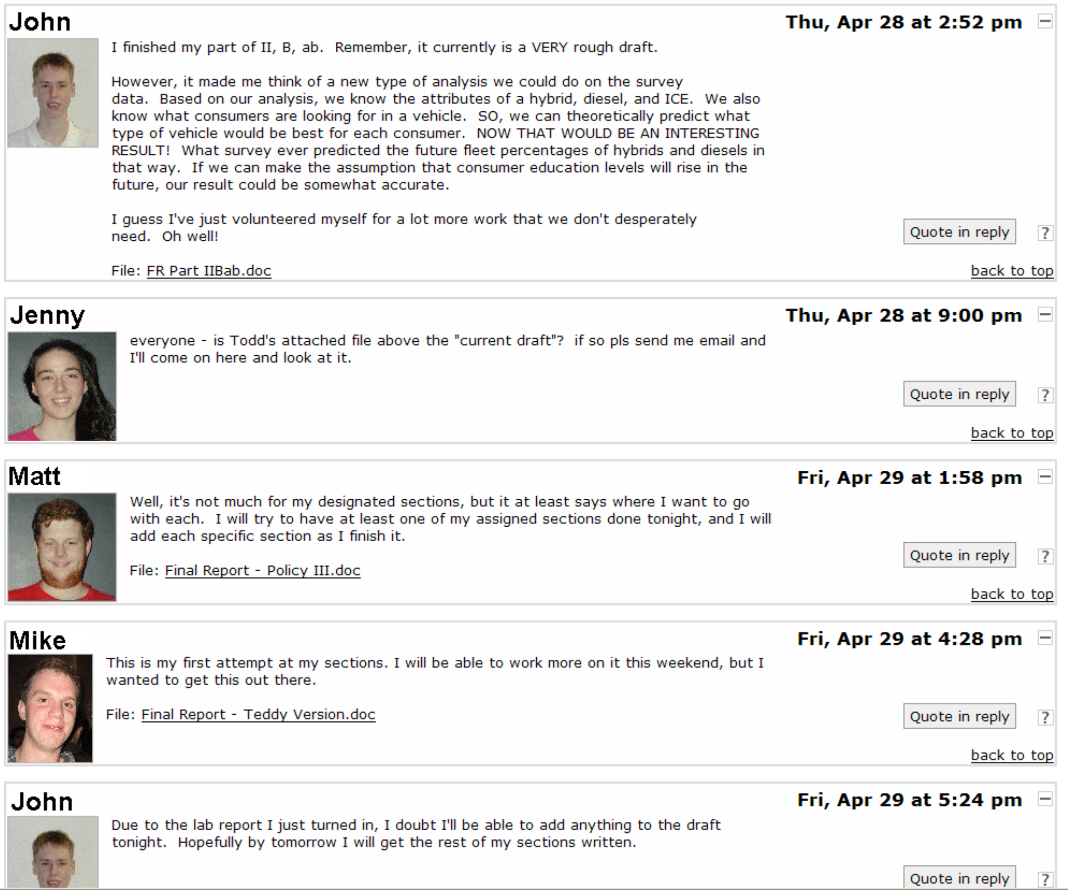

Figure 4. Typical discussion thread in the Kiva

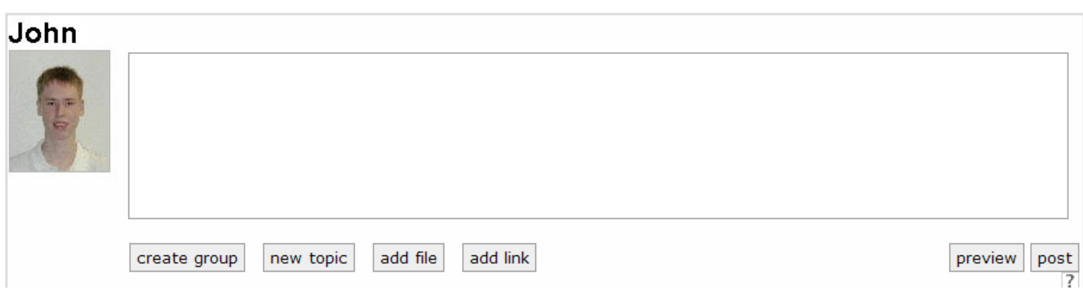

Figure 5. New post window

We have incorporated a *Work Log* for students to track time spent, reflect on work, and plan for the coming period. Time and task can be consolidated by group and by team for reporting purposes. Within the work log, students can report on what they have achieved during the current week, what problems they encountered and what they plan to work on in the following week. In addition, reflective questions can be posed in the weekly log. For example, students might be asked to report the most interesting thing they learned from a classmate this week or what the most difficult team problem was.

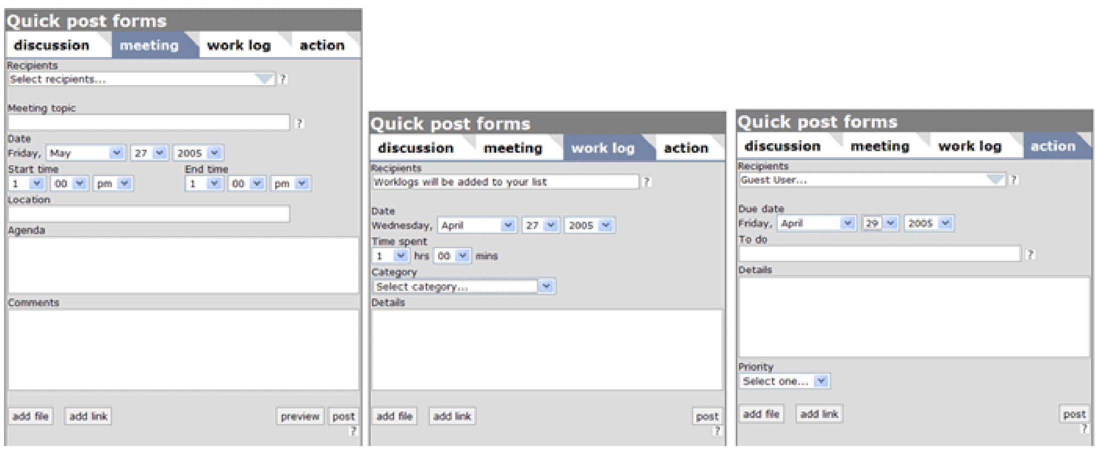

Figure 6. a) Post form: meeting b) Post form: work log c) Post form: action

5 Preliminary results

In spring 2005 at Carnegie Mellon, four semester-long project courses for undergraduate and graduate students used the complete set of web tools. All four involved multiple formal groups of four to six students to research, design, develop, and test their work, ultimately integrating them into a final deliverable. Two of the classes require a working artefact in addition to documentation. Even though the tool is still under development, our observations support the soundness of our current design:

1. Student – teacher communication is enhanced through artefact exchange and negotiation of expectations.
2. The threaded discussion prompts consistent discussion of the content of posted files.
3. Visibility of all content increases general project awareness for individuals.
4. Having a central file repository was valued by students and by faculty.
5. For Carnegie Mellon students, the portal is walk-up-and-use; however, some of the proposal collaborators required a short written tutorial.
6. The need for search and query is almost immediate with an active group.

We are currently analyzing the postings on the Kiva for quantifiable evidence of collaboration. We have developed a coding scheme to identify both design steps and collaborative exchanges within and across groups. However, even a cursory analysis shows that the students used the Kiva to exchange ideas and information. For example, in a class with 19 students, they started 560 distinct topic threads, some with more than 100 individual posts in them. Within these threads, the students posted 875 files and 74 web links.

We are also exploring the use of latent semantic analysis [9, 10, 11] to study the content of the documents the students posted. We are currently analyzing the student's responses to work log questions as well as the pre and post essays to discover any changes in the students' understanding of the design process as a result of these classes

Finally, thirteen students from three of the semester-long project courses participated in one-hour focus groups at the end of the semester. Questions focused on the process and value of collaboration in general and more specifically, how the Kiva or other computer-based tools supported or failed to support the collaborative effort. All students reported that coordinating tasks, monitoring and maintaining progress, and ensuring equitable contributions from all group members were the most difficult aspects of group work. Students thought that the Kiva helped with these aspects of group work by making it easier to publicly post and track work products. In particular, because the Kiva enabled students to comment on files that they posted, they found that they could easily focus the group's attention to the relevant aspects of the file (e.g., section of a paper that had been edited, wanted feedback on, or needed someone to add to), which helped support the coordination and progress of the group work. Commenting on posts also supported learning on-line from other students, whereby a discussion and sharing of ideas would emerge from a posted file. Students also used the post-hoc group formation function to enable small, specialized sub-groups to share and develop ideas and products. This function was valuable because it facilitated communication and coordination among the relevant members, reduced the information burden (clutter) on students not directly involved in the discussion, and helped keep all the highly relevant discussion and documents together. However, all students voiced that face-to-face meetings are critical successful group work. Face-to-face meetings served both a valuable social and cognitive function. Complex tasks or working through complex ideas needed the immediate response and feedback that the Kiva does not provide, and face-to-face meetings support the social bantering that students thought was important for group moral and motivation, and that would be too difficult to do on-line. In general, the most valuable aspect of the Kiva was the file sharing and storage function, which supported the coordination of tasks and the monitoring of work progress.

6 Concluding Remarks

Effective pedagogical tools aid students in building their own knowledge and reflecting on what they have learned. Our strategy has been to refine the tools in the context of classroom use in order to get a critical mass of usage for meaningful collaboration. Students are involved in the design because they are the target users. Now that the system is usable and useful, we can determine the impact of the tools on learning.

We have presented a vision of computer-mediated technology that can support the activities of group collaboration for engineering teams. We have employed methods from human-computer interaction to iterate on the design in the context of use. We believe this will produce an application that enhances learning both in academic and corporate environments.

The current version of the Kiva is stable, usable, and useful. Our design supports what we have learned in our studies as well as what has been established in the literature on collaborative learning. Now, we are ready to assess learning. We believe that students will benefit from their ability to have persistent project workspace that supports design process and helps them synthesize what they learn from each other through construction.

7 Acknowledgments

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