Int. J. Engng Ed. Vol. 22, No. 3, pp. 637–644, 2006
Printed in Great Britain.

0949-149X/91 $3.00+0.00

Assessing Collaborative Learning in Engineering Design*

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Through an iterative, user-centered design process, we are designing and building computer-based tools to support students learning through collaboration. We have been conducting empirical studies to evaluate the usability of the tools and how they contribute to student learning. Our goal was to design tools that would support the processes of knowledge co-construction and reflection. Co-construction is the successful activity of knowledge building and problem solving between individuals. Reflection and discussion promote critical thinking. This paper reviews the iterative design and development process of these tools.

Keywords: design; collaboration; groupware.

INTRODUCTION

CONSIDERABLE RESEARCH has been conducted looking at collaborative teams in the workplace. Although student collaborative teams share many of the features as those in industry, there are important differences. As with industry design teams, student teams need to build and retain knowledge through discussions, artifacts, and documents as their design evolves. Both kinds of teamwork require coordination of schedules, deadlines and deliverables, and the need to develop a shared language in order to work collaboratively. However, unlike workplace teams, student teams often have pressures that undermine the collaboration. They deal with competing priorities from work, school, and personal demands. Scheduling meetings is often difficult for students from different majors because of the different schedules and the lack of common work hours. Because not all team members can attend all meetings, some team members miss key information and activities; they may be unaware that decisions have been made or that critical information has been discussed. In addition, student teams are often unable to acquire dedicated project space. Team meetings take place in conference rooms, personal offices, and public spaces, which need to be cleared at the end of a meeting. The various artifacts that have been produced—including notes, action lists, timelines, digital files, paper sketches, and prototypes—are distributed among the members; the white board gets erased; and no one person can reconstruct the meeting. Often critical pieces are missing, so the team is either unable to proceed or must later revisit decisions that have already been made. Students often rely on personal recall when they are moving forward on their assigned design tasks. Without a shared repository for both physical and electronic artifacts, 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. This is particularly critical for student teams, where the ultimate objective is the acquisition of knowledge and skills and not the end product, per se. Unlike workplace teams, where the ultimate goal is the final product, for student design teams the goal is to learn about the design process and to master new domain knowledge. Thus what happens during the process is more important than the end product.

For these reasons, collaboration tools designed for industry rarely work well for student teams. In response, design faculty on many campuses have begun to work on collaboration tools for student teams, particularly for distributed teams [3–7]. Computer-mediated support can provide mobility, flexibility, and the persistence of information to meet the demands of individual and collaborative work at, and between, meetings. But, because students are novices, tools designed for them must also support the development of process skills and knowledge. Hence, our focus is to develop tools that encourage process competence, constructive skills, and reflective practice.

VISIONARY SCENARIO OF AN ENGINEERING DESIGN COLLABORATORY

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

* Accepted 14 December 2005.

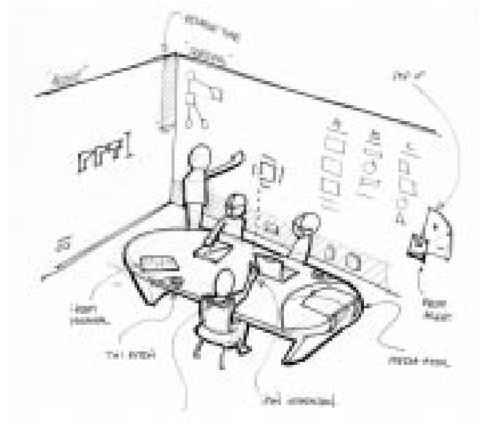

Fig. 1. Sketch of Kiva activity.

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, a gathering place.

In their visionary scenario, 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 Fig. 1).

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 artifacts, 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 [8]. 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 artifacts 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 Kiva can be projected to a *Meeting Surface* to share information in custom visualizations during the group session.

First iteration of the Kiva Web

After the class developed the first prototype, a smaller interdisciplinary team of undergraduate students, graduate students and faculty who participated in the Kiva's conception continued the work. Several of our findings on student teams mirror findings in current literature, including:

- Students are design process novices. Students have not internalized a design process, but there is often an expectation that they are prepared to contribute within an interdisciplinary team setting.
- Students are diverse in personality, culture, and discipline. Students don't always share common ground in terms of vocabulary, views, or values.

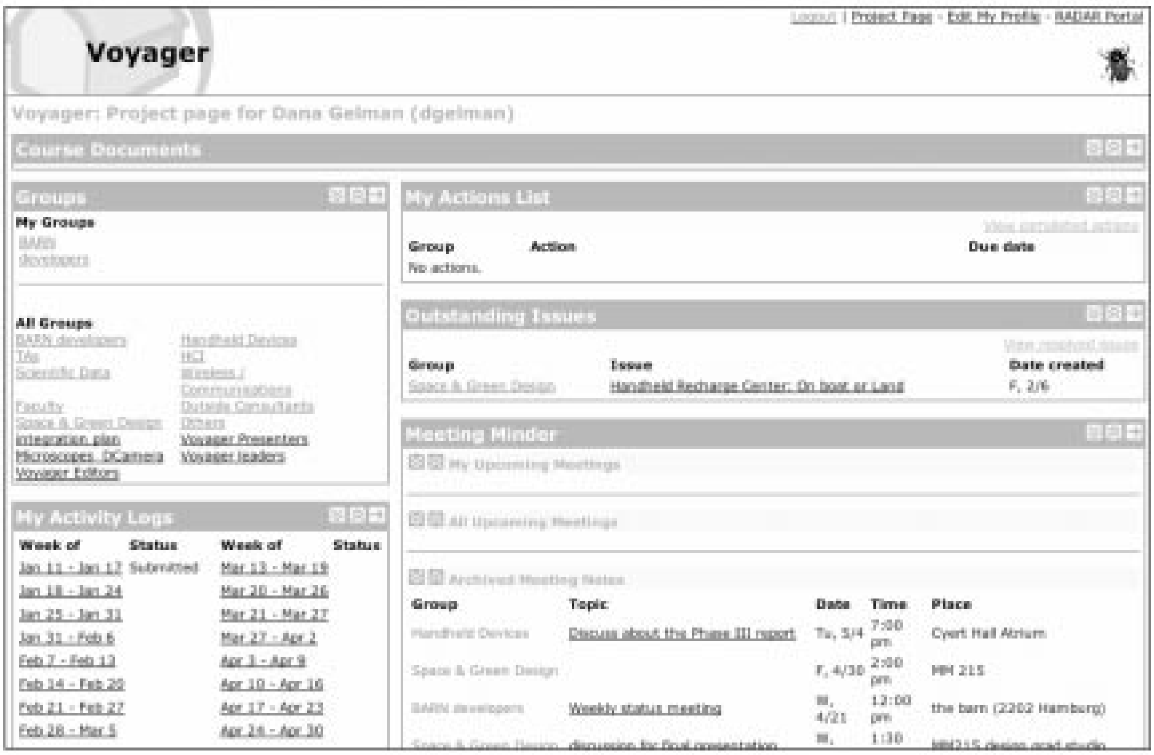

Fig. 2. Modularized first design iteration.

- Student teams are often *ad hoc.* They frequently lack formal structure or hierarchy and are teams of peers.
- Student teams don't have dedicated project space. Nomadic teams lose artifacts.
- During meetings, teams use multiple media owned by different students. At the end of a meeting, students dismantle and distribute the artifacts that constitute their work.

Our goal was to create a set of collaboration tools to be used in the Rapid Prototyping of Computer Systems class the following year in Spring 2004. We focused our attention on the Web tools and the Thinking Surface because they support content organization and construction and hence have the greatest potential for fostering learning through collaboration. In this paper we focus our review on the iterative design of the Kiva Web.

Design: This class's prototype was refined and implemented using open source software application called MimerDesk, which is a suite of group work modules. The modules included the *Meeting Minder*, a meeting scheduler with note-taker, an *Actions* list, an *Outstanding Issues* tracker, a *Work Log* for students to track their contributions, and a file repository. Tools were made interoperable so that students could elect to use some or all of them. All information was visible to all project members, opening channels for monitoring activities and exchanging information between groups.

The system included a project page with a view of all the groups in the class. This page highlighted an individual's priorities (see Fig. 2). Each group also had a separate page dedicated to their collaborative work. In addition to the formal class groups, students could form ad hoc groups to resolve and document issues.

These tools were deployed in the Rapid Prototyping 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. Tool usage was not mandatory, but teaching assistants posted project documents to the site to encourage students to use the web tool with some regularity. A multi-pronged assessment relied on convergence of data. It included:

- A survey designed to identify group processes and personal satisfaction with a group's process. The survey was administered at the beginning of the semester to record past group experiences and two more times to measure any changes.
- Pre-and-post course essays, in which students described how they would design a product. The essays were designed to reveal whether an understanding of process developed during the course, and if it was attributable to the tool.
- Student focus groups were conducted at the end of the semester to record student experiences of tool use.
- Site usage was monitored for the patterns of usage.
- Anecdotal information was gathered from teaching assistants and from a weekly meeting of group leaders.

Results: 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. The web tool did not get the critical mass of users to be an effective group memory or organization tool [9]. Still, we collected group and individual data that redefined our approach in the second iteration. The essays revealed that students often view the design process as the division of tasks among roles. The results highlighted that rigid structures (e.g. Outstanding Issues, File Repository) did not map to individual or group organization. This underscored that organization schemas vary between groups, among individuals, and with time in a process. Students needed to develop their own structure based on the time, circumstance, and personal mental models. One positive outcome was that all groups regularly relied on using the Meeting Minder for ease in scheduling meetings and reusing the agenda to take notes.

Second iteration of the Kiva Web

Design: 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. Our design criteria were:

- Establish one pipeline for communication and leverage student current acceptance of email.
- Support emerging structures by providing multiple ways for users classify, find, and view information.
- Increase context for meeting notes to clarify fragments of information.
- Facilitate comfortable eavesdropping between groups.

The resulting Kiva 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 with supporting artifacts are joined in a thread, called the *discussion topic*. Everything is submitted to the web via one type of transaction, called *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. The homepage is shown in Fig. 3.

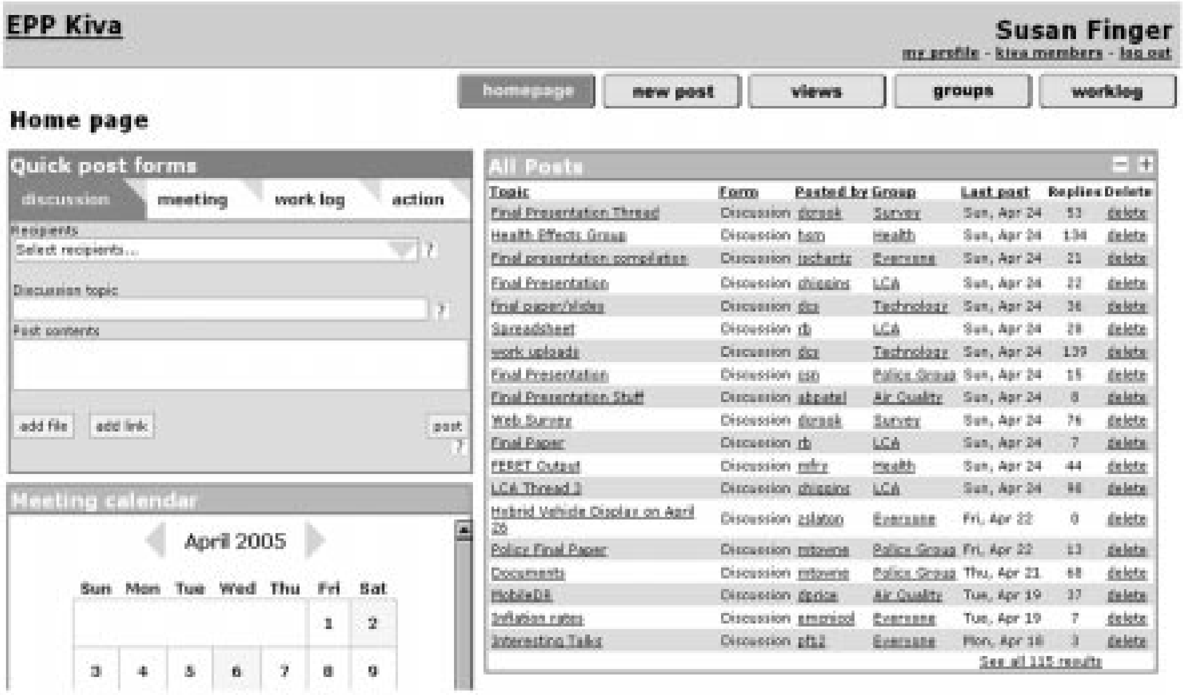

Fig. 3. Home page of the second iteration Kiva.

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 Fig. 4 a–c). Two features shape how users or groups can organize their views of information and determine whether information is public or private. The first feature is *groups*, which are public, provide infrastructure. In addition to formal group designations, users can form groups to support emerging needs. For example, the students report editors from each project team might form a new group to share templates and styles. The second feature is *views*, which are private, map to personal organization schema. A user can change how and what they see according to personal preference.

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. 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 team. Periodically, reflective questions can be posed in the weekly log. Figure 5 shows the interface for making and responding to posts.

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 artifact in addition to documentation. Even though the tool is still under development, our observations support the soundness of our current design:

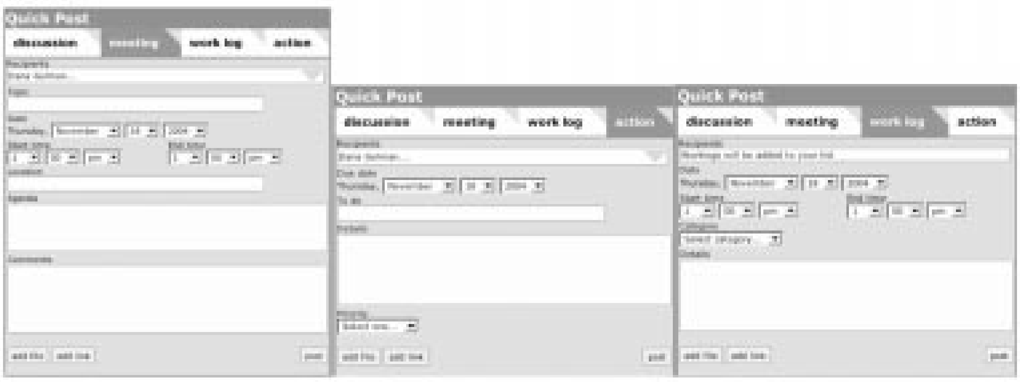

Fig. 4. a) Post form: meeting; b) Post form: action; c) Post form: work log.

Fig. 5. User interface for posting to the Kiva.

- The Kiva fosters student—teacher communication.
- The threaded discussion prompts consistent discussion of the content of posted files. Users are naturally compelled to explain the purpose and issues associated with files, extending the relevance beyond simply posting files on a server.
- Visibility of all content increases general project awareness for individuals.
- Latecomers to projects are self-educating on project focus, activities, and status.
- For Carnegie Mellon students, the Kiva is walk-up-and-use; however, some of the proposal collaborators required a short written tutorial.
- The need for search and query is almost immediate with an active group.

Focus groups: 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 easy to publicly post and track work products and by making evidence of work and contributions very public. 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 morale 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.

CASE STUDY: RAPID PROTOTYPING OF COMPUTER SYSTEMS

The Spring 2005 Rapid-Prototyping course consisted of 27 students (9 females, 18 males) spanning seven different disciplines (Electrical & Computer Engineering, Mechanical Engineering, Computer Science, Robotics, HCI, Design and Information Systems). Nine students were enrolled in graduate programs, 17 were seniors, and one was a junior. The multi-disciplinary make-up of the course contributes to the difficulty of scheduling time to meet and work together face-to-face.

The course was structured around two large-scale projects, Voyager and GM, each of which was comprised of multiple subgroups. Students selected a project and assigned themselves to the appropriate subgroup. The subgroups were interdependent: the output of one subgroup could be a necessary input for another group and so coordination and communication within and across subgroups was critical to the success of the project. Projects were divided into three phases, with each phase culminating in a presentation to the class.

Data analysis

The initial analysis of the data was done by collecting information from the data logs and by classifying threads by topic lines, which were verified by examining a small sampling of the posts. The results are a rough estimate and classification system of how students used the Kiva.

- *Did students use the Kiva?* To obtain a general measure of Kiva use we counted the total number of posts, threads and files. Overall, there were a total of 1,348 posts, 12% created by faculty and TAs and the remaining 88% (1,186) created by students. Every student posted at least once, with the average number of postings = 43.25 (S.D. = 55). Number of postings per student ranged from one to 284. Posting were organized into threads, a set of postings relating or replying to the initial postings. A total of 452 threads were started, and of these 193 generated reply posts (average number of replies per thread = 4.6).

Many of the postings contained files in addition to the post. Students posted 1212 files, of which approximately 488 were unique and the rest were revisions and expansions of these files.

- *How did students use the Kiva?* An initial categorization of the thread topics resulted in the identification of three major functions: Group coordination, knowledge and work exchange, and preparation of deliverables. For the Voyager group, this rough coding scheme accounted for approximately 75% of the threads.

For the Voyager group, coordinating the activities of the group was done through the Kiva by posting meeting schedules, agendas, and minutes. Approximately 18% of the Voyager threads focused on scheduling and arranging meetings and trips, and an additional 12% focused on the minutes of the meetings, which contained such items as current or outstanding issues, actions, decisions, and timelines. These types of posts served to coordinate inter and intra-group activities by making public the current status, future actions and decisions of the groups. In the GM group, this coordination also included the function of group creation. The GM group began the project with four subgroups but created nine ad hoc groups throughout the semester. These groups were created to support communication and coordination for specific tasks in the design process, such as presentation and report construction.

A second major use of the Kiva was to exchange, correct, and expand on ideas, aspects of knowledge co-construction. For the Voyager group, over 33% of the threads were focused on the sharing and development of ideas and work. As students posted their plans or ideas, other students would catch errors or offer suggestions. The exchange shown in Table 1 typifies this process, whereby a formula is initially selected and posted to the group and another member recognizes a problem, which then initiates additional reflection and changes.

Another common pattern was for a student to post an initial file, followed by the same or other students revising, expanding, or commenting on the work and often reposting an updated version of the file. For example, in the GM project, a student in one of the subgroups posted an initial draft of a user-scenario to all the subgroups. Over the next two weeks the file was revised, edited, expanded and re-posted 11 times, with contributions from five students from five different subgroups.

Finally, the Kiva was used to coordinate and integrate deliverables, such as presentations and reports. For the Voyager group, approximately 14% of the threads focused on the collection, integration, and revision of presentations and reports. Many of these threads consisted of posting of files, lengthy exchanges on how to organize and represent the information, as well as comments on lower level editing issues, such as grammar, spelling and formatting.

In sum, the initial data analysis based on the Kiva logs and the focus groups indicate that students used and valued the Kiva as a tool to help them manage their collaboration and learning. The Kiva helped coordinate group activities by providing an easy mechanism to schedule meetings, update group members regarding issues and actions, share and develop work products, exchange and correct ideas and information, and compile and edit presentations and documents.

To more deeply understand the nature of student collaboration via the Kiva, we are developing a coding scheme to further classify and quantify the collaborative exchanges. We are also designing a coding scheme to identify the design

Table 1. Example of students co-constructing knowledge through an exchange in the Kiva

Alan	I was asking which formula you wanted to use. which comes down to which regression line we are using to map from the fuel values to RPM. I used : y = 327.89 × 3 − 2194.6 × 2 a 5087.4 × −2719.1. R2 = 0.9997
Kim	Ah I see. To be quite honest, I was planning on discussing this issue during class for tomorrow. For now we can just use the one that you wrote above and we will talk more about it during tomorrow's lecture. Thanks!!
Chris	It also might be good to do something as a special case in the formula so that we don't return a negative number for low values of fuel consumption. It looks really weird in the dashboard. ;)
Alan	hehe.. Right. Thanks for testing that. :)
Alan	Kim: I switched formulas. Now I am using this one. y = −1812.5 × 4 + 6744.9 × 3—8322.2 × 2 + 4325.9 × +4.1796. R2 = 0.9993. This is because I had to re-center the data to 0, and this new formula works much better then the alternatives. This is engine 1 I think. (the first set of numbers)
Alan	Sigh.. another new formula. Forgot the upper bound. y = −81.054 × 3 + 311.21 × 2 + 396.24 × +10.003. R2 = 0.9859

process that students engaged in and possibly to capture how their processes developed over the course of the semester.

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. The current version of our software 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 the collaborative learning.

Acknowledgements—We would like to acknowledge the support of the National Science Foundation grant EEC-0203448 as well as the Institute for Complex Engineered Systems. We would like to thank our colleagues Dan Siewiorek, Asim Smailagic, Erica Cheng, Adam Fass, John Kembel, Jonathan Brodsky, Peter Scupelli, and Karen Wong.

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