Measuring the Performance of Online Distributed Team Innovation (Learning) Services

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e-Technologies in Engineering Education Learning Outcomes Providing Future Possibilities

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Abstract

The utility of online collaborative learning tools and services scales directly with its level of adoption by students, educators and other interested parties. Thus, the designers of such tools are challenged not only to create functional tools but also to find ways to encourage their on-going use. This paper describes the creation and promotion of a suite of Web-based services, including group-editable Web pages, Web-based calendaring, discussion forums and a document repository, aimed at enhancing a graduate project-based course. We evaluate the use of these different tools and generalize methods with which to increase adoption of new technologies.

I. Introduction

Studies of innovation consistently identify a strong correlation between the existence of social networks and high levels of collaborative knowledge sharing both within and across organizational boundaries [16]. Several generations of software tools have been developed to support corporate and academic knowledge management and collaboration. While they have increased communication, there is less evidence of improved innovation processes in the client organizations that make use of them.

We believe that there are three root causes for today's collaboration technology shortcomings:

1. they are disparate stand-alone application programs;

2. they are built for use by individuals rather than teams; and,

3. they are structured in line with a "publishing" model of knowledge.

We believe that one road map to better solutions can be seen in the findings of several recent PhD theses coming out of Stanford's Center for Design Research. The key to the power of these findings lies in an experimental research paradigm that synchronously develops and field-validates all elements of the collaboration network and its supporting technology while working with professional engineers in a continuing education framework using advanced project based learning curricula. Four insights lie at the core of the proposed work. These insights, each the product of one or more Ph.D. theses, tell us what kind of activities make innovation activity effective. Guided by findings presented in Figures 1 through 4, we endeavored to develop and deploy the collaboration-network-technology needed to advance engineering education and accelerate corporate innovation.

A. A Product Development Knowledge Acquisition Model Grounded in Practice

For over a decade the Mechanical Engineering Department at Stanford, through its Center for Design Research [4,7,18, 2], has been observing engineers working in design teams. Our intent has been to understand how learning takes place within the activity we observe. Informed by these insights, we expect to intervene in ways that will increase performance and produce better learning experiences, better engineers, and better products. Our focus has been on creating environments and information technology to enhance peer-to-peer communications, cogeneration, and sharing of design knowledge. To this end, epirical studies have been conducted in industy [12]. Findings have enabled the development of a product development knowledge acquisition model (Figure 5).

As modeled in Figure 5, we make a distinction between formal and informal aspects of practice and knowledge. Organization, Product Development History, and Product Development Processes are considered formal elements. Expert Coaches, Teamwork, and Product Development Practices are considered informal elements. The arrows represent the "acquisition" or "cogeneration" of product development knowledge.

The formal tasks and procedures embodied in a product development process must be interpreted and contextualized by product development teams. Otherwise, specific process suggestions fail to be tangible, their value unappreciated, as hard working teammates perceive advice to be overhead. What is of value to the teams is to understand the intent of the process

Function	Text Activity	Draw Activity	Gesture Activity
Store Knowledg	40	19	1
Express Ideas	2	63	33
Mediate Interactio	0	21	46
	19%	46%	35%

Figure 1. Tang [25] and Minneman [22] demonstrated that team innovation is created within a socio-technical-network and that key ideas and concepts are "owned" only by that network, not individuals. As show in this transaction table, different activities mediate different kinds of knowledge sharing.

noun-phrases in documents predict awards in peer-reviewed design competitions

Distinct Noun Phrases

1600
1400
1200
1000
800
600
400
200
0

A

B

A
A
A
A
A
A minus
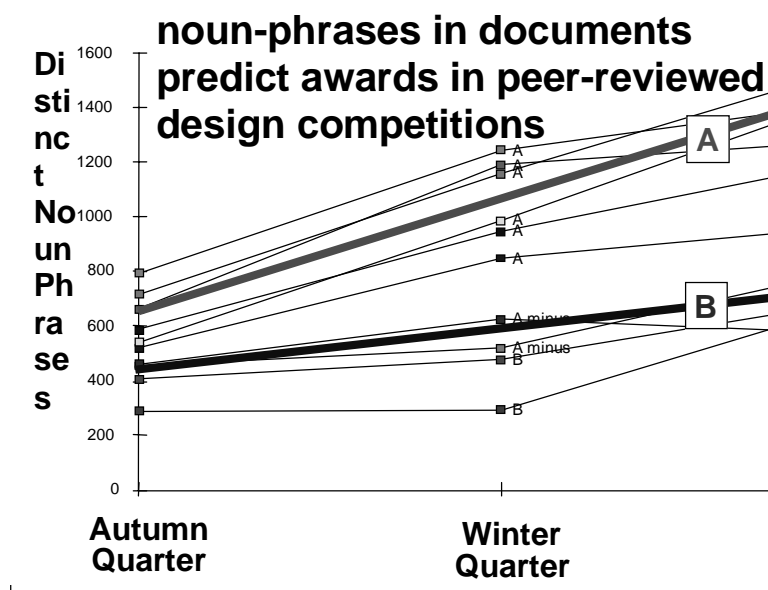A minus
B
B

Autumn Quarter   Winter Quarter

Figure 2. Mabogunje [21] identified the power of linguistic analysis of formal design team documentation (formal and informal) as a predictor of team innovation outcomes. An extension of this work by Yen [27] demonstrated the potential use of these instruments with informal communication records to give teams real-time performance feedback.

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Percentage correlation between access to team-created files
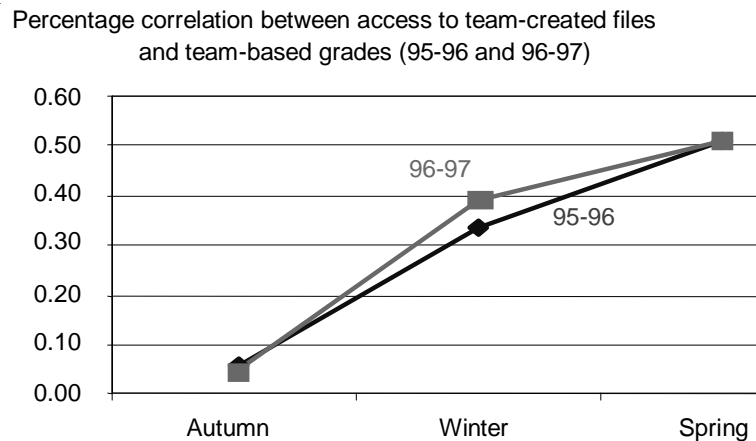and team-based grades (95-96 and 96-97)

Figure 3. Liang [19] identified a strong correlation between the incidence of document access activity and team performance. This figure shows the correlation coefficient between the number of document access transactions and the team grade for two successive years (1995-1996, 1996-1997). More importantly, a follow up study at Xerox PARC revealed that peer-to-peer knowledge sharing out performed both formal project documents and expert mentors in helping teams move through Xerox's formal new product development stages.
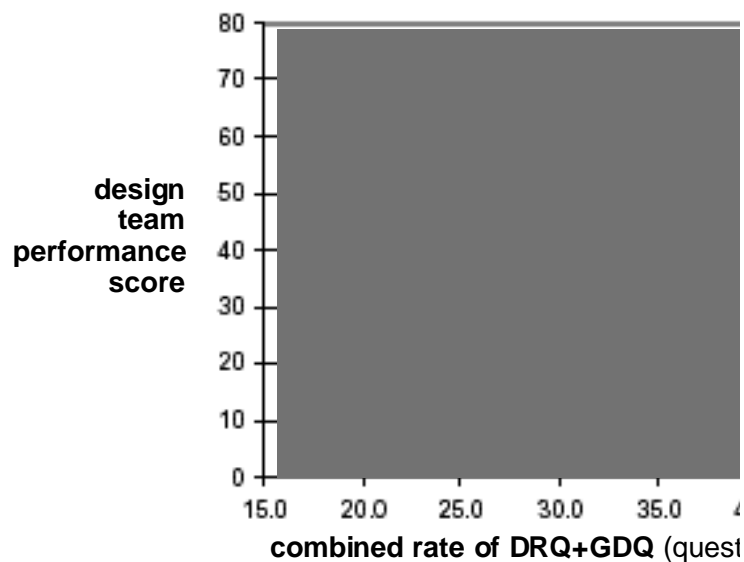

Figure 4. Eris [13] identified an extended, domain independent, question taxonomy that has been demonstrated to yield a strong correlation between the rate of certain question types and design team performance.

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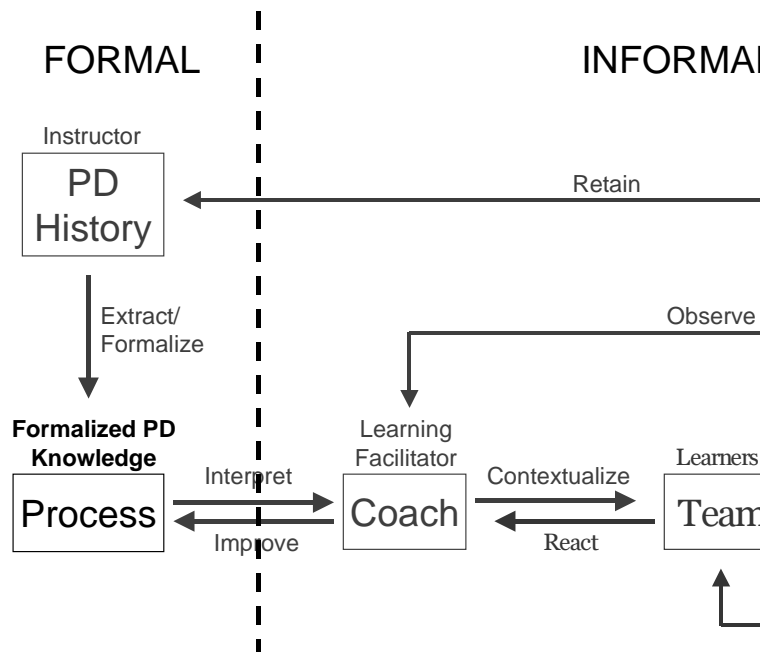

Figure 5. A grounded product development knowledge acquisition model derived from empirical findings.

suggestion—the rationale behind the definitions and procedures. The intent of new product development processes is not readily captured and represented in flow charts, resource allocation tables, task descriptions, and deliverable definitions. On the contrary, it is mainly a common informal understanding of what must be done, when and by whom, that is required to develop a product. Formal product requirement documents tend to play a minor role in comparison to informal interactions between involved parties.

It is important to note that there is no specific node or interaction where product development knowledge is "created." The model advocates that product development knowledge cannot be embodied in a specific individual, a specific group of individuals, or a formal process. Those elements can only embody aspects of product development knowledge. Interaction of those elements is what assigns meaning to the aspects of knowledge and allows for their synthesis. Therefore, it can be said that product development knowledge emerges out of the combined interaction of the involved people and resources.

B. Opportunities for Technological Intervention: Learning Mechanisms in Design Activity

Further consideration of the product development knowledge acquistion model presented in the previous section in a learning context led to the identification of three fundemental learning

mechanisms, referred to as "Learning Loops", associated with the activity (Figure 6). It is necessary to emphasize that the learning mechanisms are dependent on each other in the sense that, in modern product development projects, it is inconceivable for design teams to work in the absence of an organization, a network of experts the organization provides, and a process.

The three learning mechanisms can be seen in the following way:

- *Learning Loop 1 – Designing:* Teams apply the product development process contextualized for them by coaches in their design practice. They utilize information embodied in the process and generate new knowledge.

- *Learning Loop 2 – Coaching:* Coaches observe the design practices of teams, and use the understandings they gain in contextualizing the product development process for them. Based on the needs of teams, coaches selectively extract information from the product development process and present it to the teams in a meaningful way.

- *Learning Loop 3 – Capturing, Indexing, and Publishing:* Instructors (and managers) retain a history of the new knowledge generated during design practice, and extract new elements from it in order to improving the product development process. They manage the capture, indexing, and

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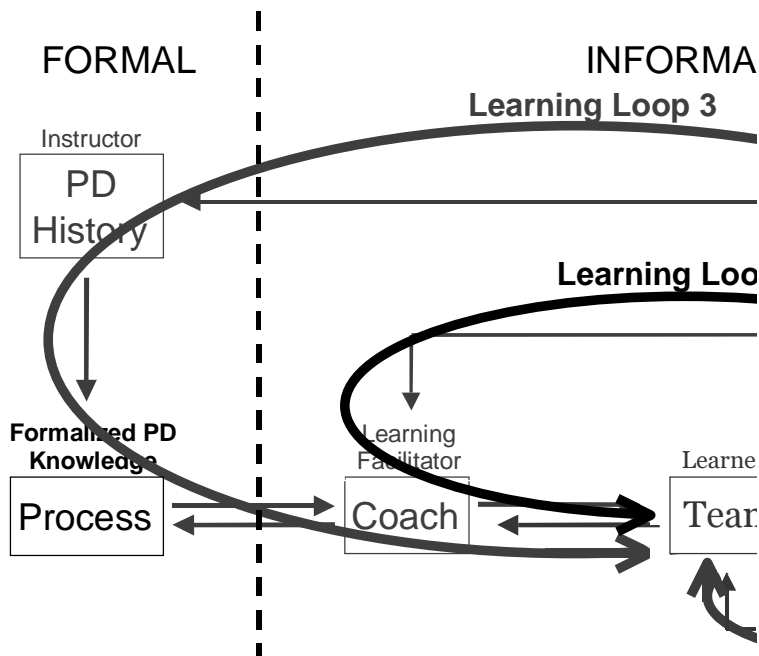

Figure 6. Three opportunities for technological intervention in enhancing design team learning performance.

publishing of new knowledge that teams generate in loop 2 in the form of product development process documentation.

The primary premise of this paper is that the learning mechanisms discussed above can be technologically enhanced. At a conceptual level, we carry out those enhancements in the following ways.

Loop 1: Since the learning directly associated with product development practice occurs at the team level, it can be best enhanced with the utilization of technology that supports and improves peer-to-peer communication such as email, digital messaging, and digital file sharing.

Loop 2: This learning activity involves coaches (members of faculty staff, industrial visiting professors or experienced graduate students) who observe the product development activity the team is engaged in. Effective coaches will adjust their involvement in the project according to the needs of the team. The process can best be enhanced with meta-level tools that measure and display the performance of the team in real-time. We hypothesize that performance metrics, if provided in real-time to coaches, will raise their awareness of the team's operational status and facilitate just-in-time coaching effectiveness. We also hypothesize that raising teams' awareness of their own performance will improve self-coaching.

Loop 3: Since the learning activity involves the formalization of the knowledge gained by team during the product development activity, it can be best enhanced with tools that can capture, archive, and index the digital content that is thought to be of value for future use so that it becomes a contribution to the Digital Library.

Within these learning loops, students are conducting the process of team based design engineering. There are many published descriptions of the design process and it is generally accepted that the process follows the stages outlined in Table 1. Although the design of any one product will generally conduct the stages in the order given, it should be noted that the process of design is highly iterative and will involve returning to earlier stages as more information becomes apparent. Table 1 also outlines the general questions that need to be answered in each stage and the sorts of information and "digital" tools that may help design teams conduct the design efficiently.

The benefits of online collaborative learning services in education are numerous: they centralize course-related information to one area, they facilitate student teams with the communication-intensive yet asynchronous nature of project-based work, and they help the teaching staff and project sponsors monitor the on-going progress of various teams. Most importantly, they help to create a living body of knowledge centered on the class that can be of great use to students in years to come.

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Table 1. The Design Process and Associated Information Requirements [12].

Design Stage	General Questions	Information Required	Helpful Tools
Negotiating the Context	What is the need? Who are the users? How will the product be used?	Details on a wide range of similar and "loosely" related products. User observations	User behavior capture tools User behavior capture tools Document access and filtering
Market Survey	What is the competition? What patents exist? How big is the market? How is the market changing?	Market surveys Forecasts and trends Details on competing products	Document access and filtering Patent Database
Requirements Generation	What exactly should the product do and how should it perform?	Performance of competing products	Comparative analysis Word processorsSpreadsheets
Concept Generation	What ways are there for achieving the functions required by the project?	Mainly a highly creative process requires human input. Access to "standard" and documented ways of achieving functions (i.e., common mechanisms)	Document access and filtering Sketching and rendering SpreadsheetsAnalysis tools
Concept Selection	What is the best combination of functions as developed in the last stage?	Comparative analysis. Often best achieved through discussion	Spreadsheets Decision tools
Embodiment Design	How can the concepts be physically modeling? How will the parts be arranged and joined together?	Similar methods used in other products	Document access and filtering 3D modeling 3D animation
Detail Design	What exact shape and size will each component be? Will they be strong enough? What material will it be made of? What standard parts shall be used? How do the parts relate functionally, behaviorally and structurally?	Material information Standard part catalogues	3D modeling Finite Element modeling Engineering analysis 2D drafting Material databases Manufacturer's on-line catalogues
Manufacture Design	How will the parts be produced and assembled together? What is the order of the processes?	Available manufacturing processes and facilities Comparative costs	Document access and filtering Design for manufacture Process planning Process simulation
Test	Does the product perform as desired?	Test results	Virtual test and simulation
Reporting	What has been achieved? How could the product be improved? What does the customer think?	For students – previous report structures	Document access and filtering Word processing Publishing

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C. Caveat

Despite these benefits, students left to their own devices seldom do a good job documenting and publishing decisions, discoveries and actions. This may be because extra time and effort is required to do a good job, and that they are not mindful of the future benefits of such efforts, both for future generations of students and for themselves. Hence, it becomes important to study ways to motivate the on-going usage of these tools and services. The same dilemma holds for professional practitioners as observed in the field studies that opened our review.

D. Case Study: Graduate Student Design Team Innovation

To characterize this problem and test possible solutions, we introduce the case for academic test-beds [18, 20]. Stanford's graduate-level project-based learning course in "Team Based Design Innovation with Corporate Partners" is one example. Students in this course (many of whom have 2-8 years of professional engineering experience) work and learn in teams to develop functional solutions to commercial design challenges proposed and financially supported by corporate sponsors. Students benefit by gaining exposure to the challenges of real engineering problems in an environment where teachers, mentors and coaches can guide them, and encourage them to reflect on and learn all they can from each experience. Sponsors benefit by having a chance to draw on fresh approaches to their engineering problems and to own any inventions that come from the students' work; by making contacts with talented students who may be future employees and faculty who may be future collaborators; and by getting exposure to current research and experimentation in improved design methods. The course also serves as a test bed for new collaboration-technology development and ways of working. Activity within the course is the subject of teamwork, engineering design thinking and design education research.

E. Team Innovation and Knowledge Management Services

A variety of first-generation computer-based collaborative design services have evolved over the past 10 years. These services were created to help individuals and teams communicate time-efficiently with each other and outsiders. Wherever possible, an emphasis was placed on capturing and reusing communication content, e.g., treating it as unique knowledge created for and within the context of a specific product development scenario. Supporting communication, both formal and informal, has become one of the key course management tenants for success. We call this environment our "distributed team innovation services." In the course year 2001-2002, we chose to use our experience from the past decade, and research results from several dissertations (cited in section A) as well as design thinking research results from elsewhere (especially University of Strathclyde [11, 24], the University of Washington [1, 2], and Georgia Institute of Technology [14]) to reconsider and rebuild

2nd generation services that would be sufficiently robust and general that they could support a wide variety of other learning teams and group activities.

As collaboration-technology development has moved from the laboratory to industry (including the efforts of some of our alumni at Xerox PARC and wiTHinc) we chose to build the next generation of collaboration services around a suite of commercial software elements. We are in the first year of the deployment of these new collaboration technology services in the course. Of course, in order to study the effectiveness of these knowledge management tools, we need the students to use them. However, mandating usage of these technologies risks hampering the students' work rather than improving it, and can blind us as developers and researchers to opportunities to improve the toolset, or to choose the appropriate technologies to aid students' work.

II. Strategic Technology Components

A. Other Work Related to Collaboration Services

The use of various collaborative Web-based knowledge management tools in the university setting has become increasingly important, as teachers strive to provide content and support to students and partners distributed throughout the world, and as students strive to work on shared projects on differing schedules. Previous research done in conjunction with this particular project-based learning course indicates that promotion of good engineering documentation leads to better engineering work, particularly in the context of collaborative teamwork, where the formulation of such documentation also provides a valuable means of communication and knowledge retention [7]. However, a recent survey of educational technologies by Phillips Research indicates that technological support for collaborative learning is still limited compared to support for multimedia lectures or consultations [9]. Case studies of different technologies such as community-editable Web pages like CoWeb at Georgia Tech [14] or WebAnn at University of Washington [6] have focused on measuring general student affect towards the collaborative information technology tools, or comparing preference between technologies. However, these studies largely depend on teacher-mandated usage.

Palen and Grudin [23] noted in their study of employee adoption of calendaring technologies that the implementation or installation of a technology into a group-work environment is no guarantee of its acceptance or adoption. Particularly in the case of community-shared document editing, large-scale "buy-in" on the technology is necessary for true success, especially since the value of the document repository relies on sincere contributions by numerous authors. Brown and Durgid [5] make a particularly strong case for the "Social Lifer of Information" that helps explain the social logic of communication tool and service adoption.

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The structure of Stanford's Team-based Design Innovations with Corporate Partners course is of particular value, because it starts in its first quarter with regular instructor-mandated assignments, but then progresses into student initiated project management for the following two quarters. We piggy-backed our technology rollout to this structure by mandating tools usage in first-quarter assignments, to familiarize students with the tools and their purpose, and then, in following terms, allowing students discretion as to which tools to use in their project work. Although it is too early to state which technologies are more relevant or popular, we have learned a great deal in our efforts to promote discretionary adoption of the various component technologies which can greatly improve future implementations of such collaborative tools.

B. The Importance of User Editable Web Page System

All of the collaboration technology is accessible through a Web browser, though some not exclusively so. Web pages are written in a combination of regular HTML and JavaScript, and a new language from Xerox PARC, Sparrow [10]. Using these technologies as glue, we have integrated five core technologies to deliver some 12 services.

Core technology includes the following applications:

1. Web-based project management calendar for individuals, teams and organizations;

2. discussion forums with document annotation for joint document authoring;

3. document repository with version control, secure access, and HTML conversion;

4. hyper-text email Web-archive with sorting and searching for tacit knowledge reuse; and

5. e-mail distribution list management for systematic notification.

Sparrow lowers the barrier-to-entry for would-be Web content producers, by providing them with a means of inputting and editing content on a Web page directly from their browsers. Users falls into one of three role categories: contributors, authors, and administrators. Contributors (students and workers) input and edit content on a Web page within the framework provided to them (no knowledge of Sparrow or HTML required). Authors (teaching assistants and project managers) copy and modify existing Sparrow templates, or create their own templates from scratch. Administrators (systems managers) configure the Sparrow software and the Web server.

C. Specific Core Technology Tools and Services

We have explored five main strategies to encourage Web-based collaboration. We know from experience that there are many barriers to success. The most fundamental barrier is human hesitancy to risk knowledge sharing (and the associated risk of exposing knowledge inadequacy). The second most fundamental barrier is the fact that collaboration technology is new. Its contribution to our work and well-being is unproven. These observations have, in part, motivated our pursuit of team performance metrics that can be affected, in a positive way, by collaboration technology.

We have used five strategies to encourage online collaboration. These include:

1. mandating usage (by homework assignment);

2. creating context-specific tools to make specific tasks easier;

3. placing tools in locations that made sense during real world work;

4. enabling and fostering personalization of the tools; and,

5. integrating our tools with others that had already been accepted and used (e.g., e-mail).

In the following sections, we describe services that we have created in the context of this strategy. The treatment will be very brief. Selected early instrumentation outcomes will be shown.

D. Collaboration Technology for Coordination and Knowledge Sharing by the Design Team in Learning-Loop-1

The following sections have been written in the first person from the perspective of the Web services development team's diary of usage and performance observations. While breaking with the expected format of a "research paper" we have chose to preserve this tone and perspective for those who will shortly follow in the Web teams footsteps, both strategically and tactically.

1) *Team Home Page:* To address the need of a team to publicly represent who they are, and what they are working on, we created the team page. At the left side of the page is a column for adding people that are related to the project. People are added into one of three categories (students, coaches, and liaisons), in the same way as any other item in Sparrow. A person is represented by their name, image, and email address. When a person is added to the page in this fashion, they are also automatically added to the email distribution list for the team.

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Most of the teams have modified their team page, anywhere from the minimal obvious modifications (adding their team name, logo, team member names), to changing backgrounds, to faithfully keeping up weekly notes, adding interesting pictures, links, etc. However, customization almost certainly hasn't been to the degree it's been in past years, where the students could start from scratch, and not have to worry about stepping on any of the Sparrow elements that they weren't familiar with, and thus breaking the page. In any case, anecdotal reports suggest that visits to the team page by team members is not particularly common; it is not serving as any kind of a central launching-point for day-to-day computer work.

2) *Team Specific Tools:* The team home page links together several Sparrow-created tools, as well as a number of other Web-technologies (Figure 7). At the top left of the page is an area to enter a brief description of the project. To the right of this is an area where a graphical logo, possibly representative of your team's sponsor, can be uploaded,

and which will appear on the page. To the right of the logo is a menu of resources, including a Sparrow prioritized to do list. Below the resource menu is a section of links to collaborative tools, instances of which have all been automatically created: a Web calendar, an email archive of the distribution list for the team, and a document repository. At the center of the page is an area an image that is representative of your project can be uploaded and displayed. Below this image is an area where weekly or daily news items can be added in a meaningful history.

3) *Team To Do List:* A prioritized to do list is available via a hyperlink at the top of the team page. When an item is added to the list, it is given a short, one-line description, a "tab-keeper" (typically the name of the person that created the item), an "owner" (the person that will do the task), a creation date, a due date, and a more lengthy description of the project. When an owner has accomplished something to do with his task, he can modify the item that corresponds to it, and update the description field.
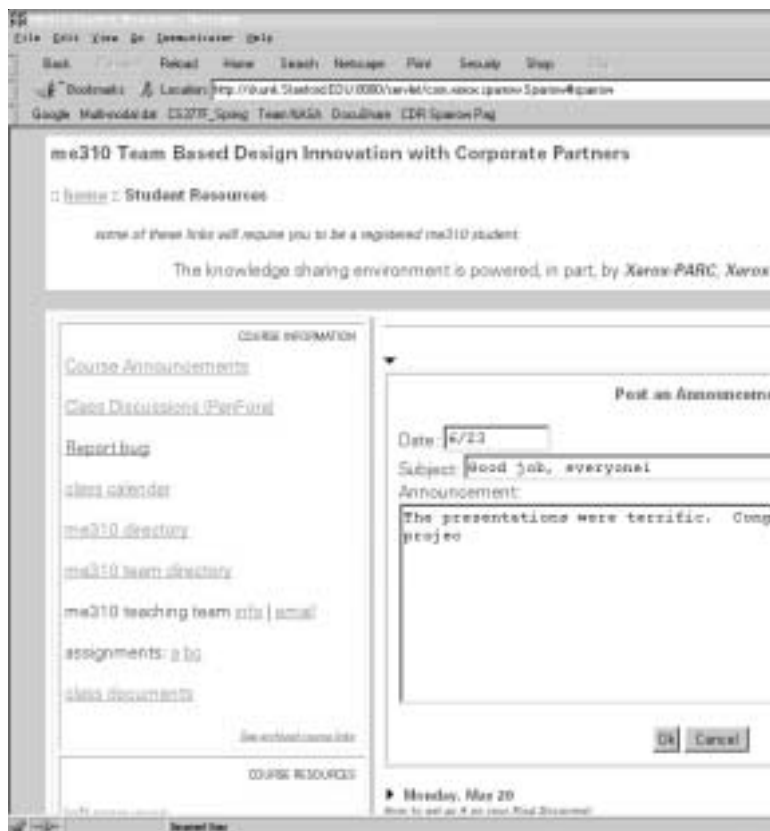

Figure 7. Course home page screen shot at the Student Resource level. While the home page serves primarily as a jumping off point to team resources, this example shows team announcement entry template. These diary-like statements are the top level of shared communication within teams and served at a first point of contact for the corporate liaison and teaching team to track work in progress.

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Initially, we had placed the list in a menu of tools that popped up when the user moved the mouse over a particular hyperlink. Once the mouse movement had triggered the menu, the user could click on one of several hyperlinks. By placing the tools in this menu, we were saving valuable real estate at the top of each team page, but still enabling the tools to be reached by a single click. We thought it was a neat solution, but it did not work. We speculate that this is at least partially because users are not accustomed to having mouse movements trigger popup menus. They did not expect the menu to pop up, so it did not occur to them to move the mouse into the right place. In a subsequent version of the team page, we corrected this by placing regular hyperlinks to the same tools directly on the page. This method took up more space on the page, but by making small adjustments to the page layout, the detriments were minimal.

4) *Team Calendar:* The creation of a team triggers the creation of a calendar to go along with it. Each team's calendar automatically inherits events from the main class calendar, so teams can have a full view of their schedule for the week from a single Web page. The calendar is linked in a noticeable place at the top of the team page.

5) *Individual Weekly Class Planner:* As part of the bio page, we provide a scheduling table. The rows of the table are broken into the timeslots for various classes. Each box of the resulting grid can be filled in, according to the student's schedule. Our intention with this service is to facilitate the determination of mutually agreeable meeting times between students.

E. **Collaboration Technology for Coordination and Knowledge Sharing between the Design Team and their Coach in Learning-Loop-2**

6) *Biographical Pages:* Adding an entry to the directory of people triggers the creation of a biographical Web page. The information entered into the directory automatically propagates to the new biographical page, so that users do not have to type it twice. Additionally, the biographical page has pre-defined section for the following information: degrees, industry experience, learning prospectus, recent publications, project experience, computer proficiencies, etc. Of course, the page can be modified to include additional sections if a user so desires. In the top left corner of the page, there is a place to upload a picture of oneself. All of these bits of information are tagged for indexing. We provide a table, whereby you can fill out your class schedule, and later super-impose it upon any other participants schedule for determining mutually compatible meeting times.

7) *Team Formation Matrix:* On the directory of people page, below the link to the photo matrix, is a link to the team formation matrix. The team formation matrix is a java servlet that pulls information out of each student's biographical Web page, and displays it in a compact, easy to read format. By using it, students are able to compare potential teammates side by side, without having to click back to the directory each time you want to look at someone new. All of the most vital information for picking teammates is available on it. To help students figure out whom they want to team up with, they can print the whole matrix out and take it with them.

8) *Wilde-Jung Personality Survey:* As part of the biographical Web pages, appears a section entitled "Wilde's Role Characterization Survey." When the edit triangle to the left of it is clicked, the user is presented with a 25-question personal preference survey, which attempts to categorize you in relation to your community, along two orthogonal axes (Judgment and Perception). Upon completing the survey, the user is rewarded with a numerical score that can be used with supplemental papers by Douglas Wilde to evaluate the "creative balance" of a proposed team [26].

9) *Photo Matrix:* At the top of the directory, you see a link to the PhotoMatrix, and click on it. You are rewarded with a table of smiling faces—all of the registrants of the class—and their names. PhotoMatrix is a Java servlet that generates a Web page from the contents of the hierarchy of biographical Sparrow pages. It opens the directory page using SparrowDB, then follows the links to each biographical Web page, which it also opens with SparrowDB, and extracts the path to each biographical image. To help remember who is who, print out a copy.

10) *Team Creation:* With the completion of the Wilde-Jung survey, students transition from the knowledge community creation process, to the process by which we create a framework for capturing the knowledge generated by a single project. There is no time to be wasted in ME310, and in the next class session, the students are randomly grouped into three or four person teams. Each team chooses a computer administrator from among their members, and this person is instructed to create the homepage for his team by following a hyperlink off the main site for the class.

11) *Team Roster:* At the top of the team, roster page is a table of documents that pertain to every team: an intellectual property agreement for the class, a purchase order form, a reimbursement form, an "administrative survival guide," and a budget spreadsheet. These documents are stored in our document repository, and only the administrators for the class have permission to modify them, although anyone can download a copy of a document by clicking on it. We decided against simply placing a link to a DocuShare

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repository containing these documents, in favor of making the documents themselves accessible via a single click. This way, they are visible each time a user navigates to their team page. To the right of each document is the date of the last modification, so that users can verify that the version they are about to download is up-to-date.

Below the common documents area is the roster of teams. The page informs you that a new team can be added to the roster by clicking a button above the table. Upon clicking it, users are asked to enter some appropriate information about the team they are creating: its name, a name for the email address that will be used as a distribution list and archive for all email communications related to the team, the name of the team's sponsor, and a URL to the sponsor's Web site. Upon confirmation that the information they have entered is correct, they are transported to the team's new home page. Simultaneously, this page is linked to its entry on the team roster.

12) *Course Assignment Pages:* To address the instructor's need for a place to advertise assignments that could be easily adapted from one year to the next, we use a set of Sparrow assignment templates. These templates are secure and can only be modified only by the instructor, and published to the class. For each quarter, we created a page analogous to the directory of teams page. The assignment page itself has a table of contents at the top, which divides the assignment into sections, and describes them by title, weight, and due date. Sections in the body of the assignment page describe each item in the table of contents. The instructor can upload an image to each of these sections. We placed three hyperlinks, one to each quarter's directory of assignments, on the home page for ME310 students.

13) *Diary Entries:* Every Thursday night, an email reminder is sent out to the entire class, reminding them to enter a log entry into their team page. On Saturday, the teaching team receives an email that concatenates all of the most recent updates from each team page. This is being done under the auspices that it will help keep the teaching team up-to-date on the student team's are work.

Students seem to find that the weekly update items on their Web pages are not too onerous, and are worth the effort. It is not clear whether the teaching team is getting much benefit from them. This may become clearer as people become more accustomed to the weekly reminders to students and summaries to the teaching team.

14) *Project Solicitation and Tracking Pages:* Because ME310 is a class with corporate sponsored projects, there is an inherent need to recruit corporate sponsors. The professor for the course and several administrators are involved in this process. Out of the multiplicity of people contacting the potential sponsors, a need evolved for a common place to describe actions that had been taken with respect to the project. These actions include telephone conversations with liaisons, and leads to other potential projects. Additionally, the administrators needed a place to simply record the contact information for the various corporate people involved with creating this type of relationship between the university and a company.

For these reasons, we created the project tracking pages. The pages are analogous to the directory of people and team roster in that a single page lists the projects being tracked, their status, the company contact, the university contact, the company unit, and when the project was last updated. New projects can be added to the list, and each project is associated with a page of notes, which is created when a new entry is added to the list. At the top of the page of notes is a place for uploading the project proposal, which is then available via hyperlink.

15) *Course Calendar Activity Reminders:* One of the most useful features of our calendars is that they can send email reminders of upcoming events. These reminders have proven extremely useful, since we have had considerable difficulty in getting the student teams to regularly visit and use their calendars. However, the teaching team has done a good job of keeping the course calendar up-to-date with assignment due dates, social events, and noteworthy outside events that are related to the class. We have found that the email reminders are actually sufficient to keep students in tune with the most important dates. Although it is nice to be able to go to the Web calendar, and see the next few weeks in a single glance, students seem to do this only rarely.

F. **Collaboration Technology for Coordination and Knowledge Sharing between the Design Team, Coach, Corporate Liaison, and the Teaching Team in Learning-Loop-3**

16) *Registration:* Registration, a simple task, serves two purposes: as an introductory exercise to learning the Sparrow system, and as a means for providing a virtual directory for locating other people involved with the class. Registration is accomplished by clicking a button, which inserts an item into a roster of people involved with the class, and prompts the user to fill out some cursory contact information: their name, telephone numbers, email address, the location of their office, their classification—student, coach, consultant, or liaison—and whether they would like to subscribe to the class mailing list. Upon clicking the "Ok" button, the page reloads, and a new record has been created and automatically categorized by classification, and sorted by name. The checkmarks for indicating mailing list membership seem to be the best example we have of a feature asked for by users whose usefulness matches the original vision.

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17) White Paper Tool: Another link that lives at the top of each team page is one to create a group-editable white paper. The white paper tool is a group-editable Web page that is meant to provide a means to jump-start the process of writing a paper that has multiple authors. In an attempt to prototype a solution to this problem, we created the white paper tool. At the top of the page is a table of contents. On the left side is a section number and descriptive title for it. In the middle is a place for notes about that section. On the right is the name of the person responsible for that section. Items can be added or removed from the table of contents via the standard Sparrow mechanisms. The white paper tool is an elegant way to get started on a paper. We used it to start this paper.

18) Document Repository: Use of the document repository was mandated in the sense that the teaching team required student teams to turn in their design documents by submitting them to class DocuShare repository. Overall, this was very effective, especially during the frenzy that ensued before presentations. DocuShare allowed teams to turn their presentation slides into a common location in a distributed fashion, and simultaneously made them available to the computer feeding the video input for the slide projector.

19) Document Repository: Our document repository, DocuShare, was linked into the ME310 Webs in several places. First, a link to the root of the repository appears at the bottom of the home page for the class. The root of the repository offers services that are applicable to the entire repository. For example, a search facility will provide a list of all recent additions to the repository. Additionally, documentation on DocuShare itself is easily accessible. A link to the repository designated for documents pertaining to the class appears on the student page, and each team page has a link to its own document repository.
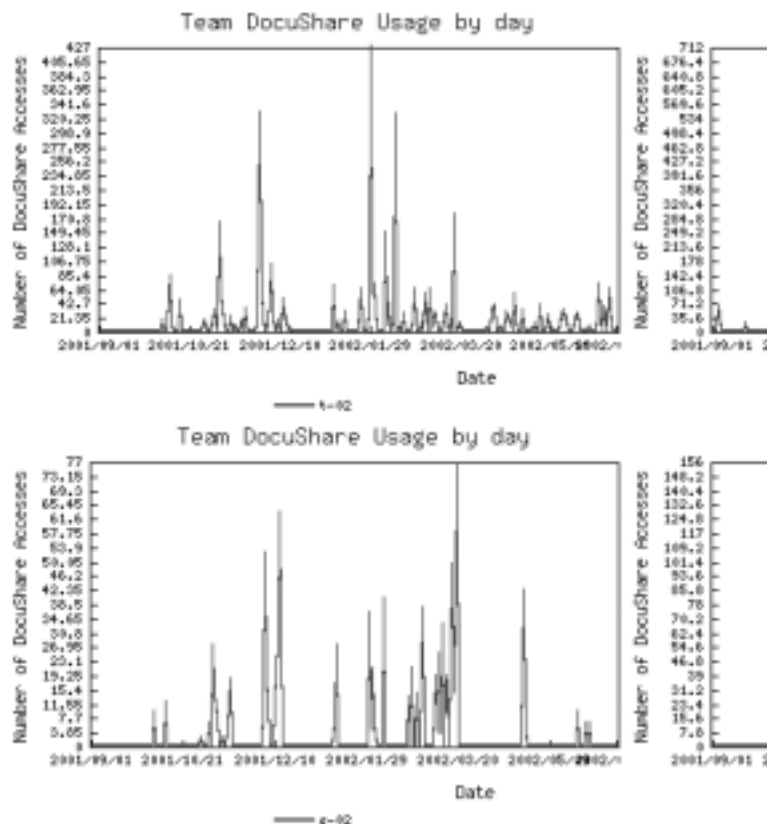

Figure 8. DocuShare Usage per Day per Term: the number of document access sessions per day has been instrumented in the interest of developing a metric for knowledge reuse and it relationship to design team outcomes. Four different teams are show here. As noted in Section-B, Mabogunje demonstrated a very high correlation between the incidences of unique noun-phrases in final design reports. This new instrument promises to reveal any corresponding relationship for "work in progress."

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20) *Mailing List and Online Hyper-Mail-Archive:* In the top right corner of the team page, we placed a hyperlink to the mailing list archive, and a hyperlink for sending email to the list (Figure 9). We found that students easily learned how to control the participants on the list by adding or removing people from the team page. However, some teams—especially the distributed ones with teammates in other countries—wanted to have more than one mailing list. This prompted us to integrate Mailman into our services. Unfortunately, students did not have as easy a time learning to use Mailman as they did with using the team page to manage their primary mailing list. Thus, integrating Mailman incurred an additional administrative overhead to our team. It is apparent that the mailing lists have been well used. In addition, the teaching team regularly examines the Web archives. However, we do not know how useful the archives have been to the students.

21) *Biographical Photos:* The photo that appears on a student's biographical Web pages is another medium by which it is possible to express some personality. Although we did host a session of mugs shots, where we took boring pictures of students standing in front of white backgrounds, the students quickly discovered that they could replace these images with whatever they preferred. Unfortunately, one of the downsides of this was that some students decided to replace their picture with a picture of something other than themselves, which made it hard to identify them.

G. Specialized Clients versus Universal Accessibility

A key benefit of Web-based collaboration tools is that they can be accessed by anyone who has a Web browser, and thus are inclusive of people who use various operating systems and applications. We believed students would dislike having to download and install numerous client applications, and that they would not motivate themselves to learn their various interfaces. However, with DocuShare, a tool that offers both a Web-based interface and a specialized client application for Windows users, we found in focus group studies, that students who used the client application were far more satisfied with the technology than those who used DocuShare via the Web, and were more likely to use it on a regular basis. Students were frustrated with the slowness of the Web, which was not a function of the network speed so much as the limitations that the browser interface brought to simple transactions like uploading and downloading a file.

We have come to understand that the Web-based interface is best for services that students may use only occasionally, where the trouble of installing a new application would prove to be an insurmountable barrier to that application's use. On the other hand, for frequently used applications, a Web-based interface is often frustratingly inefficient, and in such cases, a specialized client is appropriate.
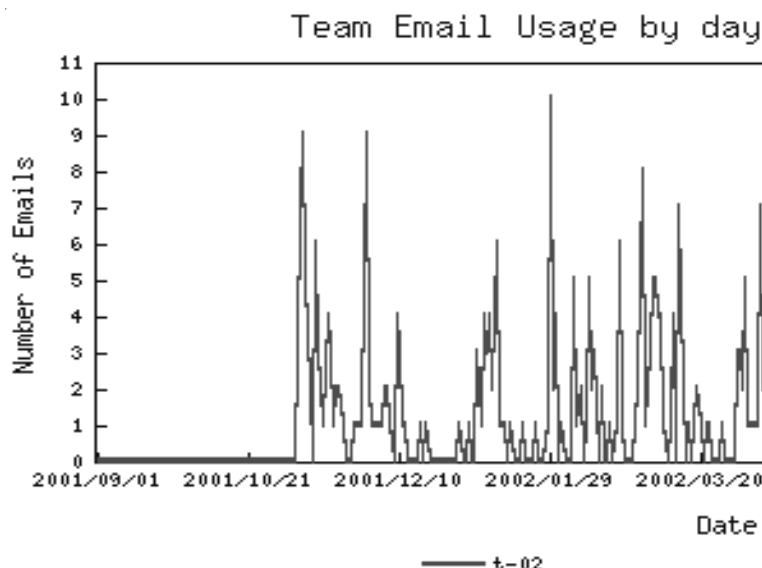

Figure 9. Usage log for the Toyota team: HyperMail service usage has been instrumented to track the level of usage over time. This feature of the collaboration-technology services was "instrumented" because an earlier study [Feland, 1996] indicated a strong correlation between email usage and project outcome quality (higher usage corresponded to better outcomes.

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III. Conclusions and the Continuing Pursuit of Metrics

We have described the tools we created to facilitate collaboration in a Web-based environment, and addressed the problem of getting the collaboration to happen. The most significant avenues we pursued in this regard are mandating usage, creating context-specific applications, placing tools in locations where they would be found useful, integrating new tools with ones that have already been adopted, and enabling the personalization of new tools. We have also been guided by the general principles for "How People Learn" as put forth by Bransford et al [3].

While mandating usage is effective in providing initial exposure and establishing a common set of references, it is decidedly not a strategy that should be used after collaboration has been properly primed. In the future, we intend to focus intently on creating more context-specific applications, and trying to eradicate instances of bad tool placement within our services. Placement ranks high on a list of the top reasons students did not use tools, and it is frequently a simple matter to rectify.

In our thoughts on tool placement, a recurring question has been that of what items to put in the first screen of a page, before any scrolling is necessary—"above the fold," in newspaper terminology. Optimally, we would like to organize pages such that there is nothing of importance below the fold, and furthermore, as the page is contributed to, nothing is pushed there. This ties into our interest in more data mobility within Sparrow. When pages become too large to fit naturally into a screen, it should be possible for Web novices to move pieces of data to other pages, in a manner more flexible than the current archiving scheme.

We surmise that our time devoted to the process of integrating new tools with existing ones was well spent. The most successful integration has been that of with email, so we would like to explore that avenue more broadly, and intelligently. We think that a more intelligent coupling with email could be the key to getting students to realize the potential of the prioritized to do list.

In the spirit of continuing our efforts at integrating our new tools with existing tools that have already been adopted, we would like to create whiteboard-to-Web and audiovisual capture-to-Web interfaces. The purpose of this would be preserving more of the knowledge that is generated by our design teams. One of the most common working scenarios we have noticed for a design team is to have a group meeting around a whiteboard, and then take a picture of the whiteboard with a digital camera. The resulting image is eventually stored in the document repository, or posted on a team page. In the future, our system will take these actions automatically.

Sparrow has proved effective at enabling a significant amount of customization of Web pages, to a certain extent, without requiring Web savvy users. However, all of the customizations allowed in this manner must be pre-programmed by the page author. For page design, Sparrow still assumes a somewhat Web-savvy user. For example, to accomplish the simple action of copying a page, the user must come up with a directory path from the Web server root. Additionally, in the near future, HTML knowledge will be a necessity for customizing Web pages beyond the use of the pre-programmed templates. We would like to experiment with a tool like Sparrow that enables less limited customization of Web pages, without the HTML knowledge prerequisite.

In closing, we would like to cite two seminal publications that will shape our next steps. The first is Hargadon's [17] identification of the power of technology brokering within innovative groups. We foresee applying this perspective to enhance the team coach's role as the broker for driving adoption of distributed team innovation technology. The second key perspective comes from Hutchings's work with learning portfolios [17]. Going forward, we will restructure and re-represent our distributed team innovation services as individual, team and organizational "learning-portfolios."

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