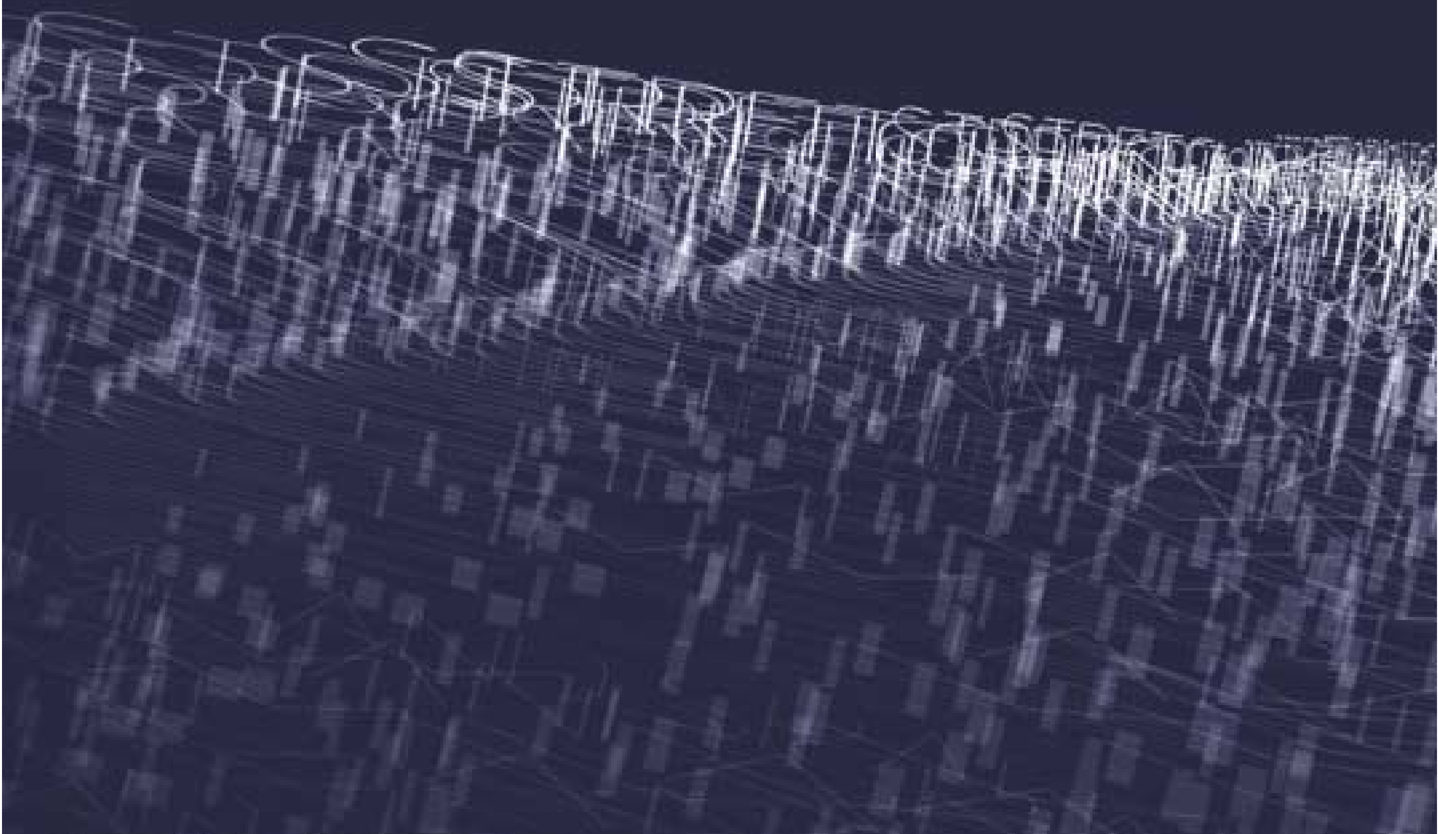

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STRETCHING TIME AND SPACE

Using New Technologies to Improve Professional Education

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Educators throughout the world and across all disciplines are experimenting with new technologies. In particular, those teaching in professional education have an especially strong impetus to experiment because of the enormous impact of new technologies on professional practice. Those same forces of change mean that educators in the professions rarely have time to reflect on their purposes, their approaches, and the factors that might promote or constrain learning and understanding with new technologies. This report serves as one attempt to redress the difficulties of reflection in times of rapid change. It analyzes technological innovations introduced by professors in two courses at the Harvard Graduate School of Design. Analysts from the Harvard Graduate School of Education present and examine these two cases to reveal both the potential benefits and the challenges of trying to improve professional education with new technologies.

The two courses vary on many dimensions: subject matter, educational problems and approaches, technologies applied, and both anticipated and unexpected results. In one course about analysis and design of building structures, the professor used new technology to help students gain understanding of difficult, yet essential, content. By recording his lectures and putting them online, along with other resources, he sought to help students gain access to the course material faster, more frequently, and in whatever form they found most valuable In the other course, two innovative professors incorporated cutting-edge technologies and techniques into their course on computer-aided design. They hoped to engage their students with new forms, foci,and tools of architectural practice, all in the context of the new paradigm of virtual places.

Analyses of the ways in which these professors attempted to stretch time and space indicate important educational, technical, and contextual dimensions to consider when integrating new technologies for learning. Computer-related technologies can serve a host of educational goals and approaches. Clarifying the dimensions and degree of educational change that are sought enhances the likelihoodthat desired goals will be met. Selecting, designing, and applying technologies inevitably creates burdens for teachers, learners, and technical and human resources within an educational institution. Making good decisions aboutthe design of educational technologies and their applications requires weighing technical demands against educational benefits. These decisions are also affected by the shifting priorities, resources, and dilemmas of the institutional and professional settings within which they are situated. The cases reported here are clearly influenced by forces, such as specialization and globalization, that are affecting the practice of architecture and the professions more generally. They also demonstrate the dynamics of individual initiatives and institutional planning that must be managed in effecting positive educational change.

This report describes and recommends an ongoing process of sustaining a "reflective conversation with the situation," as Donald Schön describes the successive cycles of enacting one's theory in a design. The groups of both professors and analysts involved in this study learned from participating in this conversation. We issue the report as an invitation for further inquiry by teachers, administrators, developers, and technicians who seek to improve education with new technologies.

Introduction

As computers and telecommunication networks radically transform workplaces, professional schools hurry to incorporate new technologies into their educational programs. How can young professionals best be prepared to use new tools of their trade?How might educational technologies improve teaching and learning? Questions like thesepermeate efforts to integrate computers with education, but the rush to innovate seldom allows time for reflection.

A recent project to introduce new tools into two courses at the Harvard Graduate School of Design (GSD) fortunately allocated resources for thoughtful analysis of the process and effects of this initiative. The funders from Microsoft Research surmised that researchers from outside the design profession might perceive general lessons through studying this project. Accordingly, a team of analysts from the Harvard Graduate School of Education (GSE)[1] conducted surveys, made observations, and held interviews with the faculty members, students, and teaching assistants in the two courses.[2] Indeed, the goals, challenges, and varied assessments of technological innovation at the Graduate School of Design illuminate important aspects of the widespread effort to improve professional education through the use of new technologies.

In this report, case studies of the two courses illustrate differences in the professors' educational goals, applications of technology, and results as well as the influence of their surrounding professional contexts. The subsequent analysis of cross-cutting themes highlights educational, technical, and contextual issues to consider in any effort to improve education with technological innovations. Conclusions derived from this analysis are addressed specifically to faculty and administrators in graduate professional schools, but may be of interest to all educators who seek to design and assess effective applications of new technologies.

STRETCHING TIME AND SPACE

The Graduate School of Design at Harvard University is considered one of the leading professional schools of design in the world. It awards master's, post-professional and doctor's degrees in three basic fields: architecture, landscape architecture, and urban planning and design. For architecture students at the master's level who enter from undergraduate backgrounds in fields other than architecture, the required course of study is known as the Master of Architecture I (MArch-I) program. MArch-I students literally work their way up from the ground floor of the multitiered studio space at the school of design, moving to a new physical level of the building at the beginning of each of their three years at the school. Through work in the shared space, students develop a strong sense of both cohesion as peers and of competition as budding designers within that cohort. Especially in the first year, the time students spend in the studio includes not only long days, but also many sleepless nights, and by the end of term, the studio actually becomes home to many students.

The physical prominence of the school's studio space mirrors the significance of "Design Studio" courses in the MArch-I curriculum. Over the first two years, students in the program take the same sequence of coursework, devoting eight of each semester's twenty credits to Design Studio, where they master the creative and interpretive skills deemed essential to their education as architects. The remaining twelve credits are parsed among four-credit courses meant to support and provide context for Studio. Although these latter courses together account for two-thirds of the required credits, the long-term design projects of Studio are by far the most time consuming for students. Other courses compete for students' attention and, in general, are given short shrift, especially when Studio presentations loom ahead at the end of the semester.

Both courses described in this report are part of the nonstudio courses required of nearly all master's degree students during their first and second years at GSD. Analysis and Design of Building Structures I was taught by Professor

Spiro Pollalis, whose broad interest in new technologies led him to co-chair Harvard's Internet and Society conference in spring 2000. Assistant Professor Jeffrey Huang co-taught Fundamentals of Computer-Aided Design with colleague Urs Hirschberg, a visiting professor from ETH, the renowned school of architecture in Zürich. Pollalis, Huang, and Hirschberg work together and conduct research in the Center for Design Informatics (http://research.gsd.harvard.edu). They developed both courses in close coordination, yet each followed a radically different approach and addressed different issues. The following cases describe the professors' educational agendas, the role of new technologies, the process of application and some results of technological innovation in each course.

Professor Spiro Pollalis of the Analysis Design of Building Structures I (GSD 6201) course

Assistant professor Jeffrey Huang and visiting assistant professor Urs Hirschberg of the Fundamentals of Computer-Aided Design (GSD 2107) course

CASE I Enlightening Structures with new Technologies

GSD 6201 - Structures Course

To reach the office of GSD Professor Pollalis, one walks along a corridor overlooking the school's Design Studio, where MArch-I and other design concentration students can be seen working feverishly around the clock on their projects. The intensity with which they work reflects the program's emphasis on the creative process and the students' desire to prove themselves as creative thinkers. It is in this context that Professor Pollalis teaches *Analysis and Design of Building Structures*, a full-year course required of all second-year MArch-I students. "It's the most boring course in the school," Pollalis is quick to say with a smile, which suggests both good humor and determination to meet the challenge.

Of course, Pollalis thinks the study of architectural materials and structures is fascinating, but he realizes that most of his students and even many of his colleagues consider this course a necessary evil at best. The course is about engineering, physical principles, and calculations of forces; it calls for a very different mindset from the creative vision of beauty that draws most students to the field of architecture. "It's different because it requires rationalization, and everything else is very poetic and very artistic around here," Pollalis explains.

For several years Pollalis has been using new technologies in a variety of ways to "enlighten" his structures course. For Pollalis, enlightenment in his course signifies the dual goals of improving students' understanding and making the course material less heavy and less dry.

Course Setting and Participants

Just as Professor Pollalis' office sits in the shadow of the school's creative design studio, the rational, empirical study of *Structures* seems to stand alone and in the shadow of a

Assistant professor Martin Bechthold, co-teacher with professor Spiro Pollalis of the 6201 course, answering a student's question and expaining the structural diagram on the blackboard in the main weekly session just before the student presentations and the weekly quiz (Gund Hall, Rm 111).

Students making a presentation on a target of difficulty in the main weekly session.

curriculum focused primarily on artistic, interpretive design. The course, drawing from the field of structural engineering, presents students with rational quantitative content steeped in calculations and technical language. For many GSD students, this course is their first exposure to quantitative methods in architectural design, and the content is difficult to understand for those unaccustomed to thinking about math and physics.

Professor Pollalis has taught *Structures* at GSD for the past fifteen years. Over the years, he has become increasingly concerned with students' ability to understand and apply the material he teaches once they become practicing architects. "The science can be learned by rote—you can crunch the numbers and complete the exercises without actually ever understanding how the physics works in real life, how the math relates to physical experience," one student noted. Students enter the course with a wide range of backgrounds, which adds to the difficulty of devising exercises that will help all students actually understand the material.

Professor Pollalis giving feedback to a student presentation of a case study during the main weekly session (Gund Hall, Rm 111).

The combination of students' time constraints, together with their inexperience in quantitative study and their perception of the material as difficult, led Pollalis to view his students' inability to apply *Structures* as partly an access issue. The material was inaccessible in both a physical and intellectual sense. Studio's demands on their time meant students were physically unable to devote the amount of attention necessary to understand the application of *Structures* within the traditional lecture/homework course format. The perceived dull nature of the material and students' lack of motivation and interest created an intellectual access problem. How does an instructor help students understand material that they consider boring and difficult within a school where students' attention is focused on highly creative pursuits? To answer this question Professor Pollalis began by analyzing his educational goals for the course, and then redesigned his approach and introduced new technologies. Perhaps an educational agenda directed toward understanding with the help of new technologies, would enable Pollalis to "enlighten" the course by making the material more interesting and accessible to students.

Educational Agenda

Pollalis confronted his dilemma by first reconsidering his educational approach to the course. In many ways, Pollalis started at a structural level, educationally speaking, equivalent to the level of analysis reflected by his subject area in architecture. In order to help students understand the material more deeply, he wanted to gird it with a pedagogical framework designed to promote reflection. He wanted to make the coursework more collaborative, with more interaction among students, and between the students and teaching staff. This might enhance students' motivation and engage them in the material at a deeper level. He also wanted to make the course material accessible in multiple representations so that each student could study the material as many times as necessary, and in a medium that was right for him or her.

Over the past five years, Pollalis has restructured his course several times, slowly increasing his use of digitized course material as a means of transmitting core content, in hopes that class time could be devoted to discussion of cases and more in-depth content.Students consistently told him, however, that the subject matter was too complex for them to understand through self-study.

Technology helps to present difficult concepts visually.

In the spring of 1998, Pollalis redesigned his course with helpfrom his teaching assistant Jane Crudden, a midcareer

Synchronized video, slides, table of contents and text in the 6201 web site (top), video streaming (bottom).

student at the GSD who had already received a master's degree from Harvard's Graduate School of Education. With Crudden's assistance, he decided to build the course around the "learning spiral," a pedagogical framework developed at the GSE's Project Zero.[1] The learning spiral involves five phases: preparation, gathering information from sources, thoughtful practice, feedback, and reflection. By modularizing the course material into ten stand-alone topics, Pollalis organized his course schedule around ten weekly cycles that ran through the complete learning spiral before moving on to the next topic. He also used the learning spiral to incorporate collaborative work among students. Students were organized into groups who selected a difficult topic to present each week during the *thoughtful practice* phase of the learning spiral. Because feedback is a central tenet of the learning spiral, Pollalis built in multiple opportunities for students to receive comments from the instructor, teaching assistants, and their peers. "I think the most important thing is that it [the learning spiral] allows us to collaborate," Pollalis observed.

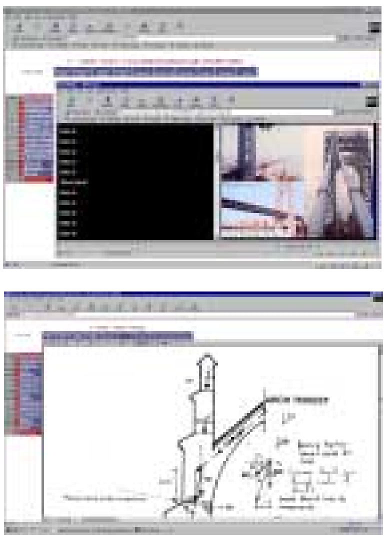
By articulating a clear educational agenda as the first step in transforming his course, Pollalis was able to identify potential solutions to the learning obstacles students faced in the course. He then turned to new technologies to see how they might enrich opportunities for reflection, collaboration, assessment review, and learning through multiple representations of the material.

Role of Technology

Pollalis has a reputation around the University for "pushing the technological envelope," and he has incorporated various new tools into his course to support his educational goals. For several years he has taught students to use software packages which analyze and design structural systems. Initially he used a program that he developed himself, and for the last ten years he has used commercial software such as Multiframe.

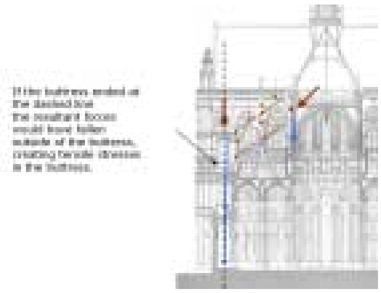
Two years ago, about the same time that he began to restructure his course, Pollalis integrated several additional technologies into the course in order to support multiple forms and cycles of learning. These included a web-based environment, film presentations, and Microsoft's PowerPoint presentation software.

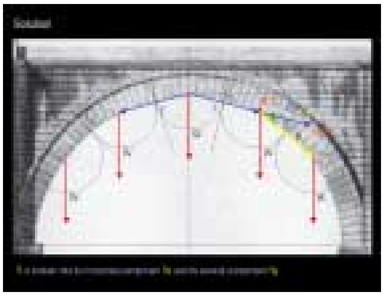
Pollalis considered the potential of a course website in relation to his pedagogical approach and solving the abiding difficulties students experienced. He viewed the multimedia, networked, and storage features of the web as a means to extend and supplement the experiences that he and his teaching assistants could provide during class time and office hours. Pollalis' educational agenda meant that his primary challenge was to create more opportunities for dialogue among the course participants and increased feedback from the teaching staff. Given the demands on students' time and their negative perception of the material, Pollalis decided to focus class time on the types of responsive exchange that can only be accomplished in a face-to-face meeting. He hoped the web-based environment would enable him to present the course material in clear and multiple ways so that he could devote class time to discussion and review. As Pollalis stated, "Putting the lecture material online is a way to try to get the knowledge into people's head better, so that when you're together you can have a conversation about those ideas and how to apply them."



Slides with audio explanations in the 6201 website.

Pollalis recorded his weekly lectures, punctuated with PowerPoint slides, on videotape. Assistants then digitized the videotaped lectures, synchronized them with the slides, and uploaded the material to the course website as online text, audio, and video. He thought access to course material through multiple formats would "enlighten" the course by providing more ways of understanding the material. A student noted, "It [the web environment] offers you this variety of different media … that you can use to learn." Pollalis also used the course website as a repository for additional problem sets, case studies, and examples as requested by some





Students' presentations on historical structures, superimposing diagrams on photographs.

students. Posting digitized content on the web environment allowed students to choose formats that worked best for them, and also provided them with the flexibility to review material as often as they wished, at times that were convenient. This customized approach proved valuable to many students. The course web environment also allowed Pollalis to incorporate more feedback and dialogue among course participants outside class time. Both Pollalis and his teaching assistants posted quiz results and reflections on weekly course topics online, in a password-protected area of the course web environment. Teaching assistants were able to provide fast feedback on homework, usually within ten hours from the time students submitted their assignments. The web environment contained a threaded discussion forum that allowed students to post questions and receive answers quickly, without having to wait for office hours, and provided the opportunity to learn from questions posted by other students as well.

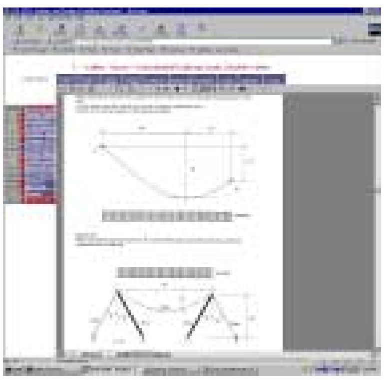
In his lectures, Pollalis also made use of films that had been prepared years earlier in order to demonstrate the effects of the physical forces and characteristics of different structures and materials. Although this film technology was not new, several students said they found these illustrative cases to be particularly valuable. One student even suggested that the educational value of these films could be enhanced by digitizing them, adding explanatory notations to emphasize the conceptual and mathematical points about physical forces, and placing them on the course website.

Pollalis used Microsoft's PowerPoint presentation software in two ways. First, he used it to present his lectures. His slides included bulleted key points for major topics, as well as diagrams and illustrations of designs elucidating structural concepts. Second, Pollalis required students to work in teams on a presentation that would illustrate a particularly difficult concept. The teams were required to use PowerPoint in their presentations as a way of practicing effective presentation strategies. Each week one team used PowerPoint to present their analysis of a key problem to the class. This approach applied new technology to meet several of Pollalis' goals. He believed that by using presentation software, students acquired a deeper understanding of the material, since it demanded that they think about how to explain the topic to their classmates in a clear and concise manner. Team members learned to collaborate by co-creating and revising the presentation. And students learned how to use modern tools for making a polished presentation, a valuable skill in theirfuture professional lives.

Implementation Process and Challenges

Course participants varied in their perceptions of the difficulty in developing and incorporating new technologies in the *Structures* course. While Pollalis tended to downplay the effort required to implement and sustain the use of new technologies, some of the teaching assistants and technical support staff indicated that creating and maintaining the material for the course website was difficult and time consuming.

From an educational standpoint, providing opportunities for increased dialogue and feedback meant additional demands on the teaching staff. While the online forum provided students with an archive of questions and answers about the course content, the teaching staff had to monitor the forum to ensure that misinformation was not circulated. Another issue involved the nature of the content.



Many questions posted by students could not be easily answered online. Assistants said that typing helpful responses to such questions took more time than they would have needed in a face-to-face conversation. Teaching assistants also had to post answer keys to quizzes and post feedback on homework assignments. Efforts to maintain the weekly learning spiral required the quick turnaround of lecture notes and video into a digitized format. The desire to incorporate a website into the course and the plan to revise the teaching approach seemed to be entwined and mutually reinforcing initiatives. A wish to provide more flexible access to more and more varied versions of learning materials seemed to develop as the potential of the course web environment became apparent.

From a technical standpoint, digitizing course material so rapidly required that Pollalis hire a teaching assistant whose sole responsibility was to manage this process. Other teaching assistants videotaped lectures and addressed technical problems when they arose. Pollalis himself experienced some challenges in translating his lectures into a format suitable for the web.

Developing PowerPoint slides for each module required time and forced him to predetermine the material and sequence for each lecture. Every week he recorded his lecture a second time, in a quiet place outside the school, in order to post a clear audio track. This often took several attempts to achieve.and the way in which they wanted toIntegrating new technologies into his course also forced Pollalis to contend with systemic institutional issues. The technical problems associated with posting audio and video versions of the lectures online made demands on GSD's computer network that required the attention of the school's technical staff. Although Pollalis viewed meeting these demands as part of the school's responsibility, the problems were unexpected and meant additional work for the staff.interact with the course material.

Results

There were several expected and unexpected results stemming from the integration of new technologies into Pollalis' course. Pollalis expected students would access the course lecture in various formats, based on their individual preferences. However, students did not become fluent immediately in the use of the web-based material. Typically, they required a couple of weeks to get a feel for the rhythm of the course and to become comfortable navigating the online environment. The head teaching assistant perceived that students needed time to figure out which format worked best for them and the way in which they wanted toIntegrating new technologies into his course also forced Pollalis to contend with systemic institutional issues. The technical problems associated with posting audio and video versions of the lectures online made demands on GSD's computer network that required the attention of the school's technical staff. Although Pollalis viewed meeting these demands as part of the school's responsibility, the problems were unexpected and meant additional work for the staff.interact with the course material.

"Typically, students require a couple of weeks to get a feel for the rhythm of the course and to become comfortable navigating the online environment."

Many students were deterred by the low quality of the digitized video and some preferred to attend the live lectures so that they could pose questions to clarify their understanding. "I can't help but think that there are some things about a blackboard that can't be reproduced in PowerPoint slides. I think that the most significant part is just seeing the teacher go through the process, step by step in real time," commented one student. In contrast, several students reported that they found the audio version to be a valuable way to experience the lecture or to review material that had not become clear to them during the live presentation. One experienced student said that he would listen to the audio lecture with headphones while working on his studio project, giving the audiotape only a small part of his attention. When the lecture reached a difficult topic, he would stop to look at the accompanying slides and concentrate on the lecture. He found this approach to learning to be much more efficient than sitting through the entire live lecture.

The teaching staff perceived that the most complex application of technology, i.e., digitizing and posting the videotaped lectures with synchronized PowerPoint slides, was the least valuable educationally. In comparison, digitizing the audiotaped lecture and posting it online was both less complicated and more educationally beneficial.

The enhancement of office hours was another planned result. Pollalis wanted to expand preset weekly office hours, and by having students ask questions over the web, he provided a means for them to learn from one another's questions online. Additionally, teaching assistants were able to quickly provide feedback on homework assignments and quizzes on the web, where students could view the online responses immediately, instead of going to the TA's office to collect their written work.

Pollalis also believed that students developed a more robust understanding of key concepts by both preparing PowerPoint-based presentations and by learning from those presented in class by their peers. In support of this view, Pollalis reported that student performance, as measured by their quiz grades and project presentations, has demonstrated a more completeunderstanding of the course material since he revamped both his pedagogical and technological approach.

Implications

Pollalis depicts his use of technology in the *Structures* course as a means of "automating the cow path." In this phrase, he signals that the technological innovations in his course have not radically transformed either the conventional course content or his pedagogical approach to it. Rather, he is simply trying to enhance the efficacy and efficiency of traditional subject matter and methods. In attempting to deepen students' understanding of course material that is necessary, but difficult and unpopular, he employed new technologies to enact, or implement, current theories of effective pedagogy. These theories emphasize the importance of using multiple formats—video, audio, text, diagrams—to present material, thereby providing opportunities for students to develop their understanding in a variety of ways, including learning with and from peers. Such formats also allow incorporating frequent feedback on students' projects and performance, as they gradually develop and integrate their understanding of physics and architectural practice. Pollalis used the course web environment and PowerPoint presentations to enact these educational principles and believes that these efforts have indeed enhanced students' understanding. Many of the students we interviewed concur. "You can choose from these different media to satisfy your requirements for learning, because everybody has a different way of learning," noted one student.

The way Pollalis uses new technologies in his course alters the way he and his assistants, students, and the GSD technical support staff allocate time to the *Structures* course. His initiatives attempt to garner educationally useful time for his course from an institutional schedule that was set before "the Internet time of teaching." Whether the impact on learning outcome justifies the investment in preparing, employing, and maintaining these new technologies is a point about which participants seem to hold varied opinions. Pollalis is most positive about the cost/benefit ratio, and most participants agree that the benefits make the investment worthwhile for the less complex technologies. The students and teaching assistants with direct responsibility for implementing the most elaborate technological innovations, have more doubts about whether their educational value justifies the required effort. "No matter how you look at this, you can't make [the course content] more interesting than it is right now," reflected Pollalis at the end of the course. "Nevertheless, you have to go deeper. You have to understand forces and materials and stresses, and it's still hard."

CASE II Transforming Architectural Design in a Networked Age

GSD 2107 - Design Course

In the spring of 2000, Professors Huang and Hirschberg at the Harvard Graduate School of Design launched an introductory course on Computer-Aided Design (CAD) that they intended to be radically different from versions of the same course taught in previous years at the school. The course they envisioned would provide the means of introducing students not only to the new tools of the design trade—two-dimensional rendering and three-dimensional modeling software—but would also allow their three dozen first-year graduate students to experience the potential of the design profession in what they call the "networked age." They would attempt to go beyond what they believed to be a limited view of computer-assisted design as a set of tools and techniques. They would explore new terrain—the role of technology in transforming the scope and practice of architectural design.

Such an ambitious agenda proved challenging for both instructors and students. The technology the professors used to support students' experiences with computers and networks was constantly evolving. On the one hand, this evolving nature of the course contributed to the students' initial confusion about its goals, and many students expressed frustration that the course was not meeting their expectations to master basic skills related to CAD software. On the other hand, it enabled the instructors to respond to emergent demands and needs of their students throughout the course. As Hirschberg acknowledged, "We were able to introduce more clarity as the semester was going on."

Nonetheless, the pioneering effort opened new possibilities for learning about design, particularly around the uses of collaboration and the architecture of virtual spaces. Exploring these possibilities ultimately caught fire in the minds of the students and fulfilled the instructors' desire to offer their students new ways of thinking about shifts in the fundamentals of design in the twenty-first century.

Course Setting and Participants

Message board and Participants face book in the 2107 website.

The approach taken by Hirschberg and Huang comes more clearly into view when seen in contrast with the customary way of tackling the topic of computer-assisted design for first-year students. The computer-assisted design course taught the previous year was geared towards introducing students to particular software products that enabled them to create geometric models of physical spaces. Students spent the semester replicating a single well-respected work by a well-known architect, using CAD software to draw a two-dimensional floor plan, and then extrude, or expand, the plan into a three-dimensional model with computer-assisted modeling software.

By contrast, Huang and Hirschberg introduced students to an array of digital tools that encompassed not only typical CAD software, but also tools for web authoring, image manipulation, and graphic design. These latter tools formed what they considered a basic toolkit for taking an active role in the digital realm. Furthermore, assignments focused on real and imagined places drawn, not from the repertoire of architectural classics, but from students' personal experiences. The instructors believed that the combination of a basic toolkit together with material drawn from students' experiences, equipped the students for participating in development of *Eventspaces*, the course website. *Eventspaces* provided students with a place to present their work, exchange ideas, evaluate one another's works, and ultimately collaborate on final projects. In developing such a "site" and designing the types of interaction meant to fill it, the instructors were experimenting with ways of mirroring the space and interaction that defined GSD design studios. As Hirschberg commented, they were "essentially recreating a situation like this building in the digital world."

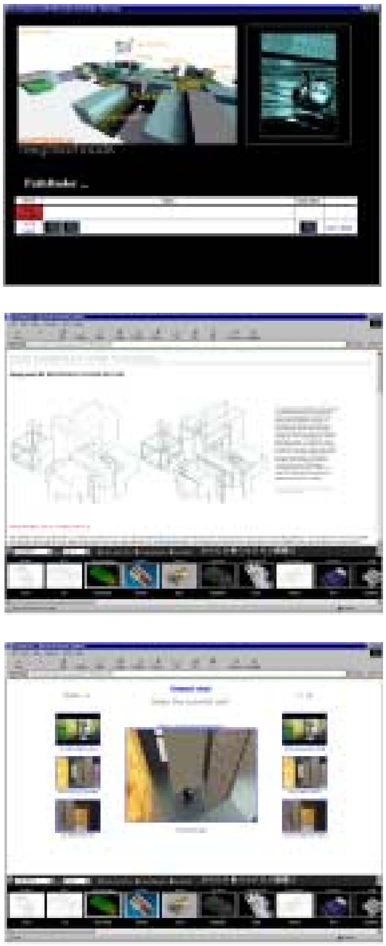
Educational Agenda

The explicit educational goals of *Design* were set up to accomplish what the instructors viewed as a necessary shift in students' use and understanding of computers. The course website outlines their goals, which focused on three areas: 1) to map the "theoretical foundations" for computer-aided design, giving students a framework for a conceptual understanding of the changing nature of architectural work using computers; 2) to expose students to an array of digital tools and techniques, what they label a "digital repertoire," so that students can then make decisions about where they might develop expertise; and 3) to give students the experience of "designing in the networked age."

Through these areas, the instructors anticipated that students would learn such things as basic computations, fundamental and intermediate concepts of geometric modeling, the integration of spatial and nongeometric data, image processing, publishing, and methods of information sharing on the Internet. Table 1 describes the three explicit goals and

Table 1: Goals and Teaching Approaches of the *Design* course

	Goal	Teaching Approaches
1	To provide a *theoretical* foundation for computer-aided design.	Weekly 90-minute lectures by the instructors.
2	To provide participants with basic *skills* so that they could make effective use of the emerging digital repertoire.	Weekly 90-minute computer lab tutorials and occasional hands-on workshops by the instructors and teaching assistants.
3	To familiarize the student with both the theoretical and practical aspects of designing in a *networked* environment.	Extensive and ongoing use of *Eventspaces* for weekly assignments and the final project on which all students worked together.



"Event Space" in the 2107 website showing the break-down structure of interrelated design projects

the main teaching approaches used by the instructors to address each.

Conversations with Huang and Hirschberg about these goals, however, made us realize that they also had several other intentions. As Huang explained, the fundamental shift in the role of computers from "tools" to "media" opened up the possibilities of exploring "a whole new social dimension." This dimension, they believed, forced students to confront issues of identity and the representation of self and others in virtualenvironments. For example, students were asked to put up their own homes (bedrooms, living rooms, bath rooms, etc.) as model designs and manipulate others' designs in imaginative ways. The instructors designed the sequence of course activities to take advantage of this "social dimension" and build upon one another, so that the intensity of collaboration among students via *Eventspaces* tremendously increased as the semester progressed.

This collaborative spirit was part of another implicit agenda, that of approaching the matter at hand with what Huang and Hirschberg described as "a playful spirit." Students were invited to "play" with each other as they explored the boundaries of this new world—probing the edges of physical and virtual designs, public and private online spaces, synchronous and asynchronous working modes, and real and surreal applications of their architectural designs. According to Hirschberg, this kind of creative play promised to lead students to "a much deeper understanding of what digital media offer for now and for the future of . . . this connected world."

Collaboration and play combined to create conditions for a third important educational facet of *Design*, that of the students' taking charge of their own learning as a group. The instructors sought ways of diminishing their role and fostering exchange among students. Huang described how he viewed his role in such an environment:

The structural digram indicating how different "Events" related among pages

" It's really this fundamental shift from our role of telling them what to do, to one of facilitating something that is happening by itself . . . My idea is to see myself not as a commander, but as a playground director. Just to set out some tools and then make sure that they don't fall over the cliff. "

Role of Technology

In this course, students learned with new technologies to use new technologies. The instructors emphasized that "This course is not something that you could learn another way, leaving technology aside. The technology is just part of what students need to learn." Students were not only supposed to learn how to use new tools, but also to employ them in collaborating and creating new approaches to architectural design that could not be completed with traditional tools.

Furthermore, *Eventspaces*, the course online environment, supported the process of teaching and learning through a wide range of activities. The website facilitated course administration, offering basic course information and resources, and providing a "help-desk" via the course message board. Most important, *Eventspaces* served as the forum for viewing, exchanging, and evaluating the students' digital works.

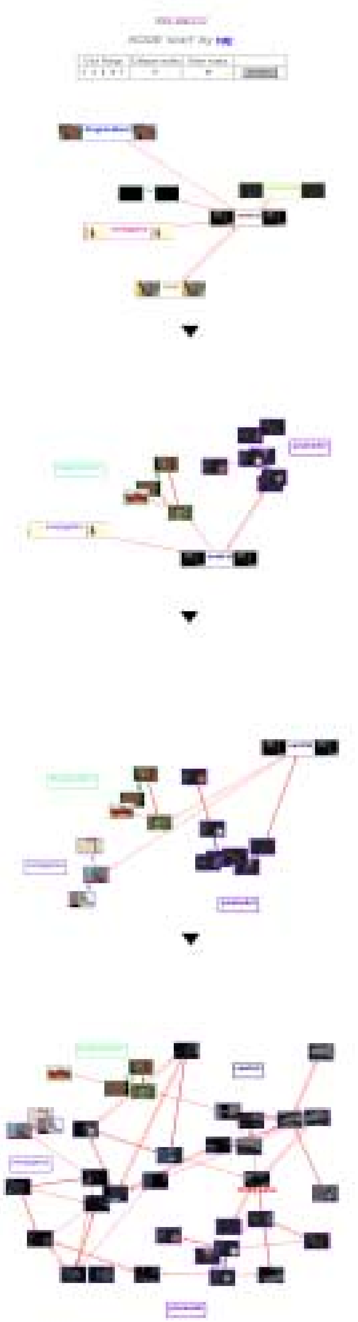
But *Eventspaces* went beyond mirroring physical studio space. As examples, we focus on two interesting concepts in online architectural designs: the "reality check" and the "time stamp." *Eventspaces* was constructed to exhibit not onlyfrozen images of students' digital work, but also to allow easy access to source files and underlying three-dimensional models from which students generated their images. Thus, students could freely share construction models and programming code for their assignments, learning from the more experienced among their peers and noting the mistakes of those who were less experienced. By modifying others' basic design models and source codes, students were forced to cope with how a colleague used the same software in different ways—what the instructors called reality checks. Huang pointed out that professional architects "have to do this in practice all the time."

Eventspaces also enabled students to track the authorship of a specific work through a simple time stamp that logged students' use of others' files. Thus, each image sat within a genealogy: a column to the left of the main image displayed postage-stamp views of its forebears—those images that the author had relied on to create the current image; and a column on the right displayed icons of the current image's offspring—those images from which it had sprung. This allowed a means of protecting a designer's ideas "without those ideas being exclusive," as Huang put it, thereby supporting both collaboration and clear lines of conceptual ownership.

Implementation Process and Challenges

Design of Educational Context and Activities.

The technology drove the structure of assignments, as instructors sought to wed greater conceptual challenge with increased technical skill. They carefully organized assignments in a clear sequence of increasing complexity. Students used



The dynamic diagram showing the relationship among project images in Event Space, this Java-based interface was powered by Benjamin Staeger and Michele Milano, ETH-Zurich.

relatively simple tools at the beginning, taking a digital image or scanning a photo of their own homes and presenting these on *Eventspaces*, along with a poem about the building and its meaning for them. For the following week, each student chose one of the classmates' home pictures and manipulated it using Adobe Photoshop, an image processing software. They then moved on to develop two-dimensional drawings with tools such as AutoCAD, and three-dimensional models with tools such as FormZ and VectorWorks, incorporating increasingly complex attributes with lighting, rendering, and animation software to enhance and complete their environments. Throughout this process, all the students' ongoing works were displayed and archived on *Eventspaces*, which turned it into an impressive gallery of digital designs.

The students' experience in the course culminated in a single, collaborative design project called *The Game*, which wove together their disparate work into a unified multimedia product available both on CD-ROM and *Eventspaces*. *The Game* required students not only to work on their individual designs, but also to collaborate in co-creating a series of interconnections among designs—what instructors and students termed "interstitial environments"—which linked individual designs into one coherent "hyperstructure," a virtual structure held together by the glue of hyperlinks. Using various metaphors such as New York's Grand Central Station or a "filthy valley," the students became immersed in the design and development of these interactive, in-between spaces that pulled together all contributions in the class in a way that was accessible and navigable only in this virtual environment. Harking back to the importance of maintaining a "playful spirit," Hirschberg explained that the end-product, *The Game*, was but one manifestation of what he called "the game aspect of the course.

Most important to him was that *The Game* came to engage all of the students' creative and intellectual faculties. In fact, the students became so immersed in *The Game* in the course that they successfully petitioned the school's administration to extend the deadline of a term paper for another course, Architectural History, so that they could meet the deadline for *The Game*. One student we interviewed on the last day of this course confessed that she had slept only about three hours during the previous five days in order to finish her part of the *Game* assignment, a workload that other students assured us was not atypical.

Online and Offline Interactions Among Students.

Throughout the semester, Huang and Hirschberg

Table 2: Types, Purposes, and Main Characteristics of Groups

Types of Groups	Purposes of Groups	Main Characteristics
1. Neighborhoods	To learn how to work over each other's designs. To evaluate the contributions to their neighborhoods through peer feedback and a group rating.	Sorted by the periods of their own homes' building year (e.g., 1900s, 1950s, etc.). Quite loose and arbitrary grouping.
2. Special Interest Groups (SIGs)	To learn more about particular computer tools to achieve particular skills (e.g., modeling, animation, etc.). To become more expert in using and understanding particular tools.	Volunteer groups in: Group 1: 3-D Modeling Group 2: Lighting & Rendering Group 3: Animation Group 4: Game — Script & Sound Resulted in "positively surprising" collaboration.
3. Teams	To exchange knowledge and skills in particular tools learned in this course. To practice a collaboration with a set of experts.	Autonomous grouping. Cross-SIGs (i.e., typically one modeler, one renderer, one animator, and one gamer in a team).

promoted extensive collaboration among students as an integral element of learning. Overall, three different types of formal groups were created: Neighborhoods, Special Interest Groups, and Teams. Table 2 describes their purposes and main characteristics.

Conceptual and Technical Changes.

The instructors' ambitious goals of simultaneously transforming both the content and the process of the course raised some difficulties, especially at the beginning of the course. Students and teaching assistants alike identified challenges at two levels: conceptual and technical. Students who were unfamiliar with the instructors' elaborate explicit and implicit agendas faced the challenge of simultaneously mastering both new tools and new visions for the use of those tools. Many students who entered the class expecting to master CAD software were initially baffled by what they viewed as a course devoted to the use of the Internet. The instructors' goal of serving as "playground directors" frustrated some students, who felt that open-ended instructions and lack of content signaled disorganization rather than opportunity for creative play.

Students faced the challenge of simultaneously mastering both new tools and new visions for the use of those tools.

Teaching assistants also expressed frustration. They had been hired on the basis of their expertise in different CAD software yet the students clearly needed help mastering the *Eventspaces* interface. One teaching assistant reported that he avoided using the website, all the while hearing frequent complaints from students that *Eventspaces* was "very chaotic and the navigation of it … very arbitrary."

Eventspaces itself evolved over the course of the semester, as students' contributions and interactions changed the breadth and depth of the site. According to Huang, this kind of co-creation was a serendipitous byproduct of collaboration, letting students experience firsthand the capabilities and limitations of the technology. However, students found that the focus on the idiosyncrasies of the interface led to what they feared would be spurious knowledge, as they sometimes struggled with difficulties in uploading and downloading files.

As we noted above, student enthusiasm for the course peaked as *The Game* came to completion. For many, participation in building *The Game* crystallized their experiences in the course in a way that made the technical and conceptual challenges, at that point, part of the overall design challenge.

Results

In the following summary, we consider the outcomes of students' participation in *Design*. First, we examine the results that were anticipated by the instructors from theoutset, and then we discuss results that were unexpected consequences of the new approaches and technologies.

Expected Results:

CAD Tools.

We have already noted that several students told us of their frustration, especially during the first half of the course, with a seeming disconnection between their expectations of developing expertise in design software and the instructors' goals of giving students the opportunity of exploring design in and through a new medium. Nonetheless, students had developed particular expertise in several different tools by the end of the course, according to their self-reports in post-course questionnaires conducted by Huang and Hirschberg. This result aligned with the instructors' perception of the sophisticated use of different tools within the Special Interest Groups and across Teams. Based on their work displayed for final review at the end of the semester, we could see that students as a whole appeared to have mastered many different kinds of tools. Summing up his own surprise at the end of the course, one student said, "Everybody was working on CAD. I would have never imagined that [midway through the course], because we have so much other stuff due."

Motivation.

One of the most remarkable results of this course was the intensity of collaboration among students, especially during the final assignment period. Despite difficulties with *Eventspaces*, this web-based studio eventually proved indispensable to students' group work and collaborative learning. Hirschberg was particularly impressed because students were taking charge of their own learning and using the instructors

as a resource for urgent questions. The instructors believed that students had come "to see the value in learning from each other and taking up each other's ideas," Huang said. Again, we see that the fluidity of interaction online and offline served as an essential glue for the intensity of student interaction. As one student remarked, "We would have collaborated as much if we had been creating products with noncomputer tools, because we all work so closely together here." This points out that the quality of the collaboration was not necessarily unique, but what was unprecedented was the fact that students were working in this way for a course that was not Design Studio.

Collaboration served as only one side of the coin of motivation. The other was competition. One student told us about his view of how *Eventspaces* served to spur a kind of constructive one-upmanship: "I think it pushed everyone to work much harder. Everybody saw everybody's work and, you know, one person goes a bit better, the next 50 other people follow … It was an amazing incentive to do better … Everybody created way more than they had to." The incentive was neither grades nor "Neighborhood Ratings"—the system of scoring contributions that Huang and Hirschberg abandoned towards the end of the semester. Rather, it was creative influence as evidenced by the number of "linkings" one had, linkings that demonstrated a chain of inspiration from a highly valued source.

Implications

Huang and Hirschberg built their course around three essential aspects of what they termed "design in the twenty-first century:" conceptual understanding of new forms of design practice, experiential understanding of that practice, and concrete skills in specific kinds of software (see Table 1). The instructors believed the first and second of these to be intrinsically linked, while the third, they believed, would arise out of each learner's engagement with the assignments and

with each other. The momentum that gathered during the final phase of the course in the development of *The Game* made clear that, to a large extent, these educational aspirations had been realized. The professors did manage to foster, through *Eventspaces*, a collaborative studio space that paralleled the creative "playground" of physical studio space, while also adding new dimensions to that collaboration in several important ways. They also appeared to open the eyes of many students to the possibilities of design in a "networked environment," and they created conditions that helped students exchange skills and begin to master software essential to the realization of those possibilities.

As we noted earlier, the experimental nature of this new and innovative approach placed heavy demands on both instructors and students. Below, we tease out two questions that merit special focus as we attempt to gauge the implications of the course for future efforts.

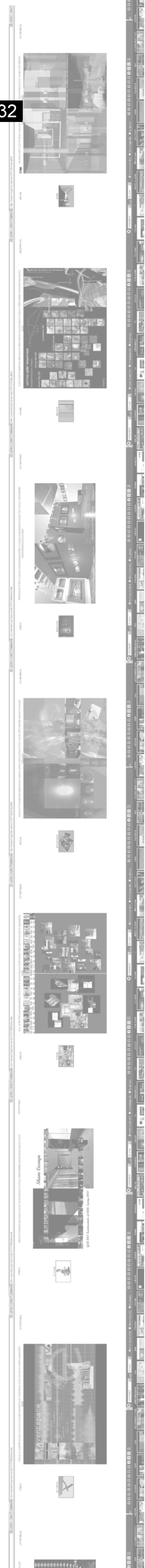
How do you provide appropriate instruction to a group that possesses varying levels of expertise? Huang described the course as "a living, evolving system because it included a diverse mixture of computer novices and technical sophisticates." While this mix clearly contributed to the creative ferment, it also led to frustration among those who were less adept. This begs the question of how to engage students of all skill levels in the course activities, while identifying and supporting those who need more help with basic skills.

To what extent can goals and criteria remain exploratory without generating uncertainty and anxiety that limit the educational agenda? Hirschberg recognized that "a certain amount of frustration is an inevitable and essential part of the experiential learning process." For students and teaching assistants alike, the pre-*Game* part of the course posed conceptual as well as technical challenges that seemed to prove more perplexing than rewarding. This appears to point to a disconnection between the "theoretical" underpinnings of the weekly lectures and the focus of the assignment cycle. On the one hand,

students easily recognized a clear progression in the assignments in the level of technical proficiency required—from 2-D rendering to 3-D modeling, for example. On the other hand, the students with whom we spoke appeared uneasy about the connections between what they were doing and its applicability to the wider practice of architecture.

The conundrum, as always, is to ignite the students' interests while providing sufficient scaffolds for their learning.

Both of these questions point to an overarching educational concern addressed by this course: *How do you teach emerging forms of professional practice?* Huang and Hirschberg rely heavily on the value of experiential learning as the key. This is, in part, an educational orientation, expressed in their intentions to make connections between the students' interests and the subject of the course, as well as among the students as co-learners. It is also a necessary approach because the subject matter they are tackling is not well-established in the field of design, but is rather, an emerging form of practice. In exploring aspects of practice, researcher Etienne Wenger discusses the essential duality of participation and reification as aspects of professional practice.[1] Participation, in Huang and Hirschberg's explorations, amounts to the experience of design in a networked environment. Reification is the artifact that forms the structure around which engagement can take place, the role that *Eventspaces*, in particular, filled in this course. The boundary between these two aspects is less secured by tradition and precedent in emerging forms of practice—such as a course on design in the digital realm—than it is in well-established forms such as a Design Studio course. Thus, the instructors constantly have to negotiate the boundaries of participation and reification as they consider what constitutes subject matter and what distinguishes that matter from method in an emerging field. The conundrum, as always, is to ignite the students' interests while providing sufficient scaffolds for their learning. The latter sections of this report delve into these concerns in greater detail along several different dimensions.



A major reason to introduce new technologies into professional education is to improve teaching and learning. Clarifying the dimensions and degree of desired educational change is important in order to plan, guide, and assess technological innovation. Analyzing the relationship between technological innovations and educational changes in the GSD cases may help educators recognize both the potential and challenges of attempting to improve education through the introduction of new technologies.

Dimensions and Degrees of Educational Change

As these cases reveal, technologies may affect a range of dimensions of the educational endeavor, including course content, the process of teaching and learning, assessment, course management, and communication and social interaction among participants. The degree of change sought in each of these dimensions may also vary. The role of technology may be to merely increase the efficiency or effectiveness of the traditional educational model, extend or slightly alter one or more dimensions of the educational goals and approach, or to significantly transform the educational agenda and process.

The dimensions and degree of educational change associated with the introduction of new technologies affect the kind and amount of challenge both teachers and learners experience in adjusting to the technology-enhanced educational practice. To make matters more complicated, the educational agenda may not be clearly defined in advance. Furthermore, the introduction of new technologies often reveals new opportunities to alter the course content, the methods of teaching and learning, and the forms and intensity of interaction among participants. Thus, the technologies and the educational agenda may influence one another in an evolving interaction.

The two cases presented here illustrate somewhat different aspirations and results on various dimensions of educational change. Professor Pollalis did not seek a radical change in the content of his course. Although he did attempt to improve his pedagogical approach with the introduction of new technologies, his intention was not to create a major shift. Instead, he hoped to improve the efficiency and effectiveness of his students' learning process and to extend the amount of time they could invest in understanding the difficult content of his course. In his words, he used new technologies mostly "to automate the cowpath," or increase the speed and success of his students' journey along the traditional itinerary. In contrast, Professors Huang and Hirschberg sought to transform both the content and the process of their course on computer-aided design. They viewed networked technology as a new paradigm for design and hoped to introduce students not only to new tools, but also to modern patterns of collaboration and communication as students co-created designs in the novel medium of a virtual environment. "What we want to teach is how to apply new technologies to design in the twenty-first century," Huang said.

Clarifying the extent of educational change associated with the introduction of new technologies can help teachers and learners gauge the challenges they must address in shifting from traditional patterns and expectations. For example, students' expectations about the Design course content seemed to be quite different from what the instructors intended. Professors Huang and Hirschberg enjoyed the pursuit of an emerging agenda centered around collaborative design in a virtual environment, while many of their students continued to expect training in current, if not cutting-edge, computer-based tools for supporting design of real-world environments. The evolving transformation of the content of this course appeared to be a tacit and, perhaps, emerging agenda for the instructors. Clarifying goals might have helped students adjust their expectations and respond more effectively.

Teaching for Understanding with New Technologies

Despite their differences in degree of intended change, the instructors in both cases attempted to use new technologies to promote approaches that are consistent with current theories of effective teaching and learning for understanding. Recent research on effective pedagogy stresses the importance of helping students construct their own robust understandings, often summarized as constructivist pedagogy or constructivism. This pedagogical approach contrasts with traditional transmission of information through direct instruction, sometimes called instructionism. Constructivists advocate taking learners' interests, ideas, and preferred modes of learning into account; supporting learners in actively using and applying new knowledge; and helping learners deliberately change their minds by fostering thoughtful reflection. These approaches are consistent with Schön's[1] notion of educating reflective practitioners by linking ideas with action, theory with application, through cycles of reflective practice that include coaching.

A recent synthesis[2] of research on constructivist practice focuses on four features of learning designs: knowledge-centered, learner-centered, assessment-centered, and community-centered. Viewing the cases through this constructivist educational framework reveals important dimensions of the educational agenda that all three GSD professors hoped to improve. It may also help other educators discern and articulate aspects of the educational agendas that they hope to address by integrating new technologies into their practice. A clearer depiction of the agenda increases the chances that new technologies will actually advance this agenda, rather than merely add expensive decoration to current educational practice.

Knowledge-Centered:

Instructors in both cases focused the application of technology on key concepts, methods of analysis, and approaches to design that were central to the subject matter of their courses. Pollalis made a special effort to use technologies to illuminate particularly important and challenging topics, sometimes called "targets of difficulty."[3] He required teams of students to choose concepts they found confusing and to develop presentations for their classmates using PowerPoint presentation software. Both the presenters and the audience gained from this extra attention to key concepts. Pollalis also made use of movies and software to demonstrate key aspects of structural analysis.

Huang and Hirschberg believed that the content of their course on CAD needed to enable students to understand the nature of design in virtual space, something that could only be grasped by working with new tools to design online environments. Learning how to use tools for the collaborative design of virtual spaces was the knowledge at the center of their course.

Learner-Centered:

Constructivists believe that learners must actively construct their own understanding. To support this sensemaking, curricula should be anchored in students' own experience and interests[4] and presented in forms that are tailored to learners' own preferred modes of learning.[5] In both courses, the instructors believed that learning develops from a dynamic interaction between knowledge and experience, which each learner constructs differently. Mezirow illustrates that transformative learning is based on self-reflection and learners actively making sense of their prior experience, preferred ideas, and assumptions.[6] Consistent with these principles, Pollalis made his lectures and course materials available in multiple formats on the course website, in order to support the diverse learning styles of his students. Huang and Hirschberg encouraged their students not only to deal with designs that had personal meaning, like their own homes, but also to engage in various group activities they created, which required the exchange of ideas and practices among learners. In order to overcome rote learning in both courses, the instructors tried to maximize the number of opportunities for students to present their own ideas, to look at others' works, to collaborate with one another, and to engage in intellectual discussions on the subject matter.

Assessment-Centered:

Recent conceptions of the role of assessment in learning focus on the value of continual feedback, embedded in the instructional process, that aims not only to monitor progress, but also to inform subsequent steps. This kind of feedback and coaching is an especially important component of professional education where the goal is to support not just conceptual learning, but also the capability to apply learning in novel and creative ways.

The goal is to support not just conceptual learning, but also the capability to apply learning in novel and creative ways.

Both courses at the GSD employed technologies as media for capturing revisable drafts of student work, providing means for feedback from multiple sources, and encouraging students to modify and improve their drafts. This was especially true in the *Design* course, where *Eventspaces* and *The Game* allowed students to generate, share, and modify their creations online. As Huang and Hirschberg pointed out, the fact that these designs were created with software allowed students to view the underlying structure of the designs, not just the final products. Viewing other students' work, along with receiving feedback on this work, amplified the traditional model of coaching and critical review that is typical of the design studio process. Pollalis also made use of the course website to promote more frequent and public assessments of student work. He and his teaching assistants provided fast feedback on homework and employed an electronic forum to address questions that students posted about lectures or problem sets. Although this use of the web did not transform the nature of assessment in a fundamental way, it increased the speed and efficiency of traditional strategies—that is, of privately marking papers and holding office hours.

Community-Centered:

A final component stressed by recent research on effective approaches to education is collaborative learning and the formation of supportive communities of learners. Especially in professional education, this includes the development of a common language for collegial exchange and the creation of a professional community,[1] where shared norms promote ongoing inquiry. Both the courses described here encouraged learning through bringing individual minds together. According to Huang, "Architecture as a creative discipline is very much about exchanging [ideas and experience] through a high degree of collaboration." The instructors wanted to prepare their students to learn how to work individually as well as collaboratively in a computer-fluent environment. By creating a self-reinforcing community of learners, the instructors expected that collaboration among learners would also generate sufficient excitement and peer pressure to engage them more fully in the course content.

In order to prepare students for the design profession, these instructors provided them with opportunities for extensive experience with the tools and techniques of modern practitioners in simulated professional contexts. Pollalis imposed a presentation tool like PowerPoint on many assignments, which encouraged students to demonstrate their knowledge and skills in a more polished form that practicing professionals might use. This situated learning activity resembles Lave and Wenger's notion of "legitimate peripheral participation," in which learners participate in an actual practice of experts, but to a limited degree and with limited responsibility for the ultimate product as a whole.[2] In Huang and Hirschberg's course, the learning activities were mainly situated in a social context. The course assignments, for example, were designed to promote personal and social engagement among students in order to create a sense of belonging and a community of practice. Consistent with ideas expressed by Lave and Wenger, who focus on the kinds of social engagements that provide the proper context for learning, this course emphasized the persistent characteristics of a community of practice, including exciting ideas, challenging practices, active engagement, and multiple ways of collaboration. This intensely social environment appears to have helped students in the *Design* course produce remarkably complex and technically ambitious designs.

Implications

New technologies may be introduced in professional education courses for many reasons, only some of which focus on improving teaching and learning. Within the subset of educational goals, technologies may be intended to alter multiple dimensions of the educational agenda to varying degrees. Becoming clear and explicit about the educational goals that new tools are intended to serve, increases the likelihood that these purposes will actually be served. As teachers and learners experience the new possibilities that novel technologies afford, their goals regarding educational content, processes, and interactions may evolve. Thus it is advisable to continually review the evolving educational agenda in relation to the application of technologies. Such analysis can be sharpened through the use of an educational framework, such as the one employed here to examine the extent to which technology made learning more knowledge-centered, learner-centered, assessment-centered, and community-centered.

There is no single recipe for choosing new technologies to support an educational agenda. There are as many strategies for using new technologies to support learning as there are educational agendas, even within the same institutional context. As discussed in the previous section, a major reason for introducing new technologies into professional education is to improve teaching and learning. Attention to clear and explicit educational goals helps ensure that improvement occurs. However, there are practical challenges to integrating new technologies that can compromise even the most explicit educational goals and impede learning if they are not addressed. The technical complexity of some technologies may create unnecessary obstacles to learning, while a complicated method for using more simple technologies may introduce equally problematic barriers.

An analysis of the use of technology in the GSD cases highlights some of the inherent technical challenges in integrating new technologies in educational practice. This section brings to light some tradeoffs between the complexity of technology versus the educational benefits realized by both the students and teaching staff. Educators must weigh the costs of using complex technologies in relation to their educational benefits and their institutional context (as examined in the other two thematic sections of this report). In the GSD cases, instructors chose varying degrees of complexity in the designs and use of technology to support their educational goals. Each choice required different levels of technical support and made different demands on the institutional infrastructure. By comparing specific choices regarding interface design, communication tools, and strategies for collaborative work from each course, the tradeoffs between ease of use versus educational benefits become apparent.

Weighing the Complexity of Design

Both the *Structures* and *Design* courses integrated similar types of new technologies: presentation software, a web-based environment, and profession-specific tools (e.g., Multiframe in *Structures* and AutoCAD in *Design*) as well as older technologies such as film. Each of these technologies contains individual features such as communication tools, the interface, and tools for collaborating on student work. Just as in the design of a physical structure, design of technologies for education can involve endless combinations of individual features. Often, features with more complex designs are associated with higher educational power, because they attempt to build in principles of effective teaching and learning for increased understanding. However, complexity in design places expected and unexpected burdens on students, the teaching staff, and technical support that can ultimately derail the very principles the designs reflect.

One example of this tension is the interface design for the web-based environment in each course. Designing the interface of educational technology demands careful attention to educational goals.[1] The interface designs of the two course websites differ greatly in look and feel, reflecting each instructor's educational agenda and views of the course within the school's context. The interface design for the *Structures* course is simple and practical with very little embellishment. The navigation system is clearly defined and structured. In contrast, *Eventspaces*, the web environment for the *Design* course, is visually complex and contains numerous moving graphical elements on the homepage alone. The navigation is not well defined and its structure is unclear to the first-time user. On first comparing the two environments, one is reminded of Pollalis' contention that his course is boring but necessary, which contrasts with Huang and Hirschberg's desire to engage students in cutting-edge technologies. Although each interface reflected pre-articulated educational goals, the simplicity of Pollalis' interface allowed students to find material easily and quickly. Conversely, students and teaching assistants in the *Design* course, while liking the look and feel of the site, expressed confusion about how to use it and how to find the material they needed.

While the overall interface design for each web-based environment dramatically differed, the design of the main communication feature for both courses, an online message board, was similar in simplicity. Each message board employed simple threaded discussions to capture questions, comments, and observations from course participants. However, the complexity of the *Design* course environment made getting to the message board problematic for many students.

The relationship between the complexity of design and educational benefits was not always negative; that is, increased complexity was not always associated with lower educational power. In the GSD cases, there are examples of very complex design and use where both students and teaching staff report high educational benefits, and simple design and use that had only a moderate educational payoff. Examples of both types of relationships are found in the efforts to promote collaboration among students.

The homepage for "Structures" (GSD 6201)

Collaboration was a central educational tenet in both courses and each instructor used new technologies to support the sharing of ideas and concepts. The technologies used by instructors ranged from a readily available and intuitive software package to customized web-based software to support the presentation of student designs.

Pollalis' use of Microsoft's PowerPoint presentation software as a tool for collaborative student presentations serves as an example of low technical effort resulting in moderate educational power. Pollalis integrated a highly intuitive, low-maintenance software package, PowerPoint, to make content accessible and to present his weekly lectures. PowerPoint allowed him and his teaching assistants to easily convert lectures and presentations into a web-based format, something students reported as having educational value.

The homepage for "Design" (GSD 2701)

Huang and Hirschberg's learning goals around collaboration were more complex. They chose to design this complexity directly into the technology itself. In this example, the higher complexity led to a higher educational payoff. They integrated customized software into the course web environment that created a virtual design studio for students. Despite the complexity in the design of the software, and the reported difficulty in using it, both students and instructors felt it had a high educational payoff. The ability to view, modify, and share designs among students was so fundamental in helping Huang and Hirschberg meet their educational objectives, that the educational payoff was deemed worth the added difficulties for both students and the teaching staff.

Naturally, not all educators have the resources to create customized software to support their educational agenda. However, these examples illustrate that educators should understand and then weigh the tradeoffs between using more complex designs and features of new technologies and gaining the expected educational benefits. The relationship between technical complexity and educational benefit depends on each course. Educators must weigh the benefits against the costs, taking their own educational agenda and institutional context into account. By doing so, they can determine a baseline required to meet their educational objectives and evaluate whether adding more complex features would generate commensurate educational benefits.

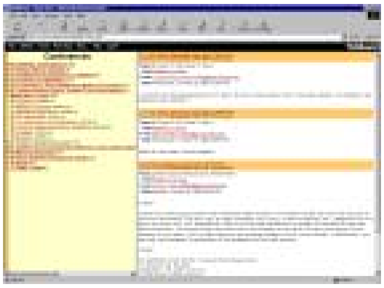
Weighing the Demands of Using Technology

Another dimension educators should consider is the demands the technologies make on their time and resources. Even the most simply designed technologies that result in effective educational payoffs can impose high demands on instructors and teaching assistants' time.[1] These demands can be so great that, when weighed against actual educational payoff, the value of the technology does not seem worth the costs.

One example of this is Pollalis' resource bank in the web-based environment for the *Structures* course. As described in the case report, Pollalis wanted to post multiple representations of course material online. He posted text (PowerPoint slides), audio, and video versions of his lectures. However, the teaching staff experienced varying degrees of difficulty in posting the material online. While PowerPoint presentations were easily transferred to the web environment, the audio and video versions involved an additional multistep process that demanded extra time from both Pollalis and his teaching assistants. This process included rerecording his lecture each week in a quiet environment and hiring a teaching assistant specifically to digitize and post the audio and video presentations.

Pollalis used both video (left) and text-based presentations (right) in his course web environment.

Overall, students found the resource bank helpful. Many of the students stated that the material allowed them to engage the content more deeply. However, students found video a difficult medium to follow online, in part, due its poor quality. Pollalis believes the online material increased his students' understanding of the course content. Examination of the case suggests the more technically demanding media appear to have held the least benefit for the students.



Pollalis used an asynchronous discussion board for answering student questions during the week and for allowing students to post their views, comments, explanations and interesting material related to the class.

As noted, even though both the *Structures* and *Design* courses used simple communication tools, they frequently demanded a great deal of time from both instructors and teaching assistants. The web-based message boards were well used by students in each course. However, teaching assistants often found that the types of questions students asked required long detailed responses that had to be typed and submitted in a timely fashion. Teaching assistants also had to keep a watchful eye on the message boards to prevent false information from being disseminated.

The GSD cases suggest that when evaluating whether or not to integrate new technologies into educational settings, educators should consider the additional resources, including time, that such a shift would demand. The amount of time and resources a technology will require of the teaching staff often is not recognized, until after the course begins. Clarifying how technology will be used and what it will require of course participants can help in determining whether its costs will be justified by the educational benefit. Consulting with an institution's technical support staff may help educators estimate the amount of time required to use a technology properly.

Weighing the Requirements for Supporting the Technology

When weighing the educational benefits against potential costs, educators must consider the demands the technology will impose on the institution's infrastructure and technical support staff. The GSD cases underscore this point. In several instances, the more complex technologies often caused students' computers to crash or caused entire the entire system to slow down due to increased demands on the school's servers. Even in situations where the costs of the technology were deemed worth the educational benefit, if students were unable to access the technology due to system overload, the educational agenda was compromised.

The Game implemented by Huang and Hirschberg in the *Design* course involved customized, proprietary software that allowed students to link their virtual designs with other students' designs. While the instructors view the educational benefits of this technology to be worth the demands on the teaching staff and students, the school's infrastructure could not always support multiple users on the site. Many students reported system crashes that made the environment inaccessible to them. Likewise, students in the *Structures* course reported that the video presentations sometimes froze school computers.

Educators must consult in advance with the technical support staff to ensure the technologies they choose will be fluent and reliable within the context of their institution's technical infrastructure and resources. They also should evaluate the technical skills of the teaching staff to determine who will maintain the technologies during the course. Multiple technical errors can lead to mistrust of a technology among students, thereby compromising its educational power. By weighing the support costs of technology, educators can determine whether there are sufficient institutional resources to support their educational innovations.

Implications

To reiterate, educators must weigh the demands on students, teaching staff, and technical support resources against their articulated educational agenda (discussed in the previous section) before integrating new technologies into their teaching. Complexity in the design, use, and support of new technologies can compromise the very educational agenda the technology is intended to support. The technical complexity of some technologies may create unexpected obstacles to learning and ultimately derail educational goals by making the content inaccessible to students. Intended educational payoffs may pale if the technical demands on the instructors and teaching assistants' time outweigh the benefits. If the institution's infrastructure cannot support the technology easily, educators risk wiping out the innovation's educational power altogether. By weighing the costs of creating, applying, and maintaining technological innovations against the educational benefits, educators are more likely to arrive at a good balance that supports their educational agenda.

Competing for Attention

The two courses we focus on here are at the margins of what the Graduate School of Design considers the core of architectural education. Design Studio courses, as we have noted in each of our case studies, take precedence both formally, in the curriculum of the school, as well as informally, in terms of how students allocate their time. Despite their position on the periphery of the studio, however, both the *Structures* and *Design* courses are considered foundational by their instructors and their importance is also indicated by their order in the sequence of courses at the school. They are required, and they fall within the first few semesters of a student's education at the school because they are considered part of the practicing architect's essential toolkit.

The inherent tensions among the requirements of the formal curriculum, core and peripheral courses, and the ways in which students actually spend their time, set up a competition for the scarcest of resources: students' attention. Instructors in the two courses make use of new technologies, in part, to claim a greater share of that attention, but they do so in very different ways. Spiro Pollalis focuses much of his energy for innovation in his *Structures* course on how new technologies transcend the limitations of *time*, liberating the content of his course from the constraints of scheduled time in a classroom. Huang and Hirschberg, however, focus their energies on new definitions of *space*, trying to offer their students a "sandbox" of new possibilities for technology-enabled interaction among designers as well as between architect and machine. Moreover, the nature of the competition for students' attention in both time and space, as well as the place of technological innovation in the competition, reflects broader shifts in the field of architecture and among practitioners concerning what constitutes the current toolkit—those skills deemed essential for architectural practice in the twenty-first century.

Below, we briefly point out the different ways that the prominence of Design Studio has shaped the use of technology in the two courses under consideration. Then we relate these perspectives on and practices around the use of technology to two tectonic shifts that are reshaping the profession of architecture and the professions in general—specialization and globalization. Our intention is to show that the way technology is integrated at the level of these individual courses has the potential for bringing into the classroom new forms of practice that mirror the changing role of technology in the profession at large. Most important, these new practices can both enhance the existing approach to learning in the field of design, and, simultaneously, exert pressure that would undermine that approach.

Structures GSD 6201: The Internet Time of Teaching

As the case study describes in detail, Spiro Pollalis recognizes that his is an uphill fight to garner the attention of students for his *Structures* course. Not only is he working against the school's clock, which runs on studio time, he is also combating attitudes within the school that relegate his subject area to second-class status as "an engineering course."

His use of technology to make the content of the course easily available in multiple formats is an attempt, as he puts it, "to have more quality time," and less of "the dry delivery of information." On the one hand, this allows students to multiply time by listening, as one student did, for example, to the audio of one of his lectures while he cut cardboard for a model. On the other hand, it propels a reorganization of how students allocate their time as they become engaged in activities for a course that many of their predecessors dismissed until the nights before the midterm and final.

To reap the benefits of technology-enabled "quality time," however, [Pollalis] had to forsake that kind of flexibility in favor of a different rhythm that demanded a greater degree of self-discipline and structure.

The increased demand on student time follows from Pollalis' own experience with time and technology in developing the course. He found, as the case study describes, that to make effective use of the technology, he had to "modularize" the contents of the course. In other words, he had to articulate more clearly periods of time throughout the semester that would be devoted to specific topics, and he had to delineate more precisely the timing and sequence of the activities around those topics. This approach he juxtaposed with his earlier attempts to teach the material from the textbook, an approach that he described more as a continuum; if he failed to cover all of the material in one lecture, at the next one, he would simply pick up where he left off. To reap the benefits of technology-enabled "quality time," however, he had to forsake that kind of flexibility in favor of a different rhythm that demanded a greater degree of self-discipline and structure.

Pollalis recognizes that adopting this rhythm has had the effect of pulling him and his students out of sync with the conventional rhythms of peripheral courses in relation to studio time. "The existing schedule is coming from the previous time, not from the web, not from the Internet time of teaching," he says. The answer, he suggests, is a reorganization of the way the semester is scheduled, an overall "modularization" not only of the contents of his course, but of the entire course sequence in ways that would allow students brief periods of intense engagement with particular subject matter. Thus, what started out as an effort to automate the cow path, as he jokingly describes his efforts to enhance his course with technology, ends up creating potential repercussions that extend far beyond the borders of the path itself.

Design GSD 2107: Quality Space

Each student at GSD has his or her own studio space for the year—typically two desks at right angles, with a computer and monitor on one and a place for drafting or building models on the other. This gives students ample private space to work on long-term projects, as well as abundant public space where they can easily share the current state of their work with fellow students, teaching assistants, and faculty.[1] Jeffrey Huang describes it:

" It's built into this building. Everybody is under one roof. Everybody sees what everybody else is doing … The way the studio works right now is, plans are on the table, then models are there, and you can look down and you can see everything that's happening. "

Such open space encourages collaboration. Those taking similar studio courses can stroll easily among their colleagues and share insights and frustrations. But such an arrangement also fosters intense competition, as students borrow from one another's work to bolster their own efforts. This balance of public and private, collaboration and competition, is vital to the intensity of the experience in studio.

The case report on *Design* details how Huang and Hirschberg set about to re-create, as they say, "a situation like this building in the digital world." They sought to create not only a separate space online analogous to the physical studio for the presentation of student work, but, most important, a virtual equivalent of the social "space" of the design studio. Thus, *Eventspaces* encouraged collaboration through membership in "neighborhoods" and the co-production of projects, at the same time it fostered competition in the "rate rounds" that required students to rank their colleagues' efforts. Moreover, just as students, consciously or not, established their identity in the physical studio through the ways they chose to outfit their space, so, too, did the activities within *Eventspaces* enable students to experiment with ways of proclaiming their online identities.

Participation in *Eventspaces* also led to practices that would not have been possible in the physical space of the studio, such as enabling students to "time-stamp" a concept, as Hirschberg puts it, and in so doing trace the evolution of that concept through its influence on others' projects. Most important to Hirschberg and Huang was offering students the experience of the emergent qualities of using new technologies—of not only co-producing assignments, but also collaborating with the instructors on defining the structure and functionality of *Eventspaces* itself, in the first part of the course, and in the latter half, developing *The Game*.

In these ways, Hirschberg and Huang wanted to move beyond the catalogue description of their course as a workshop on a fixed set of tools that support the design process in the physical studio. They pushed a more ambitious agenda—to explore what it means as an architect to, "really [use] computers in the twenty-first century." They sought no less than experimentation with emerging forms of architectural practice that established their profession's entitlement to making creative contributions to the design of this new world.

As we noted in the case report, students were often reluctant pioneers. Those we interviewed seemed to be more interested in acquiring skill with a narrow toolkit of particular types of software than in aspiring to fluency in what amounted to new forms of design practice.1 This tension in the course raises questions about what goes into the accepted toolkit of architectural education and whether an understanding of this new space is now part of the foundation of that education. While Pollalis' use of technology challenges the accepted rhythms of architectural education, Hirschberg and Huang, through their use of technology, seek to redraw the map of the territory that such an education covers.

Technology in a Professional Context

The direct consequences of the innovations we have examined here can be seen in their potential and actual effects on architectural education within the school. The innovations themselves are to a large extent manifestations of changes in the way architecture is practiced far beyond GSD's Gund Hall. All three instructors are closely attuned to the changes taking place in their field. And it is this awareness more than any other influence that has informed their use of technology. In particular, all three point to two forces reshaping architectural practice and shaping their own use of technology in the classroom, those of specialization and globalization.

The customary role of technology in the profession has been to exacerbate the distance among expert domains, a consequence of the development of increasingly sophisticated and powerful tools. This divergence of expertise has led to the need for a new kind of convergence due to the lack of a single expert who can claim mastery of all elements of design. Huang describes the demise of such a "master builder":

" Design is now distributed among many people. The engineer knows something about the structure. The manufacturers know something about the materials. The light constructor knows something about light. This knowledge needs to be coordinated for a project. In essence, the design actually emerges out of collaboration and it's not one single, potent master builder who has everything in his head and just can tell all those people what to do. "

Thus, architectural practice is more like a theatrical production, in which coordination and collaboration are integral both to the process of design as well as the realization of a finished product. Pollalis points out that one of his primary goals is to give his students the confidence and vocabulary to hold their own in just such a production. He says, "Let's say you come with a great idea and you go to the expert and the expert says, cannot be done. What we try to train our students to do, is to be able to defend their position and ask and make simple models and simple analogies to know the precedence." Thus, he takes advantage of technology in various ways to expand his students' horizons of understanding, creating conditions for technology to reveal more fully a subject matter that has eluded the students' comprehension.[1]

In a similar fashion, Huang and Hirschberg sought to counter the ways in which technology has made the design process increasingly obscure. Huang notes how the use of computers in design has led to increasingly occult knowledge, not only in the heads of experts, but also in the code of design software on the desktop. As Hirschberg describes it:

> " Before you had these large models and these large plans and you couldn't hide them from others, because they are very obviously there and people would walk around and discuss and get ideas and so forth. What is recently going on, what has changed is that people work more and more in front of the computer. … [Y]ou can actually work on your own and hide everything within that."

Through *Eventspaces*, Huang and Hirschberg sought to use technology for just the opposite purpose, giving students not only the ability to browse one another's work online, but also the opportunity to view, share, and manipulate one another's code that formed the digital basis of that work.

Design expertise is not only distributed across specialties, but it is also increasingly dispersed geographically. The two courses made explicit use of technology to bolster students' experience of the collaborative enterprise that design has become in an increasingly global world. Hirschberg and Huang developed collaborative teams along two dimensions to produce *The Game*, the final assignment in their course. They used networks to link students who shared an interest in particular kinds of software (3-D modeling, lighting and rendering, animation, and game structure), and created groups that included specialists from the first three categories to work on specific aspects of *The Game*. For his part, Pollalis formed teams that allowed students to share their expertise in the presentation and structures software used for the course. Pollalis also made use of videoconferencing to link his students at several points throughout the semester with an instructor at the University of Balboa. All these groupings represent different permutations of design teams that mirror the kinds of transnational communities of practice on which professionals have come to rely.[1]

Both courses we have examined here have developed, in microcosm, ways of transforming the practice of architectural education through the use of technology. As we have seen, the inspiration for these innovations derives in part from larger-scale changes in the nature of architectural practice as a whole. A key question remains concerning how well the kinds of local practices developed in and around these classrooms mesh with the emerging demands of the profession.[2] In the case of Pollalis' course, this question of alignment manifests itself in terms of student and faculty allocation of time. For Hirschberg and Huang, the question boils down to a matter of boundaries and how the profession integrates new domains of design practice. Both cases demonstrate the broad ramifications of the use of new technology in professional education—implications that extend well beyond a matter of tools and apply to the profession as a whole.

Conclusions

"Bricolage" is a term that one well-respected student of architectural education used to describe the process of design and design learning. The term connotes what this researcher, Donald Schön, called "a reflective conversation with the situation" and characterizes design as the successive cycles of enacting one's theory in a design, trying it out, reflecting on what happens, revising it, and trying again.[1] Bricolage seemed an apt way of capturing what we were fortunate to observe at the GSD, as three professors attempted to redesign their courses to take advantage of new technologies. In both courses, the instructors began conversations and then reflected carefully on the "back-talk" they received as their intentions met reality. Our case observations and analyses, and the cross-cutting themes we have pulled from them, serve as a partial transcript of that ongoing conversation. The dialogue to date, in our view, highlights three essential facets of the kind of bricolage we consider here, that of integrating technology in the education of architects. These facets include educational, technical, and institutional considerations. We believe these three aspects provide keystones in any attempt to improve professional education with new technologies. Within each, multiple tensions exist among competing interests. Across all, there is a need to find balance—a dynamic balance, to be sure, as we discuss below.

Educational Dimensions: Predetermined Goals vs. Emergent Possibilities

Educational philosophers have long debated the appropriate weights to assign content and process on the pans of the educational scale. The integration of new technologies provides a new kind of scale for that age-old discussion. On the one hand, instructional designers encourage a rational process of defining goals and then planning educational technologies to meet them. On the other hand, those who view learning as discovery and invention believe that learners must exercise more control and autonomy in setting the educational agenda. We side with those like John Dewey and David Hawkins who recognize the need to strike a balance between guidance and discovery achieved through cycles of bricolage that lead to clear goals while also supporting a process for the regular reconsideration of those goals.

Educators … must weigh both costs and benefits of complex yet educationally powerful technologies against those of simpler technologies that may not support their agenda as fully.

When new technologies are introduced, especially those with the potential to stimulate radical transformations in curriculum and pedagogy, the allure of tipping towards the experiential side and its emergent possibilities intensifies. Our observations of Hirschberg and Huang's *Design* course show how difficult it can be to strike an educationally sound balance between emergent goals and predetermined ones. Maintaining cycles of "dialogue with the situation" is vital to ensure that coherent goals are in view, even if they may change as that view changes. This is easier said than done amidst the powerful cross-currents of the ongoing semester. Charybdis is overwhelming chaos; Scylla, excessive rigidity.

Technical Dimension: Simplicity vs. Complexity

In designing new technologies with the aim of improving learning, a fundamental tension often exists between a tool's ease of use and its educational value. Often, the more complex the tool, the more valuable it may be, but at the same time, the more difficult it is to develop, use, support, and maintain. In situations where students are learning to use new tools, the effort they invest in this process reduces the time and attention they can invest in learning other core subject matter. The process of successive improvements of the technology through bricolage can further complicate students' learning if the technology itself is unproven or evolving. Complex technologies exact costs not only on students, but also on instructors, teaching assistants, and the institution's technical resources and support personnel. Educators who would use new technologies must weigh both costs and benefits of complex yet educationally powerful technologies against those of simpler technologies that may not support their agenda as fully.

Institutional Dimension: Stimulants vs. Irritants

Both of the cases presented here arose from individual initiatives fueled by the infusion of funds from outside GSD. New technologies are typically introduced into institutions through such grassroots efforts undertaken by the pioneers or early adopters of innovative practices. Encouraging experimentation and entrepreneurial development on the part of creative members is a good way to foster growth on the cutting edge of a field. Yet, these individually championed, externally funded initiatives can become an irritant as much as a stimulant within an institution. They can burden the core infrastructure, especially the technical facilities and the technical resources required to maintain and support them. Such pilot efforts often require more human support than anticipated, and funding typically covers hardware and software rather than personnel and professional development. Furthermore, these innovations can send ripples of unanticipated consequences throughout the institution and beyond its boundaries. They can, for example, put pressure on conventional uses of time and space, demand the reconsideration of roles, and influence the nature of work for a range of people who may not be directly involved with the innovation.

The cases described here suggest how bottom-up technological initiatives can be both a stimulant for ever-broadening innovative practices, and an irritant that disrupts and redirects the flow of resources within an institution. This suggests the need to balance the encouragement of such individual experimentation with consideration of the broader institutional framework and the ways in which a particular innovation may come to have wider effects.

The stories of two innovative courses at the Graduate School of Design reveal the complex aims, processes, and results associated with the introduction of new technologies in education. Although this analysis concentrates on the particulars of the courses and their professional and institutional context, the themes highlighted by this research would be relevant to the application of new technologies in any other course, profession, or setting. If new technologies are to realize their promise as tools for significantly enhancing professional education, their promoters must encourage careful thinking about educational agendas, technical design, and professional contexts.