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Chapter 1

SYNCHRONOUS, IP-BASED, COLLABORATIVE ENGINEERING DESIGN EDUCATION

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Abstract

Engineering organizations, in both the private and public sectors, are increasingly employing design teams that are geographically dispersed. When first confronted with conducting business at a distance, organizations often stumble since they frequently try to use techniques that have been developed for face-to-face situations; new tools and techniques, both technical and social, are required to effectively perform engineering design in multiple locations. To teach students about geographically-dispersed collaborative engineering, Syracuse and Cornell Universities have teamed to offer a two semester, synchronous, IP-based, design/build/test, distance learning course. The course was developed under the sponsorship of NASA, an organization with geographically dispersed research centers that need engineers with collaborative skills. This course, in which each team consists of students from the two universities, teaches teamwork at a distance, as well as exposing students to state-of-the-art technical facilities that are similar to those they may encounter when they enter the workforce. Key questions posed and researched through this course include:

1. What technologies are essential for an effective IP-based distance design course?
2. How best to introduce these technologies to students and teachers?
3. How best to form teams from distant schools?
4. How to evaluate the effects of IP technologies on teaching and learning in a distance design course?
5. How to provide high quality technical instruction using room and desktop based video conferencing tools?
6. How are IP-based tools best used for design collaboration?

I. Introduction

In global organizations, it is increasingly common for design teams to be composed of engineers and other technologists working from geographically dispersed sites. Such teams, often referred to as "virtual teams" or "global virtual teams" (VTs), are reported to be used in over 50% of companies with more than 5000 employees [1]. All the difficult issues in multi-disciplinary team collaboration are compounded by non face-to-face communication. Advanced information technologies (IT) such as Internet Protocol (IP)-based video conferencing and collaboration environments, in combination with existing technologies such as telecon and email, are being increasingly deployed in business and promise to improve the communication and functioning of dispersed teams [2,3]. For example, contractors for the Crew Exploration Vehicle (CEV) are required to use the NASA Integrated Collaborative Environment (ICE) to develop and manage data, including CAD drawings, bills of materials and documentation of modeling and simulations [4]. In a recent report, the National Academy of Engineering points out the need for future engineers to make effective use of virtual communication tools for design and collaboration [5].

The core tools for facilitating distance design are web-based collaboration environments and video conferencing. The design and use of these tools is the subject of a number of studies. For example, Norris *et al.* describe the design of collaborative operations facilities to support the Mars Exploration Rover mission [6]. In an early experiment using an asynchronous computer conference system known as MeetingWeb [7], Warkentin *et al.* found that although teams using this computer mediated communication system (CMCS) exchanged information as effectively as face to face teams, they could not outperform traditional teams in a simple exercise. In addition, the CMCS team members had a lower perception of their team's interactions. Briggs reviews existing collaboration technologies and argues for a technology-supported work process approach to the design of such technologies [8]. Lee discusses the room metaphor for collaboration environments [9]. Hollan and Stornetta point out that successful computer mediated communication and collaboration will require the development of tools and methods of using those tools that, rather than trying to mimic face to face meetings, are based upon the strengths of telecommunication [10]. The efficiency and acceptance of Lin2K, a web-based collaboration tool for engineering students was studied by Hadjileintiadou *et al.* [11]. Fuller and Moreno discuss the use of a web-based collaboration tool in the context of an introductory engineering course [12], finding that the proper application of the tools improves learning and changes teaching methods. Lahti *et al.* studied the evolution of collaboration among students using IT collaboration tools to design textiles [13]. Their study shows that computer mediated collaboration can be integrated into design, but that "it is not enough to offer the collaborative technologies; an appropriate social infrastructure is also needed…" Ocker and Yaverbaum compared computer mediated communication (CMC) to face-to-face (FtF) collaboration in the context of a Harvard Business School case analysis and report [14]. Mixed results were obtained in that the CMC environment produced equivalent results as FtF for task outcomes; however, student satisfaction was higher in FtF. Cottrell and Dannenhoffer provide a student's perspective on virtual teaming [15]. The acceptance of technology and its role in the social network needed for successful collaboration is discussed by Lee *et al.* [16].

The use of virtual teams and the supporting information technology appear to be rare in engineering *design* education. As a geographically dispersed engineering design organization and one that has faltered due to failures in distance collaboration [17] NASA has expressed the need for change in how engineers are prepared for distance collaboration in design [18, 19, 20]. In 2002, NASA challenged Syracuse (SU) and Cornell (CU) Universities to address this need by creating a multi-disciplinary, synchronous, IP-technology intensive, senior-level, collaborative distance design course. We decided to address the following key questions in the design and evaluation of this course:

1. What technologies are essential for an effective IP-based distance design course?
2. How best to introduce these technologies to students and teachers?
3. How best to form teams from distant schools?
4. How to evaluate the effects of IT technologies on teaching and learning in a distance design course?
5. How to provide high quality technical instruction using room and desktop based video conferencing tools?
6. How are IP-based tools best used for design collaboration?

The course and the technology used to support it are first discussed followed by a description of our evaluation methods and results of our educational experiments. We argue that an effective, IP-based, multi-university, collaborative design course can lead to very successful learning outcomes with the proper design and use of collaboration tools and attention to team formation.

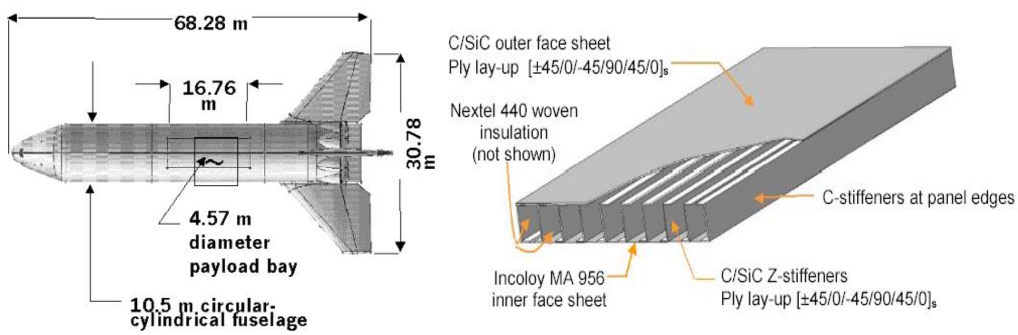
II. Course and Technology Description

The course, taught jointly by SU and CU faculty from several different engineering disciplines, is a year-long, capstone design experience involving approximately 15 students from each university. The principal design objective was an innovative thermal-structural system for a re-entry vehicle. The course organization and content varied somewhat over the three years it has been offered to date, reflecting ongoing lessons learned by the faculty. Therefore, although the core aspects of the course remained unchanged in each offering, the description below is best representative of the 2003-04 course.

A. Fall Semester Curriculum

At the start of the course, the students were divided by choice into three short courses, or “discipline specific tracks”, thermal systems, materials, and aerospace structures, each taught by a different faculty member. Of the ten students in each track, five were from CU and five from SU. Lectures and discussion sessions were given synchronously at CU and SU using IP-based videoconferencing. Generally, the course notes were in somewhat sparse Powerpoint format. They were provided to the students ahead of time, although the versions given to the students were incomplete, missing, for example, derivations or key data. This forced students to pay attention and to take notes in class. It also created the need for a technology that would allow faculty to complete their Powerpoint notes in real-time and with blackboard-like efficiency, and for the students to complete notes in a digital format. Through these short courses, each student developed a specific skill and set of analysis tools that would be needed by their team to complete the design project. Students completed four to five individual, analysis based, homework assignments in the short courses. We experimented with procedures for collecting assignments, including allowing for paper copies, faxed papers and email submission. However, the procedure that in the end proved most straightforward and consistent was to have students upload all assignments electronically to their personal dropboxes on the course's web-based collaboration site. The evolution of the IP and note-supporting technologies used for the short courses are described in the Course Technology Section, below.

Working at a distance (with one or two in-person meetings), each team developed a preliminary thermo-structural design for a portion of a hypothetical reusable launch vehicle, Figure 1a. Students were provided with tables of structural and thermal loads as well as design examples and a pre-screened collection of NASA and other reports containing material properties, test results and other information relevant to the design. In addition to using the provided papers students made great use of additional information resources found through general web searches and through accessing the NASA reports server [21]. Design requirements included protection against re-entry heating, strength to resist given loads, and minimum weight.



(a) (b)

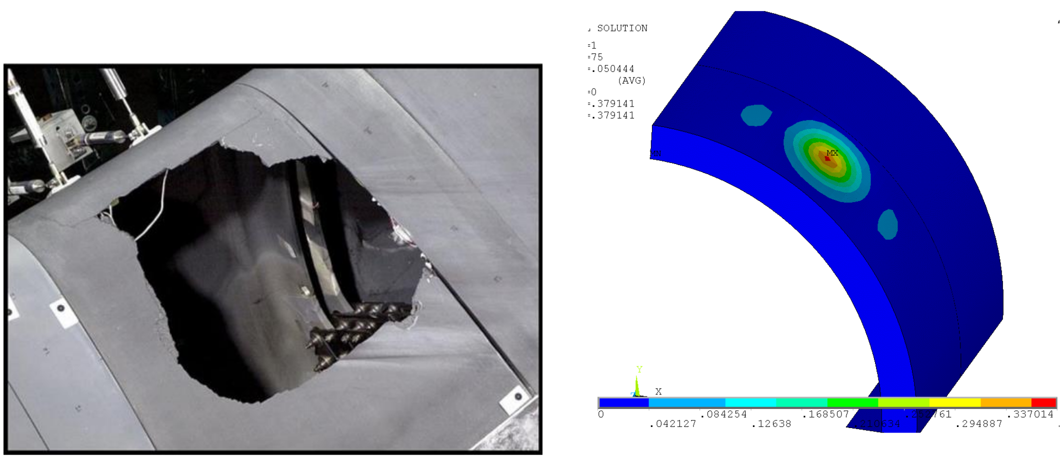
Figure 1. (a) Proposed 2nd generation reusable launch vehicle. (b) Example preliminary design for a thermal-structural system developed by a student team.

Student teams prepared oral and written reports on the design project. Each of the five design teams had a faculty coach. The coach helped the team get organized, reviewed design concepts and reports, and facilitated interaction among the team members. An example of a student team developed structural design is shown in Figure 1b. This and all designs must pass rigorous mechanical and thermal analyses. Grading was based on student's individual assignments in the short courses, on team written and oral reports and on self and peer evaluations performed twice during each semester.

In addition to focusing on the technical disciplines and design project, the course included presentations and interactive exercises on design from the big picture, team formation, report writing, best practices for graphs, figures and slides, practice sessions for giving oral reports, and rapid feedback from the faculty on presentations. An important part of the design experience were team building exercises carried out using the web-based collaboration tools. A favorite exercise involves each student sitting at his or her individual computer and interacting with team members through desktop conferencing. The team is assigned the task of making a ranked list of items that they would bring on a survival exercise. Working through this exercise allows the students to practice and to learn teamwork while at the same time learning to use the IP-tools.

B. Spring Semester Curriculum

This division of instruction and learning described for the Fall semester was repeated at the start of the spring semester but with three new short courses and a different design project. The courses covered: (1) use of finite element software (ANSYS) for dynamic structural analysis of impacts, (2) use of computational fluid dynamics software (Fluent) for assessment of aerodynamic flows and (3) systems engineering concepts, teaching students how to think about and analyze the entire system to minimize risk of failure and maximize the overall performance. Motivated by the space shuttle Columbia accident, in which foam shed from the external fuel tank ruptured the wing leading edge of the Columbia orbiter, see Figure 2a, in the second semester the teams designed, constructed and tested alternate wing leading edge systems and modified the Space Shuttle system aerodynamics to minimize the risk that foam coming off the tank would impact the wing at a critical location. An example simulation of the deformation due to foam striking a student designed alternate leading edge system is shown in Figure 2b.



(a) **(b)**

Figure 2. (a) Hole in Shuttle wing leading edge due to foam impact test. (b) Example analysis of impact on student developed replacement leading edge structural system.

As in the Fall semester, students were evaluated based on individual work completed for the short courses, individual and group efforts on the design project and proficiency in communication. Unlike the Fall semester, student teams built and impact tested their proposed alternate leading edge designs allowing them to check by direct observation if their analyses and designs were accurate and robust.

C. Course Technology

The technical infrastructure supporting this collaborative engineering design course was required to satisfy several learning and team requirements including: (1) full-class events, (2) multiple simultaneous partial-class events, (3) synchronous and asynchronous team collaborations, and (4) online course management. To this end, an "Advanced Interactive Discovery Environment" (AIDE) was conceived, designed, and implemented. Further, a technical review process was used to assess student and faculty feedback to improve upon or enhance ease-of-use, productivity, and performance features of the AIDE. As a result, several technical changes were implemented after each academic year. In the following discussion, the AIDE is described in terms of how the learning and team requirements were satisfied as well as how the technical implementation morphed over a three year period.

Technology for Full Class Meetings

Full-class events that included lectures and student project presentations were held synchronously using distance learning classrooms technologies installed at SU and CU. Each room was equipped with a teleconferencing system providing high-quality, two-way audio and video. Cameras at both the front and back of each room provided the ability to receive either the image of the presenter or of the audience at the remote location. The images were projected to screens in both the front and back of each room, allowing both the audience and the presenter to see the remote site. A separate video screen was used to project presentation materials (e.g. PowerPoint presentations or other applications) from a local computer and shared via NetMeeting™ to the remote site. Figure 3 shows a typical full-class meeting as seen from CU. Image (a) depicts the student's view of the remote instructor at SU seen on the left screen and the lecture presentation on the right screen. Image (b) is the presenter's view where the remote classroom can be seen on the rear screen. In this configuration, the instructor and students have an equal experience regardless of their geographical location.

(a) **(b)**

Figure 3. Distance learning classroom. (a) Student view. (b) Faculty view.

During full-class events, an electronic "whiteboard" (a SmartBoard™ at SU and a Sympodium™ at CU), was used to provide the presenter with sketch and annotation capabilities in much the same way as is done with traditional chalk-and-talk. Desktop microphones at each student position were used by the students to respond to or ask questions. The presenter utilized a wireless microphone which could be configured for manual or automatic camera tracking. Initially SU used a ceiling-mounted whole-room microphone for a more natural discussion feel. However, due to ambient noise and a behavior of "talking to the ceiling", this system was replaced with the desktop microphones in the second year. Otherwise, no significant technology changes were made to the full-class environment over the period.

Differential skill sets among team members was identified in year 1 as a critical success factor for teams by avoiding the behaviors where a single team member does it all or does nothing. Thus, it became necessary to conduct multiple, simultaneous instruction of differentiated engineering disciplines to small dispersed student groups. During these instructional events, the instructors required the same teaching capabilities and features of the full-class environment. However, college space allocation and cost prohibited the replication of the distance learning classroom for these small groups. The initial technical solution was to configure a single desktop camera system, Smartboard™ whiteboard and conference phone to emulate the distance learning classroom. This approach was marginally successful and was greatly limited by audio and video quality. The final solution was to utilize the AIDE's synchronous collaboration software in a one-to-many online meeting and for the instructor to use a tablet-PC for whiteboard markup of presentation slides. In the final year, all students were equipped with a tablet-PC, web camera, headset, and microphone. A detailed description of the AIDE follows.

Technology for Project Team Collaboration and One to Many Instruction

Student project team collaboration and course management services were provided by the AIDE. In year-1 a custom software solution was used to implement the AIDE services. However, supportability and stability issues motivated a migration to an "off-the-shelf" solution. Many commercial and custom products were available for this, including WebCT™, Blackboard™, SharePoint™, QuickPlace™ and others, see refs. [3, 6, 7]. The IBM Lotus products QuickPlace™ and SameTime™ for asynchronous and synchronous collaboration services (respectively) were selected primarily for full feature set, low startup cost, ease of customization, and low administrative overhead. The asynchronous services included a shared document repository, team or course announcements, threaded discussion board, project calendar, task management and online presence awareness. A more detailed description of the asynchronous features is described subsequently. The synchronous AIDE services included full motion video and audio over IP, shared whiteboard, application sharing, instant messaging, posted documents, and hand-raising for meeting management. The implementation of these services underwent a paradigm shift during year-2. The original implementation was centered on replicating traditional face-to-face team activities using the AIDE. Basically, do what we've always done, just virtually. After the shift, the view of technology was refocused from centering on the face-to-face activity to the collaboration outcomes. Thus, team collaborative processes were allowed to change according to optimal use of the AIDE to accomplish team outcomes rather than forcing the technology to perform tasks that it wasn't well suited for. This shift is best explained by describing a typical team meeting.

The initial implementation of the AIDE tended to mimic traditional face-to-face practices. For instance, local team members would gather about a single PC to participate in a virtual meeting with peer team members at the remote university. At each site, students used a single web camera, desktop microphone and speakers to communicate through the AIDE. In this configuration several dysfunctional behaviors emerged including: local group problem solving versus whole team, single spokesperson for each group instead of equal participation, low audio and video quality caused by excessive background noise or audio feedback, and members being off-camera. After the paradigm shift to optimize the AIDE's capabilities by changing team processes students were provided with an individual PC, headset, microphone, and web camera with all members connecting to the meeting through the AIDE regardless of location. This technical approach resolved aforesaid issues and significantly improved the effectiveness of online student team meetings. In fact, the team meeting improvement was sufficient that some teams elected to meet using only the AIDE and never met in person during the project.

In addition to the technical improvements we began to train the students to use SameTime, the synchronous component of the AIDE, in a manner that built on the strengths of the technology rather than mimicking face to face meetings. For example, in a brainstorming session students can in parallel sketch out ideas onto the whiteboard and type comments into the chat. The whiteboard and comments are archived for future consideration. If a team is trying to develop a consensus on a design or on a plan of action, the meeting moderator can create a form containing questions and check boxes for responses and then

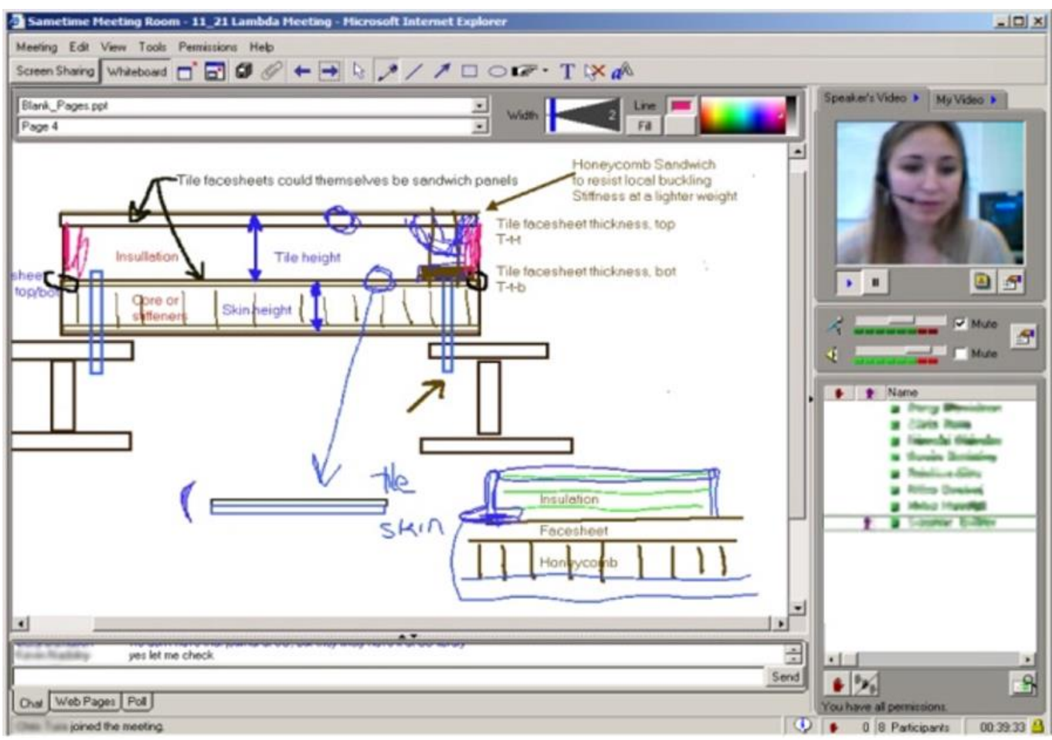


Figure 4. Sample of web-based meeting, discussing, in this case, the TPS system design. Participants can see the current speaker, share applications, chat and markup whiteboard for discussions.

import this form to the meeting whiteboard. The team can then quickly mark up the form indicating their preferences regarding a particular topic. In this manner a consensus often quickly emerges. This procedure also works very well for scheduling meetings, taking the place of rounds of email or phone calls to find a common time.

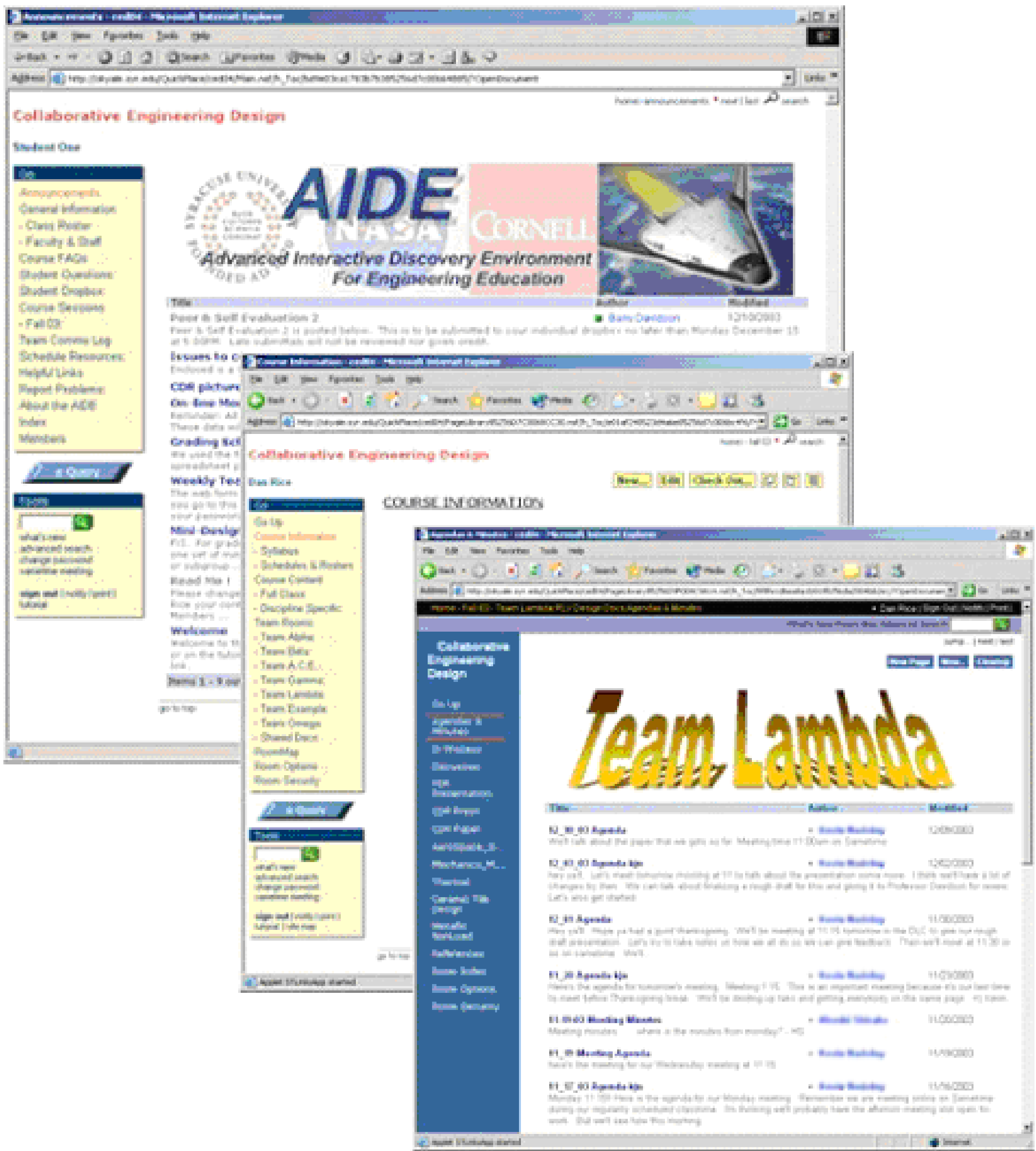


Figure 5. Views of the asynchronous AIDE

Figure 4 is an example of a student online meeting in the year-3 AIDE. The large white space is a shared whiteboard containing design drawings and marked up team comments. Below that is a shared chat window and to the right is the speaker's video, A/V controls, and member list. Below the member list is a hand-raising icon to indicate a non-verbal indicator to request attention or for voting. The shared whiteboard space can be used for shared applications such as MS Office, Ansys, Pro/Engineer, etc. Each of the windowed spaces can be resized as necessary. In year-4 the students were all provided with Tablet-PCs in addition to a headset, microphone, and camera. The use of the Tablet-PC enhanced student's ability to mark-up and sketch on the whiteboard or shared applications. Year-over-year, students reported increasing levels of online meeting effectiveness using the AIDE.

As previously stated, the asynchronous AIDE provided both student team project support as well as overall course management services. Figure 5 is a collection of various views of the year-3 AIDE asynchronous environment. In the background is the homepage as viewed by a student with current announcements in the central content space and left-menu site navigation. The central image is a faculty view of the course information page and a different left-menu customized to the faculty's additional content. The foreground image is a student project team page that has been customized to suit that particular team's preferences.

The basic layout design for the asynchronous AIDE environment remained unchanged over the period. However, the number of levels and site navigation was simplified year-over-year to minimize mouse clicks and to flatten the structure based on student feedback. As a document centric system, students and faculty reviewed, posted, or revised content as a single web page or attached document based on individual or team security permissions. Each student's page view was a customized page that enabled a student specific view of course schedules, lecture presentations and homework assignments, submitted homework, and posted teamwork. Thus, a single technology was used for both course management and student team collaboration.

Design Studios

To facilitate the extensive computer mediated communications as well as to provide access to simulation software such as MatLab™, Ansys™ and Fluent™, "design studios" were built at each university. The design studios contained workstations with large screens, web cameras and headsets, projectors and SmartBoards™. The design studios were specifically design to support small local work groups and to easily communicate with remote team members.

III. Method of Team Formation

As with any project centric course student teams must be formed to perform the project-based work. In year-1 two large teams of nine and twelve students were formed for a single year long project. In subsequent years, three sets of four to six member teams were formed per year on average. As previously mentioned, students were differentially trained in a specific engineering disciplines to insure team member diversity as well as geographic diversity within each teams. Aside from the geographical and DST constraints on team formation, many team selection approaches could be used in the final team selection from random selection, peer preferences, faculty judgment, personality preferences, or by other student attributes. Given that prior research [22,23,24] suggests the use of personality profiles such as the Myers-Briggs, Five-Factor Model (Big 5), or Six Thinking Hats for team selection, personality profile data was used as one of the selection criterion. Research performed by our group early in the project [25] showed that social network analysis [26] can be used to select teams that will all have a good chance of performing well. Thus, a multi-dimensional selection process was developed for team formation based on DST and location diversity, social network uniformity, personality factors and faculty insights. A background for each selection dimension follows and the selection process is summarized.

Social Network Analysis

Social network analysis (SNA) has been used in a variety of contexts ranging from sociology to economics. The social network perspective suggests that knowledge is a social and collective outcome, embedded in a social context. One benefit of social network analysis lies in its flexibility of use, which can range from small interpersonal groups to global Internet structures [27]. Social and behavioral sciences utilize network approaches for analysis because of the unit of analysis: the relation. Fundamentally, the focus of SNA studies is on the relation between social entities. Social network studies focusing on patterns of interactions among a group of actors in a network suggest that analysis of these patterns offer predictive capabilities regarding individual attitudes and behavior. Regular patterns of relations are referred to as structure; structural variables quantify relations in networks.

Within social networks, individual actors differ in the degree to which they are prominent, or 'visible.' Several metrics are available to measure this feature, the simplest of which is degree centrality. *Degree centrality* measures the extent to which an actor, or student, communicates with other students in a given social network (in this case, the two engineering classes) [28]. It measures the proportion of existing social connections for an actor in a network to the total number of available connections in that network. In other words, highly central students in the network communicate regularly with more individual peers than low-centrality students. Thus, central students are said to be the most active communicators in a network. Further, these actors are accustomed to maintaining a high level of social contact, which correlates with early adoption of new technology and generally greater communication skills.

Network centrality has been found to be associated with a wide range of benefits through both field studies and experimental research. In organizational contexts, Roberts & O'Reilly [29] found that structurally central actors had higher evaluations of job satisfaction. In experimental studies, central actors were also the most satisfied [30]. From an economic perspective, central actors have control of information resources within networks, which is associated with power [31] and are more likely to be promoted [32]. Research suggests that central actors in a network are more productive with technology, and reported the most positive experience [33]. Studies also suggest that central actors have a strong influence on other actors regarding the diffusion of innovations and in shaping employee perceptions in organizations [34].

The evidence outlined above suggests network centrality is associated with positive outcomes. Thus, we are interested in exploring the extent to which social network measures can be used to *engineer* teams with a greater likelihood of success in the context of DL environments. We utilize this approach because social network data are becoming easier to obtain as communication is increasingly mediated by technology, and in organizational contexts, network measures will continue to become more readily available, affording a practical means of reliably constructing distributed, collaborative teams. Thus, the following research question was examined:

Can Social Network Analysis Inform the Design of Collaborative Engineering Design Teams?

Successful teams, in this context, have been operationalized as demonstrating low apprehension toward new communication technology and high evaluations of intra-group communication. Given that distributed design teams are forced to communicate through CMC channels, low apprehension toward novel communication technology is very important. Further, given that the teams are required to work over a six-week period on their projects, positive team communication dynamics are also an important factor for a sustained level of productivity and eventual success. These dimensions are particularly relevant in that they function as a good foundation for the development of effective teams.

Personality Profiling

The personality profile inventory used was the Harrison Innerview [35]. The Harrison Innerview profiling system (HI) evaluated each student according to forty-eight unique personality traits that measure individual work preferences and is used for employee-job selection for industry human resource departments. A subset of these traits (centered on communication, support, and work style preferences) was then used to assess the students for pair-wise compatibility relationships. High compatibility scores indicated the degree of dissimilarity between members. Teams with the lowest total score were considered to be better for team personality compatibility.

Team Formation Summary

Within the first few weeks of the course, five teams of six students were formed. Team formation was informed primarily by social network analysis and the Harrison Innerview with the constraints that each team had three students from each school and two members from each of the discipline specific tracks. The constraints insured that the team was geographically and technically diverse. No one student had all the necessary background to complete the design hence the team *must* find ways to communicate effectively.

IV. Evaluation Methods

Evaluation of the course, the technology, and its effectiveness in facilitating team building and supporting the design process were evaluated using a multi-faceted approach. All students completed an end-of-semester questionnaire in which they numerically ranked various aspects of the course. These included asking to what extent course objectives were met, how effective were the faculty individually and as a team, what students thought about the course content and how effective was their team. Students were also asked to respond to several open-ended questions, including describing things they liked and disliked about the course, what suggestions they had for future offerings, what improvements would they like to see to the course technology, how effective was your team using the ST meetings, and, if you could always meet face-to-face, would you? The use of and effectiveness of the tablet PCs was evaluated through a similar set of questions posed just to the CU students. Focus group interviews of students and logging of student interaction with the IP tools were also used to provide a richer analysis base.

V. Results and Discussion

A. Course Technology

The key technologies that enabled course participants to collaborate from a distance were the desktop video conferencing, the web-based collaboration system and, for Cornell students, the tablet PCs. A sampling of the evaluation results and a discussion of conclusions that can be drawn from these results is given below.

Synchronous AIDE (SameTime™)

In the first year of using SameTime (ST), the synchronous component of the AIDE, it was assumed that students, being very computer adept, could and would learn to use desktop video conferencing on their own. However, our experience proved otherwise and in the second year, ST was introduced to the class in a guided and incremental manner, by having the design teams meet with their faculty coach using ST. The coach set the agenda and guided the team through a series of exercises on using the various aspects of the technology. The first agenda item was always that the team would adjust sound levels and cameras so that each member, sitting at his or her own computer, would be heard at essentially the same sound level. This is important, since, unlike face-to-face meetings, only one person can be speaking at a time in a ST meeting. The software switches the microphones according to who is speaking. Thus the switching sensitivity and volume of each meeting participant must be approximately equal; otherwise it could happen that one member is never heard while another is always heard. A requirement that each meeting have an agenda and that minutes are recorded was put in place and enforced by the faculty coach. Responsibility for setting up and developing an agenda for meetings then rotated among team members in subsequent meetings. Students were taught to use chat and the whiteboard to communicate in parallel with the audio, taking advantage of the ability to use more than voice to communicate in ST meetings. This guided introduction to ST was a *key element* in the successful use of this technology.

With the introduction to ST, the students generally felt that they were sufficiently prepared and effective using ST. Examples of comments were: “*I felt prepared and it was easy to learn to use*.” “*I can use most of ST’s function relatively well*.” “*ST is very easy to use after a few days, early it was tough, but it got easier*.” Despite the evidently sufficient training with ST, the students identified the time lag in the audio and the generally poor audio/video quality as hindrances to team meetings. For example low bandwidth and breaking up of audio when scrolling a shared document were noted.

When asked to comment on how prepared their *team* was when using ST the results were mixed. Comments included “*Our team was effective in using it when there were no technical difficulties beyond our control*.” “*Very effective; especially w/ white board and sharing docs*.” Others pointed out the importance of an agenda and a moderator. The audio lag caused problems. “*Sometime hold back cause always feel like you’re interrupting*.” “*Due to the lag,* *members often talked into each other*." As the audio/video switches only to the current speaker it was relatively easy for a student to stay quiet and essentially not participate in a meeting. *".. not all were talkative as they would be in F2F*." *"..some people can hide out*."

Careful attention to the proper adjustment of microphones, speakers and switching sensitivity can minimize desktop video conferencing problems. Nonetheless, technical improvements that would bring the audio quality up to that of a high quality telephone would go a long way toward improving desktop video conferencing.

Asynchronous AIDE (QuickPlace™)

Table 1. Spring 2003 student evaluations of the web-based collaboration environment. 1-7 scale.

	Mean	SD
Perceived usefulness	5.17	1.23
Perceived ease of use	5.73	0.82
Use	4.94	1.11
Satisfaction	5.45	1.24

Student and faculty use of QuickPlace (QP), the asynchronous component of the AIDE was extensive. In a typical semester thousands of visits to QP are recorded and hundreds of documents shared. Students rated the use and satisfaction of the collaboration environment. The results, summarized in Table 1, show that the students perceive the system to be useful and that they use it often. Management of the documents and rooms proved to be difficult. Students commented that "*pages/folders tend to get out of hand*," and "*list of files gets to be a bit much*". Fewer levels, more consistent navigation, and the ability of teams to have more control over the organization of their team spaces and email groups were also desired. Shared documents were often edited by multiple members of a team. Several students wrote that they would like to have the ability to check out documents and edit them directly in QP rather than edit in a separate application and then re-load the file to QP. This ability was added in later years.

Tablet PC's

In year 1 of the course, CU students were loaned low-end laptop PC's with external wireless cards. Students found these underpowered, heavy, and not conducive to web-based collaboration. In year 2, they were loaned first-generation tablet PC's. These, too, were found to be underpowered, with short battery life, and with such awkward audio-video features that they were soon set aside. Cornell students reported mostly positive experiences with the 2nd generation tablet PC's loaned them in year 3. These had built-in wireless, much improved write-to-screen capability, and were readily adaptable to the web-based collaboration. These provided the students with the ability to work and communicate anywhere, anytime. The small screen size and relatively slower speed of the tablets relative to comparably priced laptops was still noted as a negative by some students. The chief advantage of tablet PC's, the ability to take notes by hand and to save them using a notebook-like application appeared to have limited but growing use. As the cost, size and resolution of these systems improves, our results suggest that their usefulness and acceptability will also. One student summed it up saying "*they were great although I bet the next generation will be better*."

Communication Routes

Students communicated with each other and with the faculty using a number of methods, as summarized in Table 2. The results show that satisfaction was closely coupled to the ease of use of the tools. Note in particular, that although desktop audio/video conferencing was extensively used, the satisfaction with its use was substantially lower relative to more familiar tools such as email and instant messaging.

Table 2. Results from Survey on use of communication tools. Use is number of times per day. Other columns rated on 1-7 scale.

	Use	Usefulness	Ease of Use	Satisfaction
Audio/Video Conference	2.75	5.46	4.35	4.35
Instant Messaging	1.93	5.48	6.43	5.78
Chat	0.91	4.7	5.74	5.26
Team Document Sharing	2.74	6.52	6.19	6.04
Email	2.22	6.15	6.41	6.33

B. Course Content

Table 3. Results from course satisfaction survey. 1-7 scale.

Term	Satisfaction
Fall 2001	4.31
Spring 2002	4.32
Fall 2002	5.08
Spring 2003	5.16
Fall 2003	5.97
Spring 2004	5.38

Along with the technology, the content, delivery methods and organization of the class evolved significantly during the three years the course was taught. In particular, the faculty team, numbering as large as seven at times, required significant time to normalize their styles, expectations, grading criteria and levels of feedback given to students. As a result of this evolution and of the improvement in the course technology, course satisfaction increased steadily as shown in Table 3. Evaluations of various aspects of the course content were generally positive. Asked to report what they liked and disliked about the course, students wrote that they enjoyed the team-oriented nature of the course. The distributed nature of the short courses early in each semester was popular as well. Many comments addressed the benefit of working with students from another university and the benefit of gaining experience with the technology integrated in the course. Several students commented that the 'real world' feel of the class and design project were a rare and positive experience in engineering classes. Students disliked the amount of work required for this class and several comments suggested that too much time was spent on activities other than the design project.

C. Team Effectiveness using Computer Mediated Collaboration

The key measure of the success of this project is the extent to which computer mediated communication facilitated the formation and functioning of effective design teams consisting of students from two geographically distant universities. Team effectiveness was evaluated through numerical surveys, open-ended questions and information network analysis.

Table 4. Team effectiveness survey. 1 = strongly disagree; 7 = strongly agree

	Mean	Std dev
Early face-to-face meetings are important for effective virtual collaborations by geographically separated teams	5.47	1.29
The experience I've gained in virtual collaborations will help me in my career	5.75	1.27
My team's ST meetings were as effective as if we had met in person	3.78	1.64
Skills gained from working on a team will help my future career	5.94	1.08
I could depend on my teammates to complete tasks on time	4.91	1.61
Posting agendas and taking minutes are essential for effective ST meetings	5.59	1.34
Modifying doc's real time in ST is better than paper markup in person	4.94	1.56
Some team functions are performed better in virtual meetings versus face-to-face meetings	5.03	1.28
My team could have accomplished more if we were at the same university	5.19	1.38
My team created the best possible solution to the project in the time allotted.	5.63	1.36

Table 4 shows that students agreed that early face-to-face meetings were important and that the experiences and skills gained in this class will help them in their future careers. However, the students generally disagreed with the statement that the ST meetings were as effective as if they had met in person. Despite this, in open-ended statements students were about evenly split between an absolute preference for face-to-face meetings or meetings using ST. Those preferring online meetings noted the advantages such as utilization of screen sharing and overall convenience given that the teams were geographically distributed. Note the relatively strong (5.63) agreement that their team created the best possible solution to the project in the time allotted.

D. Social Network Analysis and Correlation of Centrality with Team Success

Team Centrality

Surveys measuring two types of emergent communication networks (social and task) were administered three times during the course of the fall semester (beginning, middle and end). Students were asked to identify who they communicated with, through which communication channels (i.e. email, face to face), at what frequency and whether for social or task (class) related purposes. In addition, surveys contained multi-item scale measures assessing apprehension toward using the AIDE, and perceptions of intra-group communication dynamics. The second survey, administered immediately after group formation and prior to use of the AIDE, measured apprehension toward using the AIDE. The third survey measured students' overall perception about and satisfaction with group interaction.

Based on network measures calculated from the second survey, a degree centrality value was calculated for each student and five student design teams were created. Recall that teams are comprised of three students from each university. Using these values, teams were structured by grouping students with similar centrality values together. Groups range from low centrality to high centrality, as indicated in Table 5, below.

Table 5. Average centrality score for individual teams.

Team	Average Centrality
1	9.83
2	10.17
3	12.77
4	16.33
5	16.83

Social Networks and Teams

At the start of the semester, two distinct social networks were evident (divided between universities). This was expected given that students, at this point, have not had an opportunity for social interaction. As the semester progressed, however, students were required to interact with each other to complete their class projects. As such, it was expected that they would form a communication network mediated by the collaboration system.

A contrast analysis of variance was used to test whether differences between groups emerged, focusing on the following dependent variables: average centrality, expectations for social, performance, distance learning, and teamwork functions of the AIDE. The 'expectation for social functions' variable was consisted of 4 items, where students responded to the following questions: Using the AIDE, I expect to… maintain relationships, get in touch with other people, feel entertained, and have fun. The performance function of the AIDE was comprised of 7 items focusing on use of the AIDE to access new and useful class and project-related information, as well as facilitating enhancement of organization skills and studying effectiveness elements of the technology. The scale used to assess expectation for distance learning was comprised of 5 items measuring whether students felt collaborating with remote participants would facilitate access to new, diverse ideas and perspectives, and whether a class like this one would enhance overall quality by incorporating useful resources in different locations. Finally, expectation for teamwork was measured with 5 items focusing on whether participants felt that being a member of a project team would increase their ability to perform effectively.

Statistically significant differences were found between teams based on centrality, as a contrast analysis of variance revealed. Differences in student initial apprehension toward using the AIDE communication portal were not statistically significant, but were linear in nature such that low centrality teams were associated with high apprehension (see Table 6, below). Low centrality teams had greater apprehension than high central teams, opposed to high centrality people who tend to be innovators/early adopters, and this relationship was expected. Low centrality is generally associated with lower performance and teamwork expectations, as well.

Table 6. Differences in expectations for various aspects of the project by team.

Team		**Social**	**Performance**	**Distance Learning**	**Teamwork**	***Total***
1	Mean	4.44	5.88	5.03	5.44	***5.20***
	SD	1.36	1.47	0.88	1.09	
2	Mean	4.72	6.29	5.23	5.28	***5.38***
	SD	1.57	0.68	0.75	1.39	
3	Mean	5.44	6.50	5.60	5.94	***5.87***
	SD	0.75	0.47	0.25	0.65	
4	Mean	4.83	6.50	5.70	6.11	***5.79***
	SD	0.81	0.52	0.84	0.66	
5	Mean	5.11	6.33	5.67	6.11	***5.81***
	SD	1.07	0.66	0.85	0.86	
Total	Mean	4.91	6.30	5.45	5.78	***5.61***
	SD	1.13	0.82	0.75	0.97	

Table 7, below, summarizes responses to the end-of-semester evaluations. The final survey measured participant's satisfaction with the AIDE, as well as evaluations of their team experience. AIDE satisfaction was comprised of three items, which focused on whether participants felt the technology made them more efficient, facilitated achievement of class goals, and if the use of this technology was generally a good idea. Five questions addressed individual teamwork evaluation included students' feelings about coordination of effort, honesty, support, conflict resolution, and a feeling of open group communication. Differences in student evaluation of their intra-group communication (teamwork evaluation) were statistically significant and linear. Low centrality teams had lower evaluations of teamwork than high centrality teams. Given that the university class is structured around distributed, collaborative teams, and that student teams by necessity have to use CMC technology to complete their design projects for the class, teams with high expectations and evaluations on the above mentioned dimensions are likely to be successful overall (generally increasingly positive attitudes).

Table 7. Final evaluations of technology and teamwork.

Team	AIDE Satisfaction		Team Evaluation
1	Mean	4.90	4.52
	SD	*1.14*	*1.37*
2	Mean	4.60	4.76
	SD	*1.24*	*1.03*
3	Mean	5.10	3.52
	SD	*1.34*	*0.55*
4	Mean	5.75	5.56
	SD	*0.76*	*0.30*
5	Mean	5.50	5.43
	SD	*0.84*	*0.62*
Total	Mean	5.20	4.80
	SD	*1.07*	*0.99*

Evolution of Social and Information Network

Additional information on team functionality is revealed by the graphical social and information network analysis. Students were asked to report with whom and how often they communicated on a social basis and to exchange project related information. The results are presented graphically in Figure 6. Each point on the graphs represents a course participant. Density of communication is inversely proportional to the distance between points. The social, or friendship network at the start of the 2003-04 academic year shows SU and CU clusters, as expected The denser SU network (right hand side of Figure 6a) reflects the common major (Aerospace Engineering) of the SU students. The CU students came from three different majors. By the end of the Fall 2003 semester, there were numerous social connections between SU and CU. Even more dramatic is the dense information network. The social network increased further by the end of the spring semester as did the information network.

Social Network Analysis Summary

We have demonstrated that social network analytic techniques can be effectively applied in the context of structuring student engineering design teams. Specifically, based primarily on social network, or communication, measures among students in the class, teams were formed that demonstrated a range of expectations toward use of the AIDE, expectations toward distance learning, and subsequent evaluations of teamwork. Further, teams ranking on the low end of centrality consistently demonstrated lower evaluations regarding DL and intra-group communication, and higher apprehension toward using new technology. To mitigate these differences, in subsequent years, teams were formed to have approximately equal centrality scores.

Future research should focus on the impact of creating teams, based on social network analysis, which are composed of a wider range of centrality-based actors. That is, to what extent can social influence from other students (i.e. other *team* members) impact low-centrality actors' expectations toward DL and apprehension toward new technology, thus increasing overall team experiences. For example, research suggests that shared social settings (proximity), norms and mental schemas affect behavior and attitudes (Barker, 1968). In other words, when people share social settings with others, over time they also come to share similar expectations, experiences and perspectives. Although the shared space, in the context of the distributed groups discussed in this paper, is more abstract than that of traditional collocated groups, the current results suggest consistent similarity in group expectations and attitudes. Future research examining the extent of social influence in distributed group contexts is a promising avenue of exploration, as well.

Many questions remain about the team performance differences. For example, perhaps the communication tools used by individual teams differed. Or, maybe a formal organizational structure was adopted by some teams, and not others. If successful teams have similar communication strategy, that would be an interesting finding.

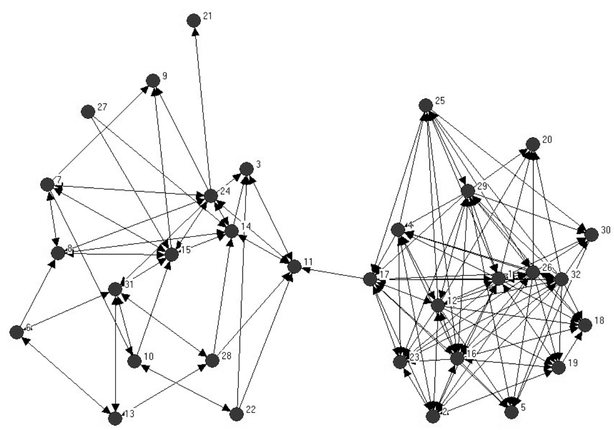
VI. Conclusion

The use of geographically dispersed design teams communicating through the use of IT based collaboration tools is quickly becoming the rule in government and industry. Despite these changes in how engineering is performed, virtual teaming and CMC are virtually ignored in engineering education. To demonstrate that geographically dispersed undergraduate design teams can perform well and to learn how to facilitate this performance most effectively, SU and CU have performed a three year long study consisting of a year-long, senior, capstone design course coupled to an extensive evaluation program.

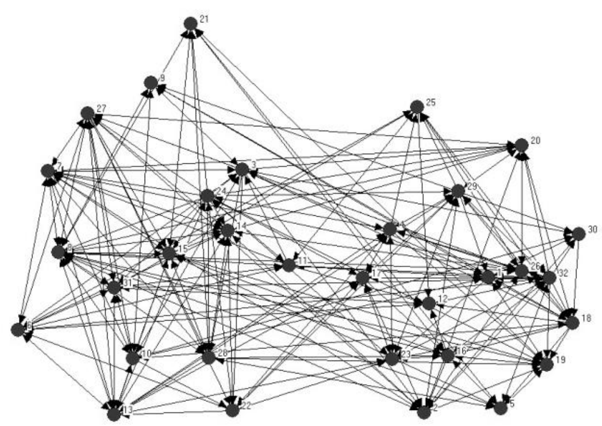
The most salient conclusions and lessons learned from this study are:

- Effective, multi-university collaborative design is possible with the proper use of web-based collaboration tools, attention to social networking issues, and technological and pedagogical education/adaptation of the participating faculty.
- The use of social network analysis and Harrison Innerviews provided effective bases for team formation, and helped the faculty to understand team functioning and disfunctioning.
- The "real-world" feel of collaborative distance design is a strong motivation for student participation in this demanding course.
- The synchronous and asynchronous web-based collaboration tools currently available can be used effectively by students only if they are given sufficient instruction and practice in their effective use. The course experimented with different systems before adopting the SameTime™ and QuickPlace™ applications that proved adequate and adaptable. There will be continuous improvement in web-based collaboration tools driven by the marketplace, so continuous evaluation of new and improved products is necessary in academia.
- Introducing the IT tools in a graded manner in which faculty at first took the lead in virtual meetings, but gently ceded the leadership roles to the students was a key technique for teaching the use of the IT tools.

- Students generally disagreed with the statement that the virtual meetings were as effective as if they had met in person. Despite this, in open-ended statements students were about evenly split between an absolute preference for face-to-face or virtual meetings. Those preferring online meetings noted the advantages such as utilization of screen sharing and overall convenience given that the teams were geographically distributed.
- Use the IP tools in a manner that exploits the strengths of the technology rather than in a mode that attempts to mimic face to face meetings.
- Properly equipped classrooms and design studios at each university were necessary. Multiple cameras, projectors, screens, and microphones are needed in the classrooms. Design studios need workstations with large screens, web cameras and headsets, projectors and SmartBoards™.
- Video and audio over the web quality is still somewhat of a hindrance to effective CMC. Anticipated technological advances in this area will go a long way towards improving the acceptance of CMC.

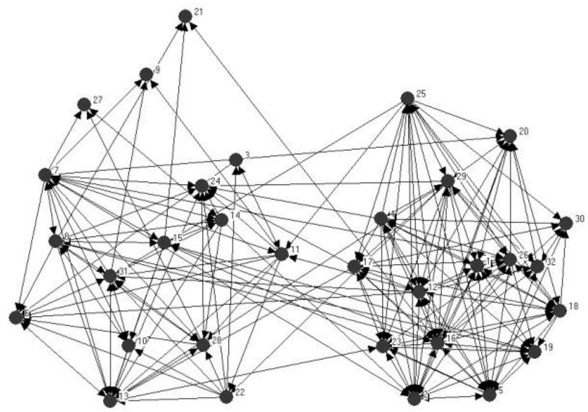


a. Social network Fall 2003.

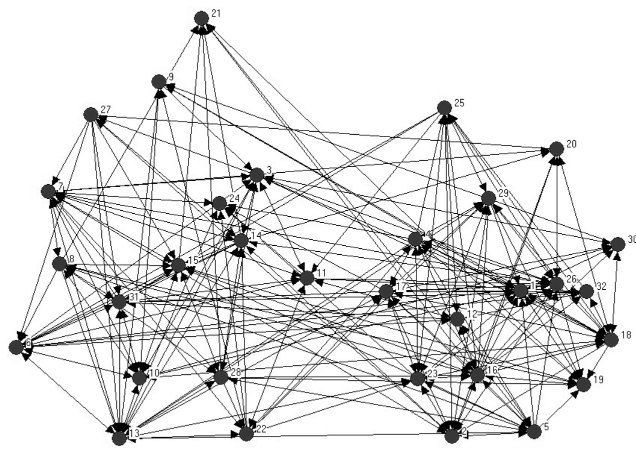


b. Information network Fall 2003.

Figure 6. Continued on next page.



c. Social network Spring 2004.



d. Information network Spring 2004.

Figure 6. Evolution of social and information networks.

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