Costs, Culture, and Complexity:

An Analysis of Technology Enhancements in a Large Lecture Course at UC Berkeley

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ABSTRACT

As colleges and universities nationwide anticipate enrolling more than two million new students over the next decade, UC Berkeley is exploring options for serving more students, more cost effectively, in large lecture courses. This research project analyzes economic and pedagogical questions related to the use of on-line lecture and laboratory material in a large introductory chemistry course at UC Berkeley. We undertook a quasi-experimental two-year study to determine if the utilization of on-line teaching materials results in significant restructuring of staff time in laboratories and lectures, if teaching facilities can be used by more students, and if the technology enhancements affect student performance and/or attitudes. What emerged is a rich, yet complicated, profile of the effects that technology enhancements have on the individuals and organizations involved in implementation and testing.

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BACKGROUND

Public and private colleges and universities nationwide expect to enroll more than two million new full-time students by 2010, a phenomenon referred to as Tidal Wave II. The University of California (UC) ten-campus system faces an increased enrollment of almost 63,000 full-time students—a 43% increase. The anticipated influx of new students over the next decade has prompted UC Berkeley to explore options for serving more students, more cost effectively, without increasing teaching and support staff in large lecture courses. It has been argued that the strategic use of on-line resources in large lecture classes can result in some savings and redistribution of teaching staff time, also known as a substitution of capital for labor. Determining the effectiveness of technology enhancements in higher education settings, however, is not a simple undertaking.

This Andrew W. Mellon Foundation–funded research project analyzes economic and pedagogical questions related to the use of on-line lecture and laboratory material in a large introductory chemistry course at UC Berkeley. We undertook a quasi-experimental two-year study of this course to determine if:

- the utilization of on-line teaching materials results in significant restructuring of staff time in laboratories and lectures,
- teaching facilities could be used by more students, and
- the technology enhancements affect student performance and/or attitudes.

A primary goal of this research was to place our findings within the larger context of the institution. Therefore we used a wide range of data collection techniques to track student and staff behavior, economic costs, and campus culture. What emerged is a rich, yet complicated, profile of the effects that technology enhancements have on the individuals and organizations involved in implementation and testing.

STUDY DESIGN

Chemistry 1A, the first-semester introductory chemistry course offered at UC Berkeley, has one of the largest enrollments of any course taught on campus. Approximately 2,000 students take this introductory course each year, and approximately 100 teaching and support staff are required to teach and manage the course. The technologically-enhanced version of the course is referred to as “Digital Chemistry 1A.” The technology enhancements in this course included:

- deployment of on-line quizzes and pre-laboratory assignments;
- conversion of the lecture chalkboard content to digital slides; and,
- broadcast of video lectures, with synchronized and indexed slides, over the Internet for on-demand replay.

Our research was conducted over two academic years: 2000–2001 (Year 1) and 2001–2002 (Year 2). We collected a wide range of quantitative and qualitative data on student performance and attitudes and on faculty/staff teaching and preparation activities. As a part of our cost analysis in Year 1, we conducted a controlled experiment between students who did and did not have access to selected technology enhancements. In Year 2, the Department of Chemistry decided that all technology enhancements would be made available to all students, and we were unable to replicate a similar quasi-experimental design.

Measuring Cost Effectiveness. Our goal was to compare overall course costs for the two formats of instruction in Chemistry 1A (traditional and technology-enhanced) using an activity-based costing method. We identified activities through interviews of the instructors, Teaching Assistants (TAs), and non-teaching staff who were involved with the course. We also observed lectures and labs. We measured the cost of resources *used*, which are not necessarily the same as the resources acquired by the university for the course. Activities for the course were divided into development, delivery, and revision categories.

Teaching Staff Time and Attitudes. We were interested in redistribution of staff time; therefore, we used a variety of methods to collect data on teaching staff (instructors and TAs) time and attitudes over the two-year study. These methods included interviews, student and TA surveys, time logs, observations, and focus groups.

Student Background, Performance, and Retention. We examined the impact of the technology enhancements on various aspects of student performance: student learning as measured by grades on quizzes and exams, a carry-forward experiment, and course retention rates. We also analyzed performance relative to student demographic and other background data.

Student Attitudes about the Course. We used a combination of pre- and post-surveys and focus groups to measure other possible changes in student learning, such as student access to the technology used in the course, their use of it, their opinions regarding using it, whether or not the students believe it impacted their learning, and how it affected their attitudes towards the course and learning.

Student Use of Technology. We collected usage statistics for both years of the study. Analysis of usage statistics included these on-line features: lecture webcasts, slide presentations from lecture, quizzes, lab manual, course information and homework assignments.

Other Courses. For comparative purposes, we collected and analyzed a variety of data from other chemistry and non-chemistry courses on campus. These data included randomized visual attendance scans, student evaluations, and faculty interviews.

DISCUSSION OF FINDINGS

Although the technology enhancements increased the cost of Chemistry 1A in the initial pilot year, these costs are a relatively small percentage of the total cost of the course. The technology-enhanced course in Year 1 cost $13 (1.7%) more per student than the traditional course. In Year 2, the technology-enhanced course cost $59 (7.8%) less per student than the traditional course. The investments in technology-enhanced materials (development) paid for themselves over the two course offerings (one offering each in Years 1 and 2) when savings in delivery costs are calculated in.

Development costs (website, lecture slides, on-line quizzes) would decrease in future years if instructors were to revise or reuse existing digital or multimedia products in their courses. The degree to which reuse of the technology enhancements by other faculty will occur is not clear, as the introductory chemistry course at UC Berkeley is taught on a rotating basis by tenure track faculty who are active researchers. The result is that each faculty member has a distinct philosophy, strong preferences, and considerable flexibility in how to teach the class.

Instructors spend less time doing repetitive tasks in the technology-enhanced version of Chemistry 1A. Specifically, our data show that instructors spend considerably less time preparing for class since the introduction of the lecture slides.

Instructors spend less time answering routine questions in the technology-enhanced course because students are able to find the necessary information on-line. Instructors spend approximately 50% less time answering routine questions about the course, including time spent in office hours. More than 60% of students report that they go to the website rather than teaching staff office hours to get answers to questions at least some of the time.

Teaching Assistants are relatively inexperienced teachers and spend a large amount of their time at the start of the semester negotiating the varied responsibilities of being a TA, not using technology to enhance their teaching. TA surveys indicate that that by some measures, they were more comfortable with the technologies and the benefits provided as the semester progressed (e.g., use of webcasts, perception that technologies saved time and freed up time in lab).

The TAs in the treatment group spent less time grading, and appeared to spend less time on administrative tasks both in and out of the classroom. The availability of on-line grading of quizzes reduced time spent grading, which is a task most TAs find menial. Because TA salaries and benefits are 60% of all course costs for Chemistry 1A, reducing, or at least reallocating, TA time presents opportunities for saving money, serving more students, and/or redistributing TA time to allow for richer interactions with students.

Laboratory sections could hypothetically be reduced from four hours to three to better utilize lab space. If a time reduction proves practical, Chemistry 1A could add approximately 20 lab sections per week and accommodate approximately 600 students without acquiring new space for labs. While more TAs would need to be hired to teach additional sections, no additional costs would be incurred for new facilities in this scenario. Although data show that a reduction of lab time from four to three hours is possible, it is not probable. The four-hour section seems to be the desired interval for the activities that take place in lab, which include not only the experiment but formal discussions and informal one-on-one interaction among students and TAs.

Student performance was not significantly affected by the technology enhancements in the Year 1 experiment. We have found no significant difference between students in the treatment and control groups in grades, retention, or their conceptual understanding in the following semester of chemistry.

Students find the technologies to be an exceptionally positive component of the course. A little explored topic in cost-effectiveness studies is the impact on student "costs" (i.e., what do students perceive as benefits/costs of the technology?). Our attitudinal data collected over two years suggest that students perceived the suite of enhancements as a significant contributor to their overall satisfaction with this large lecture course. web usage data, when triangulated with performance and attitudinal data in Year 2, suggest that students use the enhancements: (a) on an "as needed" basis; (b) as a significant resource in their study strategies, especially when preparing for exams; and (c) as safety nets for their individual circumstances (e.g., disabilities, English proficiency, personal schedules).

Lectures can be a positive draw for students. Our findings from Chemistry 1A and an introductory astronomy course show that excellent lectures presented by dynamic teaching staff are a huge draw for students. In Chemistry 1A, reasons for attending the lectures included interaction with other students and the instructors, the experience of live demonstrations, and improved personal discipline and concentration.

A large number of students regularly do not attend lectures. At no time was full lecture hall capacity (N=1569) approached in our attendance counts (range=762 to 1024). In Year 2, 31% of survey respondents report attending lecture less than three times per week and 25% report replacing the lecture with webcasts. Attendance data on another introductory science course, which did not use webcasts, indicate that webcasts alone are not the reason for decreased student attendance at lectures. Comparative attendance and viewing data from other courses that used on-line video lecture archives at UC Berkeley suggest that the degree to which students opt out of attending lectures may be heavily influenced by time of day and style of lecture delivery.

The availability of the on-demand replays of lectures has the potential to allow a larger number of students to be enrolled in the course. Our data indicate that most students in Chemistry 1A use the on-line lecture webcasts primarily as study aids, and the majority (>80%) would not substitute remote viewing for attending lecture. Students still report, and we observed, however, that they do not attend lecture the "required" three days per week—but rather closer to an average of two days per week.

Reduction in the number of lectures given each day from three to two (or one)—perhaps by requiring some students to attend lectures virtually—could realize appreciable savings in faculty time devoted to lecture as well as free up lecture hall space for other courses. Apparently all students attending lectures could have been accommodated in two lectures instead of the three that were allocated. Because the same lecture is given three times per day, staff and facilities costs could be saved if a proportion of students formally opted out of attending lectures.

CONCLUSION

Challenges to Conducting Robust Research

The challenges associated with executing a robust research analysis of a "fast-running" experiment of this scope are substantial. The size and complexity of the Chemistry 1A teaching and learning environment and its placement within an even larger and more complex public research university cannot be overemphasized. Implementation and evaluation of large-scale experiments of this sort require not only robust campus technology support structures, but the gathering of different types of data (costs, learning outcomes, server statistics) from disparate campus units and individuals (institutional, faculty, staff, students, etc.).

The Importance of Convenience and Choice for Students

Large lecture courses have a reputation among educators as being poor learning settings, although there are good data that suggest lectures serve many useful purposes for students and faculty. Our data show, however, that students were both exceptionally enthusiastic about the lecture component of the course and engaged with the on-line materials. Survey responses and transaction log analysis showed that the course website in general, and the lecture slides posted on the website in particular, were popular and well-received. Transaction log analysis of lecture webcasts showed clearly how and why students used this on-line resource. Attendance data indicate that, although students valued lectures, they frequently opted out of attending them.

We posit that the positive reception of the Chemistry 1A course and the associated technology enhancements is related to a number of factors, which include the fact that the enhancements were minimally disruptive to the teaching style and pedagogy of the teaching staff, they increased convenience for both students and faculty, and they were "generic" and pedagogically neutral enough that students could use them flexibly and on their own terms.

The Implications for Sharing, Reuse, and University Culture Change

Campus culture will have a significant impact on the likelihood that on-line teaching materials will be shared and reused by other faculty. Our findings suggest that some cost-savings could be realized under certain circumstances, which may or may not carry over from semester to semester at UC Berkeley or other campuses that pride themselves on having active research faculty teach introductory courses. Our knowledge of Chemistry 1A and other campus faculty behavior suggests that the successful wholesale adoption of technology enhancements from one semester to the next cannot be assumed. Replicating support mechanisms and customizing materials to one's own course require investments of time and energy by teaching staff. We should note that the experience at UC Berkeley is probably not directly comparable to institutions where non-research faculty are responsible for teaching large introductory courses. In fact, the sharing of electronic teaching materials among faculty may occur more readily in institutions where introductory course curricula are standardized and where research faculty cede course development and delivery to lecturers or adjuncts.

Given a change in campus culture and thinking, there is certainly the possibility that several UC Berkeley instructors, or even instructors on other UC campuses, might be able to share on-line lecture materials. Additionally, a rethinking of the time faculty devote to repetition of the same lectures multiple times in a week could potentially free instructors to creatively use the lecture time as a more student-interactive experience and/or reallocate space for other purposes. This rethinking seems particularly relevant given that students have independently found ways to integrate technology enhancements into their time management and study strategies.

Finally, we suspect that any large scaling benefits will come either (a) when newly hired faculty, who might be more adroit with new technologies, enter the department; (b) if the course can be "modular" so that faculty can select materials that fit their learning goals, should their learning goals differ from the developers' intentions; and/or (c) if the materials can be made available to off-site student populations at other institutions.

Costs, Culture, and Complexity: An Analysis of Technology Enhancements in a Large Lecture Course at UC Berkeley[1]

I. INTRODUCTION

Public and private colleges and universities nationwide expect to enroll more than two million new full-time students by 2010, a phenomenon referred to as Tidal Wave II (CPEC, 2000). The University of California (UC) ten-campus system faces an increased enrollment of almost 63,000 full-time students—a 43 percent increase. The University of California, Berkeley (UC Berkeley) campus is being asked to explore how to absorb an additional 4,000 students by 2010. The anticipated influx of new students over the next decade has prompted UC Berkeley to explore options for serving more students, more cost effectively, without increasing teaching and support staff in large lecture courses. As with other campuses, UC Berkeley is contemplating a range of solutions that includes offering classes during the summer, expanding regular enrollments during fall and spring semesters, and making use of technology to expand on- and off-campus learning opportunities.

It has been argued that the strategic use of online resources in large lecture classes can result in some savings and redistribution of teaching staff time, also known as a substitution of capital for labor (Massy & Zemsky, 1995; Twigg, 2003). Determining the effectiveness of technology enhancements in higher education settings, however, is not a simple undertaking (see, for example, Phipps & Merisotis, 1999, and Fisher & Nygren, 2000). This paper reports on a rigorous economic and pedagogical analysis of questions related to the use of online lecture and laboratory material in an online introductory science course, and their potential to free up teaching staff time and/or serve more students off-site. Our primary goals were to determine:

- if the utilization of online teaching materials results in significant restructuring of staff time in laboratories and lectures,
- if teaching facilities can be used by more students, and
- if the technology enhancements affect student performance and/or attitudes.

To answer these questions, we undertook a quasi-experimental two-year study (September 2000 to June 2002) of the use of technology enhancements in the teaching of Chemistry 1A. A primary goal of this study was to place our findings within the larger context of the institution. Therefore we used a wide range of data collection techniques to track student and staff behavior, economic costs, and campus culture. What emerged is a rich, yet complicated, profile of the effects that technology enhancements have on the individuals and organizations involved in implementation and testing.

[1] This work is supported by a grant from the Andrew W. Mellon Foundation's Cost Effective Uses of Technology in Teaching (CEUTT) program initiative. Additional support was provided by UC Berkeley's Center for Studies in Higher Education, the Berkeley Multimedia Research Center, the College of Chemistry, and the University of California, Berkeley.

II. BACKGROUND

A. Course Description

Chemistry 1A is one of the largest, most visible courses at UC Berkeley—nearly 2,000 students, or one half of the freshman class, enroll in Chemistry 1A each year[2] and approximately 100 teaching and support staff are required to teach and manage the course. In addition to the large number of students served and the large number of staff involved in the course, Chemistry 1A is also an important gateway to more advanced study in many disciplines. The technology enhancements in the UCB "Digital Chemistry 1A" course include:

- deployment of online quizzes and pre-laboratory assignments;
- conversion of the lecture chalkboard content to PowerPoint slides; and,
- broadcast of video lectures, with synchronized and indexed slides, over the Internet for on-demand replay.

Table 1 summarizes the course and its components. In the fall semester, one of three semesters in which the course is taught, one to two instructors (tenured faculty and/or lecturers) deliver nine lectures (three lectures per day, three days per week). These instructors are supported by approximately 50 Teaching Assistants (TAs), of whom 45–50 teach lab sections. An additional eight support staff also play an active role in implementing Chemistry 1A by assisting with lecture demonstrations, coordinating lab sections, preparing laboratory rooms for student experiments, and other miscellaneous tasks.

Table 1: Overview of the Course

Category	Year 1 Fall semester	Year 2 Fall semester	Description
Enrollment	1,258	1,202	Students enrolled after third week.
Students in Treatment Group	287	*n/a*	Students enrolled after third week.
Students in Control Group	971	*n/a*	Students enrolled after third week.
Lectures	9	9	3 different one-hour lectures presented 3 times (MWF) per week; lecture delivered 3 times per day in 523-seat lecture hall.
Lab Sections (Total)	45	42	Per week. Each section met once per week, allotting 1 hour to discussion, 3 hours to experiment; up to 12 four-hour sections were scheduled daily Mon–Fri.
Lab Sections (Treatment)	11	*n/a*	Per week. Students in these sections had access to on-line quizzes plus all other technology.
Lab Sections (Control)	34	*n/a*	Per week. Students in these sections did not have access to on-line quizzes but did have access to all other technologies.
Lab Section Meetings	14	14	Per semester per lab section. Students are required to attend 1 section per week. A total of 630 lab section meetings (45x14) took place during the Year 1 fall semester (588 meetings in Year 2)
Experiments during section	10	10	Per semester per lab section.
Exam review during section	4	4	Per semester per lab section.
Exams	4	4	Per semester. 3 two-hour midterms and 1 three-hour final exam are given each semester.
Exam Proctoring & Grading	~32 hrs	~32 hrs	Hours per semester per TA (~7–9 hours per exam)
TA Meetings	16.5 hrs	16.5 hrs	Hours per semester per TA (1.5 hours per week)
Office Hours	30 hrs	30 hrs	Hours per semester per TA (2 hours per wk)
STAFF			
Teaching Staff—Instructors	2	2	1 professor and 1 lecturer
Teaching Staff—TAs	49	45	Total TAs employed for the course @ 20 hours/week, salaried
Lab section TAs	45	42	TAs who led lab sections
Head TAs	3	2	TAs who organized curriculum, course policies
E-TA	1	1	TA who assisted with on-line technologies
Non-teaching Staff	~33	~33	
Permanent	8	8	Lab Manager, Stockroom Manager, Demonstration Expert, Webmaster, and other administrative staff
Temporary	~25	~25	Part-time staff and student employees

[2] During both Year 1 and Year 2 freshmen comprised approximately 89 percent of Chemistry 1A.

B. STUDY DESIGN

Determining the effectiveness of technology enhancements in higher education has been an elusive exercise (see for example, Phipps and Merisotis, 1999; Fisher and Nygren, 2000). The Mellon Foundation's grant allowed us to experiment with a wide range of data collection methods. Our goal was to employ as many techniques as possible to maximize our ability to triangulate findings within a highly complex organizational, cultural, and technological environment.

The study was conducted over two academic years: 2000–2001 (Year 1) and 2001–2002 (Year 2). As a part of our cost analysis in Year 1, we conducted a controlled experiment between students who did and did not have access to selected technology enhancements. In Year 2, the Department of Chemistry decided that all technology enhancements would be made available to all students, and we were unable to replicate a similar quasi-experimental design.

In Year 1, students and TAs were divided into two groups, with differing access to specific technology enhancements. The course content and requirements for each group were identical; the only difference was the medium used to accomplish certain tasks. Of the 45 scheduled lab sections, we randomly assigned students and TAs in 11 sections to the treatment group; those in the remaining 34 sections were in the control group. Of the total students enrolled in Chemistry 1A during Year 1, 23 percent of students (287) were in the treatment group and 77 percent of students (971) were in the control group. Students and TAs could not opt in or out of the two groups. The treatment group required students to perform homework quizzes and pre-laboratory assignments on-line—tasks that students in the control group conducted in labs. Table 2 summarizes the types of technology available to students in the two groups. All students had access to all technologies in Year 2.

Table 2: Student Access to Technology Enhancements, Control vs. Treatment Groups

	Year 1		**Year 2**
Technology Enhancement	**Control Group**	**Treatment Group**	**All students**
Lecture			
Lecture slides	X	X	X
Lecture Webcasts	X	X	X
Course Website	X	X	X
Lab			
On-line Bulletin Board	X	X	X
On-line Lab Manual	X	X	X
On-line Pre-lab Assignment	*n/a*	X	X
On-line Homework Quiz	*n/a*	X	X
On-line Office Hours	*n/a*	*n/a*	X

C. TECHNOLOGY ENHANCEMENTS

It is important to note that Chemistry 1A is constantly changing and evolving; technology enhancements have been introduced to the course in an incremental fashion over the span of several years. Therefore we were unable to directly observe a fully traditional or fully technology-enhanced course during Year 1. In order to draw comparisons of costs between the traditional and technology-enhanced versions of the course, it was necessary to define a hypothetical traditional course, even though we were unable to observe a fully traditional course. We did this with the aid of retrospective interviews of instructors and other staff.

Table 3 provides an overview of the technologies making up three “versions” of the course: Traditional, technology-enhanced Year 1, and technology-enhanced Year 2. We distinguished between traditional and technology-enhanced costs only during Year 1 of the study. During Year 2, the course was fully technology enhanced and did not include a control group.

Table 3: Traditional versus Technology-Enhanced Version of the Course

Traditional Hypothetical Construct	Technology-enhanced Year 1: Hybrid Experiment, Differential Access	Technology-enhanced Year 2: All students have access
Chalkboards	Digital slide presentations (PowerPoint)	Digital slide presentations (PowerPoint)
(No lecture webcasts)	Webcasts of lecture	Webcasts of lecture
In-class video projection and videotaping	In-class video projection and videotaping	In-class video projection and videotaping
Hard copies of pre-lab assignments turned in to and graded by TA.	* On-line pre-lab assignments—graded automatically	On-line pre-lab assignments—graded automatically
In-class homework quizzes—graded by TA	* On-line homework quizzes—graded automatically	On-line homework quizzes—graded automatically
(No course website)	Course website	Course website
(No on-line grades database)	On-line grades database	On-line grades database
(No course materials available on-line)	On-line course materials (course syllabus, lab manual, etc.)	On-line course materials (course syllabus, lab manual, etc.)

* Only the treatment group had access to these technologies. All other technologies were available to the entire class.

D. Study Participants

Staff (teaching and non-teaching staff) and students were invited to participate in this study by members of the research team. Though students and TAs could not opt out of the type of section in which they were enrolled (treatment or control group), we were required by the Committee for the Protection of Human Subjects (CPHS) to get student consent to collect individual data.[3] Table 4 shows the number of students completing the course who consented to participate.

Table 4: Number of Consenting Students Who Completed the Course

	Year 1				Year 2			
	Enrolled		Consented		Enrolled		Consented	
	%	N	%	N	%	N	%	N
Total number of students	100%	1,190	56%	672	100%	1,135	70%	797
Students in Treatment Group	23%	277	61%	168	*n/a*		*n/a*	
Students in Control Group	77%	913	55%	504	*n/a*		*n/a*	

[3] In Year 1, we did not collect data on minors because it was too onerous to collect parental consent forms; however, in Year 2, we were able to collect this information because CPHS waived the parental consent requirement based on the fact that most students turned 18 during the fall semester. This resulted in higher response rates in Year 2.

III. RESULTS

A. MEASURING COST EFFECTIVENESS

Our goal was to compare overall course costs for the two formats of instruction in Chemistry 1A (traditional and technology-enhanced). As recommended by Levin and McEwan (2001) and Erhmann and Milam (1999), we estimated the cost of resources used to teach Chemistry 1A using activity-based costing.[4]

To identify activities used in either the traditional or technology-enhanced version of Chemistry 1A, we interviewed instructors, TAs and non-teaching staff who were involved with the course, and we observed lectures and labs. Based on these interviews and observations, we identified 50 activities necessary for offering Chemistry 1A, which we list in Appendix A. For each activity, we collected cost data related to the staff, supplies and equipment, and facilities required to perform that activity. We collected data about both ongoing course-delivery activities and activities related to the development and revision of course materials.

We measured the cost of resources *used*, which are not necessarily the same as the resources acquired by the university for the course. For example, we find that TAs use less time for particular grading activities in the technology-enhanced version of the course. We view such a reduction in time as a reduction in the cost of resources *used* for those grading activities regardless of whether the university reduces its TA payroll or reassigns the teaching assistants to other productive tasks or does nothing with the freed up TA time.[5]

1. Data Collection

1a. Interviews

We interviewed the instructors as well as non-teaching staff who were involved in the coordination and teaching of Chemistry 1A through semi-structured one-on-one interviews. These interviewees were from several departments on campus, including the College of Chemistry, the Office of Media Services, the Berkeley Multimedia Research Center, the Instructional Technology Program, Information Systems and Technology and Student Services. We asked interviewees to identify:

- teaching and non-teaching staff activities and time spent on each activity;
- supplies and equipment (S & E) necessary for performing each activity (e.g., computers, software, chemical supplies); and
- location where each activity was performed (e.g., lecture hall, office).

During Year 1, we asked TAs to fill out weekly time logs, identifying their hours spent on in-class and out-of-class activities. We personally observed 16 and 68 randomly selected meetings of lab sessions in Years 1 and 2, respectively. In Year 2, TAs completed end-of-semester surveys reporting their time spent on typical weekly activities. We corroborated these self-reports with interviews, observations and our knowledge of TA activities.

For each of the 50 activities, we collected cost data for the following major resource types:

- "Staff" resources, meaning the salaries and benefits of instructors, TAs and non-teaching staff;
- "S & E" (supplies and equipment) resources, meaning the cost of using computer and other equipment, the cost of using software, and the cost of using supplies; and
- "Facilities" resources, meaning the cost of using such facilities as lecture halls, labs and office space.

As explained below, we measured costs using good proxies for the opportunity costs of resources used (Levin and McEwan, 2001). For example, to compute the cost of using a lecture hall, we used the cost of constructing additional lecture hall space, not the depreciation based on the historical cost of the building.

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[4] Levin and McEwan (2001) use the term "ingredients," which is essentially the same concept as activity-based costing.
[5] See Maher, Sommer, Acredolo and Matthews (2002).

1b. Staff Costs

For each staff person—instructor, TA, and non-teaching staff—we computed a cost driver rate using the following formula:

Cost driver rate = [staff person's total salary and benefits] / [total hours employed]

For example, if a TA was employed for 20 hours per week, we computed the rate as the TA's weekly salary and benefits divided by 20 hours per week.

We obtained salary and benefits information from the Chemistry Department administration, the university's published schedule of pay rates, and staff interviews.

1c. S & E Costs

We obtained cost and usage information about consumable supplies, such as chemicals used in experiments, from the Chemistry Department. We amortized the costs of assets, such as equipment and software that have a multi-year life, using the following discounted cash flow formula (Levin and McEwan, 2001, pp. 65–70):

$$e = C \times [\, r\,(1 + r)^n \,] \,/\, [\,(1 + r)^n - 1\,],$$

where

e = estimated annual cost,
C = initial cost of acquiring the asset,
r = annual discount rate, and
n = expected life of asset in years.

This formula takes into account both the annual amortization and the opportunity cost of the funds used to acquire the asset. We used a five percent discount rate, which is at the high end of the range recommended by Levin and McEwan, but appropriate based on UC Berkeley's experience in financing assets.

We used three- to five-year life estimates for software and three- to eight-year lives for equipment. We divided the annual cost by three—for the three terms in which the course is offered (fall, spring, and summer)—to derive the costs per term.

1d. Facility Costs

For the facilities that Chemistry 1A used, including lecture hall, lab space, and office space, we obtained the cost per square foot for new construction and the estimated life of facilities from the UC Berkeley Office of Planning and Analysis. These data indicated construction costs ranging from $150 per square foot for basic instructional facilities to $400 per square foot for the laboratory building, and an estimated facility life of 50 years. We measured each facility to obtain square footage data, and calculated the facility's cost by multiplying the construction cost per square foot by the number of square feet. Chemistry 1A used the lecture hall nine hours per week out of its practical capacity of 50 hours per week. Therefore, we assigned 18 percent (nine-fiftieths) of the lecture hall's facility costs to Chemistry 1A.

We amortized the cost of facilities used for Chemistry 1A using the amortization formula shown above and using the five percent discount rate discussed above.

Many of the S & E and facilities' resources were used for a single activity—lecture hall costs for the activity "delivering lectures" and chemical supplies costs for the activity "gathering chemicals for experiments," for example. For those resources used for multiple activities, such as computers and PowerPoint software, we assigned costs to activities based on interviews with instructors, TAs, and non-teaching staff.

1e. Infrastructure Costs

For the purposes of this study, we included only costs that were directly relevant to course activities. We did not include the costs of utilities and maintenance of facilities nor the salaries of campus administrators, for example. Furthermore, we included only costs to the institution, not costs to the students.

2. Results

Tables 5 through 11 show the results of our cost analysis comparing the traditional and technology-enhanced courses for Year 1, while Tables 12 and 13 compare the costs of the technology-enhanced courses in Years 1 and 2. The rows in each table show activities. We have clustered some of the 50 activities for ease of presentation. For example, we combined five activities for writing, proctoring and grading exams into one activity for presentation purposes. We show the detailed list of 50 activities and their related costs in Appendix A.

The columns in Tables 5 through 11 show the *Year 1 Traditional* course costs, the *Year 1 Technology-Enhanced* course costs and the *Savings* provided by the technology-enhanced course, while the columns in Tables 12 and 13 compare the costs of the technology-enhanced courses in Years 1 and 2.

2a. Development/Revision Costs

Development/Revision activities relate to the production or modification of course materials that will be reusable over multiple terms, such as producing the lecture slide presentations, programming computerized quiz questions, and rewriting the laboratory manual. The costs of development/revision activities, which appear in Table 5, were $68,731 higher for the technology-enhanced course, which is an incremental cost of $54.64 per student—less than the cost of a typical science textbook. These higher costs were mostly for preparing lecture graphics and overheads and designing and preparing the course website. Although not detailed in Table 5, nearly all of the additional costs were staff costs—$67,391 of the $68,731 total.

Table 5: Development/Revision Costs

Activity	Year 1 Traditional	Year 1 Technology-Enhanced	Savings*
Preparing lecture graphics and overheads	$0	$43,592	($43,592)
Creating and updating lab manual	$873	$873	$0
Revising discussion handbook	$2,108	$2,108	$0
Preparing and programming questions for on-line quizzes and assignments	$0	$3,075	($3,075)
Designing and preparing course website	$0	$22,064	($22,064)
TOTAL	**$2,981**	**$71,713**	**($68,731)**
Cost per Student (n = 1,258)	**$2.37**	**$57.01**	**($54.64)**

* traditional minus technology-enhanced

While Table 5 presents development/revision costs that created capacity to use technology for many semesters, Tables 6 through 9 present our results of the costs of delivering the course each semester.

2b. Delivery Costs—Lectures

Table 6 presents the costs of activities related to lectures, such as the cost of delivering the lecture, preparing and conducting the chemistry demonstrations in lecture, and producing the lecture webcasts. In total, the technology-enhanced course saved $40,172 (savings of $31.93 per student) compared to the traditional course. The technology-enhanced course saved instructors a substantial amount of time in preparing for lectures by eliminating the need to put materials on chalkboards before class, which saved approximately 15 hours per week. In addition, by organizing the lecture materials in PowerPoint slides, the instructors saved time in collecting materials for class, organizing materials for the lecture, and practicing their lectures. This savings in lecture preparation—$47,259 (Table 6)—more than paid for the $43,592 investment in developing lecture graphics and overheads (Table 5). This is a case where the development of technology paid for itself in the first year.

Table 6: Costs of Delivering the Course, Lectures

	Year 1 Traditional	Year 1 Technology-Enhanced	Savings*
Delivering the lecture, including demos and in-class video display	$68,561	$71,377	($2,815)
Encoding, streaming, archiving of lecture webcasts	$0	$2,837	($2,837)
Preparing for lecture (instructor)	$77,391	$30,132	$47,259
Setting up lecture browser presentation	$0	$1,435	($1,435)
TOTAL	**$145,952**	**$105,780**	**$40,172**
Cost per Student (n = 1,258)	**$116.02**	**$84.09**	**$31.93**

* traditional minus technology-enhanced

2c. Delivery Costs—Laboratories

Table 7 presents the costs of activities related to laboratory instruction, such as teaching laboratory sections and providing chemicals for laboratory experiments in addition to the implementation of structured Discussion sessions. Although these activities accounted for nearly half of the total costs of offering Chemistry 1A, we found virtually no cost difference between the traditional and technology-enhanced courses for laboratory activities.

Although the costs do not appear to be different between the two versions of the course, in fact, these cost data fail to reveal important underlying phenomena for TAs' activities. The TAs in the technology-enhanced version of the course (i.e., the treatment group) saved time in collecting and returning hard copy assignments and exams and in administering quizzes, time which they reallocated to working one-on-one with students, and to the Experiment and Discussion.

Table 7: Costs of Delivering the Course, Laboratories

	Year 1 Traditional	Year 1 Technology-Enhanced	Savings*
Supplying chemicals for experiments	$70,976	$70,976	$0
Attending TA meetings and lectures	$138,773	$138,773	$0
Teaching and administering lab sections	$123,502	$123,502	$0
Preparing for laboratory teaching (TAs)	$54,265	$54,265	$0
Recruiting, training, and monitoring teaching staff	$36,577	$33,797	$2,780
TOTAL	**$424,094**	**$421,314**	**$2,780**
Cost per Student (n = 1,258)	**$337.12**	**$334.91**	**$2.21**

* traditional minus technology-enhanced

2d. Delivery Costs—Quizzes, Exams and Grading

Table 8 presents the costs of activities related to performance assessment—quizzes, exams, and grading—which are performed outside of lecture and laboratory sections, and may cover material from either lecture or laboratory or both. The development of on-line quizzes and assignments resulted in the major savings in the technology-enhanced course. Comparing these savings to the costs of developing on-line quizzes and assignments in Table 5 plus the delivery costs of on-line quizzes and assignments in Table 8, we see that on-line quizzes and assignments provided a substantial net benefit, computed as follows:

Cost of technology enhancement—on-line quizzes and assignments:
Table 5, development costs $3,075
Table 8, delivery costs.. 5,706
Total costs of technology enhancements $8,781

Cost savings from on-line quizzes and assignments, Table 8 .... $23,063

Net benefit from on-line quizzes and assignments $14,282

Our results parallel those at the University of Wisconsin-Madison, which also reported a savings in TA time from putting homework and quizzes on-line (see for example, the Pew Grant Program in Course Redesign website).[6]

Table 8: Costs of Delivering the Course: Quizzes, Exams, and Grading

	Year 1 Traditional	Year 1 Technology-Enhanced	Savings*
Grading homework quizzes, check-in quizzes, and pre-lab exercises	$32,559	$9,496	$23,063
Grading lab write-ups	$88,633	$88,633	$0
Creating quizzes (traditional version)	$462	$0	$462
Grading (instructor)	$5,560	$5,560	$0
Setting-up/maintaining on-line assignments/quizzes	$0	$5,706	($5,706)
Writing, proctoring, and grading exams	$85,910	$84,428	$1,483
TOTAL	**$213,125**	**$193,823**	**$19,302**
Cost per Student (n = 1,258)	**$169.49**	**$154.07**	**$15.34**

* traditional minus technology-enhanced

2e. Delivery Costs—General

Some activities were not directly associated with any of the above three categories, but instead provided the basic infrastructure to support instruction in each of these areas. These general course-related activities included enrolling students, maintaining the student database, course-level planning and administration, and design and maintenance of the general course website. Table 9 shows that the cost of these activities was higher for the technology-enhanced course. Both maintaining and hosting the website and student enrollment and related activities cost more for the technology-enhanced course. These higher costs were offset somewhat by cost savings in instructor office hours for the technology-enhanced course.

Table 9: Costs of Delivering the Course, General

	Year 1 Traditional	Year 1 Technology-Enhanced	Savings*
Course-level administration and scheduling	$22,019	$22,019	$0
Office hours (instructor)	$27,465	$19,741	$7,723
Maintaining and hosting website	$0	$12,257	($12,257)
Tutoring and other out-of-class student support	$11,400	$11,400	$0
Out-of-class teaching activities	$103,542	$103,656	($114)
Student enrollment, account, and database management	$3,753	$9,493	($5,740)
Updating, editing, and publishing the syllabus	$3,074	$2,703	$371
TOTAL	**$171,252**	**$181,269**	**($10,017)**
Cost per Student (n = 1,258)	**$136.13**	**$144.09**	**($7.96)**

* traditional minus technology-enhanced

[6] Unlike the University of Wisconsin, our cost analysis was more detailed and covered the entire cost of the course, including such things as chemical supplies.

2f. Summary of All Course Costs

Table 10 presents the "bottom line" of cost comparison. Overall, the technology-enhanced course cost $16,494 more ($13.11 per student), which was less than two percent of total costs. All things considered, the technology-enhanced course's additional *development* costs of $68,731 were mostly offset by the first year savings in *delivery* costs amounting to $52,237.[7] The single largest cost savings, $47,259, came in lecture preparation, as noted earlier in this section. Note that we did not amortize development costs. It is reasonable to expect that the development costs for the Year 1 technology-enhanced course will generate savings in future year delivery costs.

Table 10: Summary of All Course Costs

	Year 1 Traditional	Year 1 Technology-Enhanced	Savings*
Development/Revision	$2,981	$71,713	($68,731)
Delivery:			
Lectures	$145,952	$105,780	$40,172
Laboratories	$424,094	$421,314	$2,780
Quizzes, Exams, and Grading	$213,125	$193,823	$19,302
General	$171,252	$181,269	($10,017)
TOTAL	**$957,405**	**$973,899**	**($16,494)**
Cost per Student (n = 1,258)	**$761.05**	**$774.16**	**($13.11)**

* traditional minus technology-enhanced

2g. Breakdown by Source of Cost

Table 11 shows that more than 90 percent of all costs are staff salaries and benefits, from which we infer that using technology to create cost savings should focus on personnel costs. In particular, if the university seeks to manage costs in the face of rising enrollments, then the university should find ways to reduce TA activities (and therefore, TA costs).

Table 11: Breakdown by Source of Cost

	Year 1 Traditional		Year 1 Technology-Enhanced		Savings*
Staff:					
Instructors	$152,940	16%	$132,065	14%	$20,875
TAs	$619,887	65%	$598,366	61%	$21,521
Non-Teaching Staff	$97,154	10%	$149,210	15%	($52,057)
Supplies & Equipment**	$48,767	5%	$54,907	6%	($6,140)
Facilities	$38,657	4%	$39,350	4%	($694)
TOTAL	**$957,405**	**100%**	**$973,899**	**100%**	**($16,494)**

* traditional minus technology-enhanced
** including computer software and hardware

For Chemistry 1A, technology enhancements required additional resources from non-teaching staff, for example to design and prepare the course website, resulting in additional non-teaching staff costs of $52,057. Note the cost savings for instructors and TAs in Table 11. Would the university reduce payments for instruction or reduce the number of TAs hired? The answer to that question is beyond the scope of this study, but the cost savings reported in Table 11 indicates freed up time for instructors and TAs.

[7] Total delivery cost savings amounted to $52,237 in Year 1 ($954,423 - $902,186; See Table 14).

2h. Comparison of Year 1 and Year 2 Development/Revision Costs

Table 12 compares the development/revision costs for the technology-enhanced course in Years 1 and 2. For this analysis, we used the same salary, benefits, and other costs of activities in Year 2 as in Year 1 to make the years as comparable as possible.

Table 12: Comparison of Year 1 and Year 2 Development/Revision Costs in Technology-Enhanced Courses

Activity	Year 1 Technology-Enhanced	Year 2 Technology-Enhanced	Cost Savings in Year 2*
Preparing lecture graphics and overheads	$43,592	$10,615	$32,977
Creating and updating lab manual	$873	$378	$495
Revising discussion handbook	$2,108	$2,193	($85)
Preparing/programming on-line quizzes/assignments	$3,075	$1,228	$1,847
Designing and preparing course website	$22,064	$9,105	12,959
TOTAL	**$71,713**	**$23,519**	**$48,194**
Cost per Student (n = 1,258 Year 1, n = 1,202 Year 2)	**$57.01**	**$19.57**	**$37.44**

* Year 1 minus Year 2

Comparing Years 1 and 2 shows a substantial decrease in development/revision costs in Year 2—$48,194, or about two-thirds of the Year 1 development/revision costs. After instructors and non-teaching staff put in the time for such technology enhancements as developing the lecture slides and designing the course website for Year 1, their time requirements were reduced in Year 2. Does Year 2 represent a steady-state level of activities? If it does, then the technology-enhanced course would likely have lower costs than the traditional course, as explored further in the next section.

Note that the two years are not perfectly comparable because of the different cost driver volumes. Year 2 had 56 fewer students and three fewer TAs than Year 1, for example. Nevertheless, these differences between years are not large enough to explain the cost differences in Table 12.

2i. Comparison of Year 1 and Year 2 Course Delivery Costs

Table 13 compares the costs of delivering the technology-enhanced course in Years 1 and 2. As we did for the development/revision costs, we used the same salary, benefits, and other costs of activities in Year 2 as in Year 1 to make the years as comparable as possible. As Table 13 shows, costs were about five percent lower in Year 2, which, considering three fewer lab sections and 56 fewer students in Year 2, implies little additional cost savings from technology enhancement in delivering the course. As noted above, the development/revision costs were substantially lower in Year 2 than in the Year 1 technology-enhanced course.

Table 13: Comparison of Year 1 and Year 2 Course Delivery Costs in Technology-Enhanced Courses

Activity	Year 1 Technology-Enhanced	Year 2 Technology-Enhanced	Cost Savings in Year 2*
Lectures	$105,780	$95,727	$10,053
Laboratories	$421,314	$411,091	$10,223
Quizzes, Exams and Grading	$193,823	$138,246	$55,577
General	$181,269	$174,834	$6,435
TOTAL	**$902,186**	**$819,898**	**$82,288**
Cost per Student (n = 1,258 Year 1, n = 1,202 Year 2)	**$717.16**	**$682.11**	**$35.05**

* Year 1 minus Year 2

Table 14 compares the total course costs in the traditional course, Year 1 of the technology-enhanced course, and Year 2 of the technology-enhanced course. Comparing the Year 2 cost per student of $701.68 to the cost per student of $761.05 for the traditional course in Year 1 reveals nearly $60 per student cost savings.

We caution the reader that there may be some problems with this comparison because of different activity levels (e.g., number of students, number of TAs). In addition, Year 2 of the study saw a reorganization of the campus technology support units and increases in the associated costs, the hiring of an additional full-time course staff person (lab manager), and the streamlining of TA grading procedures. Nevertheless, there appears to be a real cost savings in technology enhancements, even without amortizing the time spent developing them.

Table 14: Total Course Costs

	Year 1 Traditional	**Year 1 Technology-Enhanced**	**Year 2 Technology-Enhanced**	**Year 2 Savings***
Development/revision	$2,981	$71,713	$23,519	($20,538)
Delivery	$954,423	$902,186	$819,898	$134,525
TOTAL	**$957,405**	**$973,899**	**$843,417**	**$113,987**
Cost per Student (Y1, n = 1,258; Y2, n=1,202)	**$761.05**	**$774.16**	**$701.68**	**$59.37**

* Y1 traditional minus Y2 technology-enhanced

B. TEACHING STAFF TIME AND ATTITUDES

1. Data Collection

One focus of this study is the question of redistribution of staff time; therefore, we used a variety of methods to collect data on teaching staff (instructors and TAs) time and attitudes over the two-year study. These methods included interviews, student and TA surveys, time logs, observations, and focus groups. Because of the sheer numbers and expense of TAs, a large part of our data collection focused on their time, especially in labs. We were particularly interested in whether the technology enhancements changed the way TAs used time in the labs. Assessing TA time, however, was fraught with difficulty because of inconsistency in self reports of time. Therefore we relied on triangulation of many data sets (time logs, observations, surveys) as detailed below.

1a. Teaching Assistants

Table 15 summarizes participation of TAs in the research project. During Year 1, TAs completed weekly time logs and a survey at the end of the semester. We also conducted observations of randomly selected lab sections and focus groups. In Year 2, due to TA inconsistency and some resistance to time logs in the previous year, we decided to substitute direct observations as a better measure of time spent in labs, and conducted partial observations (see "Direct Observation" below) on a larger set of lab sections. It should be noted that each year of Chemistry 1A involves a new cohort of TAs, most of whom are first-year graduate students.

Table 15: TA Participation in the Research Project

	Year 1						Year 2	
	Total TAs		Control Group		Treatment Group		Total TAs	
	%	N	%	N	%	N	%	N
Total number of TAs*	**100%**	**45**	**69%**	**34**	**22%**	**11**	**100%**	**41**
Consented to general project	82%	37	79%	27	91%	10	81%	33
Responded to Pre-survey	*n/a*		*n/a*		*n/a*		81%	33
Responded to Mid-survey	*n/a*		*n/a*		*n/a*		76%	31
Responded to Post-survey	80%	36	*n/a*		*n/a*		68%	28
Participated in Brief Interviews	*n/a*		*n/a*		*n/a*		46%	19
Participated in Focus Groups	16%	8	12%	4	36%	4	*n/a*	
Turned in time logs	82%	37	79%	26	100%	11	*n/a*	
Observed in lab	8%	4	6%	2	18%	2	98%	40
	Total Lab Section Meetings		**Control Group**		**Treatment Group**		**Total Lab Section Meetings**	
	%	**N**	**%**	**N**	**%**	**N**	**%**	**N**
Total lab section meetings	**100%**	**630**	**76%**	**476**	**24%**	**154**	**100%**	**588**
Full observations	2.5%	16	1.7%	8	5.2%	8	2.0%	12
Partial observations	*n/a*		*n/a*		*n/a*		9.5%	56
Total observations	2.5%	16	1.7%	8	5.2%	8	11.6%	68

* Instructional TAs only. Each year there was also an additional e-TA and multiple Head TAs (3 in Year 1; 2 in Year 2).

TA Time Logs. During Year 1, TAs were asked to fill out time logs on a weekly basis. We provided forms for the TAs with descriptions of activities related to their weekly Chemistry 1A schedule. We investigated a subset of TA self-reports by comparing time logs from TAs in observed sections in order to check for reliability. The difference between reported and observed time in lab during Year 1 shows a nine-minute overestimation on the part of the TAs on average, which falls well within the standard deviation range (Table 16).

Table 16: Time in Lab, TA Report vs. Direct Observation, Year 1, Reported in hh:min

N	Time Logs Mean ± SD	Lab Observations Mean ± SD	Difference
14	3:30 ± 0:35	3:21 ± 0:31	0:09

Direct Observation: Full and Partial Observations. In Year 1, four lab sections (two sections in the control group and two in the experimental group) were selected for observation after students were enrolled and TAs section assignments were made. Each section was observed four times for a total of 16 full lab observations. In Year 2, three lab sections were randomly selected for four observations each during the semester for a total of 12 full lab observations. Additional lab sections in Year 2 were observed throughout the semester by a scanning process in which observers rotated throughout six lab sections during the first and last hours of the scheduled time period (i.e., either 8:00a.m. to noon, or 1:00p.m. to 5:00p.m.). A total of 68 laboratory section meetings were observed.[8]

TA Surveys. The Year 1 survey was responded to anonymously by TAs at the end of the semester. TAs in Year 2 were polled three times during the semester, with their identities recorded. The surveys included questions covering TA experience with educational technologies used in Chemistry 1A, preference for educational technologies in general, and technical/computer skills; and they also gave TAs the opportunity to offer suggestions for improving the course and course technologies.

TA Focus Groups and Interviews. In Year 1, a small number of TAs participated in focus groups conducted by the research team. We did not conduct focus groups in Year 2. In Year 2, brief *ad hoc* TA interviews were conducted at the conclusion of the partial observations.

2. Results

2a. TA Profile

Our observations, interviews, and TA surveys noted that there was a great range of variation in TA background, teaching experience and knowledge of educational technology tools.

Teaching Experience. Of the Year 2 survey respondents, 36 percent of TAs reported that they had no teaching experience. Sixty-four percent reported some teaching experience of either a semester or more. Of those TAs with teaching experience, the great majority (86%) claimed that they gained teaching experience while undergraduates.[9] Less than one-third (29%) of experienced TAs had graduate-level teaching experience. Of those TAs with teaching experience, 76 percent said they taught chemistry. Nineteen percent indicated some other science.

Technology Access and Ability. Overall, TAs reported moderate to high levels of technology access and ability. Most Year 2 survey respondents had previous experience with educational technologies such as course websites, lecture slides, on-line grades, and on-line quizzes. Fewer TAs had experience with either webcasts or on-line office hours. In short informal interviews, a large number of TAs (68%) reported using email or a homemade listserv to communicate regularly with students in their sections but only a few (10%) used the chat rooms provided.

Attitudes about Technology and Teaching. All TAs (100%) responding to the Year 1 post-survey indicated that grading and tasks related to grading were a burdensome process.[10] More than one-third (39%) of TAs specifically noted the lab write-ups as time-consuming. One quarter (25%) of TAs referred to entering grades as being an unnecessary task. TAs in the control group also reported spending more time on grading outside of class than TAs in the treatment group.

[8] For a few observations (5 of 68, 7%), observers were unable to observe the exact end-time of the Experiment or lab section meeting because it ended early. In these cases, we used the most conservative estimate, given our observation data.
[9] Most (86%, N=18) of those TAs who had experience indicated that they gained experience while they were undergraduates. It is possible that TA respondents may have perceived one-on-one tutoring experience as equitable to classroom teaching experience. Therefore, the actual number of TAs with classroom teaching experience may be lower than reported. (Note that undergraduates make up approximately 14% of Chemistry 1A TAs during fall semesters and 100% in summer courses).
[10] In Year 1, TAs were required to keep a handwritten grade book in addition to multiple digital databases. They could not upload this information into a central database; rather they had to enter all grades multiple times from a single computer. This process was simplified in Year 2 with the implementation of a centralized on-line grades database that TAs could access anytime, anywhere. Though TAs must still maintain a handwritten grade book for departmental reasons, on-line assignments are uploaded automatically.

Of note is that more than 80 percent of Year 1 TAs surveyed reported that they would be willing to migrate in-class administrative tasks (e.g., quizzes) to an on-line environment. This, then, is an area where technology could potentially improve the TA experience. In Year 2, the majority of TAs felt that technology was a timesaver as well, though their opinions improved and became more widespread as they became more familiar with Chemistry 1A technologies. For example, the overwhelming majority (90%) of Year 2 TAs reported in the pre-survey that they felt that computer-based technology was a useful resource or teaching aid. More than half (58%) of TAs cited time-savings in general as the primary reason for this opinion. As the semester progressed and TAs' experience with technology and teaching increased, their opinions of technology's role in the course also improved. By the mid-semester survey, most TAs (75%) claimed that technologies allowed them to save time in general and the vast majority (82%) agreed with this statement in the post-survey.

TA optimism about whether technology could enable them to reallocate time in the classroom increased throughout the semester. In the Year 2 post-survey, more than half (54%) of TAs believed that technologies allowed them to spend more time with students compared to only one-third (33%) of respondents in the pre-survey. Although TAs perceived the technology as useful for saving time, they apparently did not perceive it as a rationale for shortening labs.

TA opinions about the utility of technology to improve student learning also changed. In the pre-survey, 27 percent of TAs indicated that they believed that on-line activities improved the student learning experience compared to 18 percent of TAs in the post-survey. This perception mirrors that of students who see technology in the classroom as a useful tool for time management rather than a replacement for the in-person learning experience.

2b. TA Time in Lab Section Meetings

<u>Partitioning of Time in Labs</u>

Table 17 shows the breakdown of scheduled time in lab section. Administrative responsibilities, such as administering the homework quizzes and collecting or returning pre-laboratory assignments or exams, were expected to take about 15 minutes and were scheduled at the beginning of the lab section for the control group. In the treatment group, where some of the work was transferred on-line, TAs were not required to administer a homework quiz or to collect or return pre-laboratory assignments because students completed them on-line. As a result, TAs in the treatment group often did not use this time for administrative purposes and instead began with the required Discussion.

Table 17. Scheduled Time in Lab Sections, Year 1, Reported in hh:min

Section Type	Homework Quiz	Administration	Discussion	Experiment
Control Group	0:05	0:10	0:45	3:00
Treatment Group		Partial	0:45	3:00

Self reports and observations indicate that actual time spent in lab section meetings varied by week, TA, and individual student. Overall, TAs spent as much time in lab section meetings as necessary to meet students' needs. Observations in Year 1 revealed that TAs in treatment groups often reallocated saved time in the classroom to spend more time on activities related to student learning (e.g., treatment group TAs spent more time working with students individually, and more time on the Experiment and Discussion). TAs in the treatment group also reported spending less time on grading activities, which appears to be related to students' on-line quiz-taking patterns. Observations indicate that the ability to manage time effectively varied greatly among individual TAs, which can most likely be attributed to experience, individual dispositions, and personal time-pressures. It is worth noting that student survey data indicate that students in the treatment groups were less likely to feel "rushed" in labs. Details of the two-year analysis are presented below.

Self Reports of Overall TA Time, Year 1 and Year 2

In the first year of the study, TAs reported in time logs that they spent an average of 18 hours each week in activities related to Chemistry 1A. TAs in the control group spent an average of 18 hours and 23 minutes per week compared to TAs in the treatment group, who spent an average of 17 hours and 13 minutes per week in activities related to their duties (Table 18).

TAs in Year 2 reported spending an average of 18 hours and 43 minutes per week on activities related to teaching Chemistry 1A (Table 18). TAs in Year 2 were only asked to report time on task once at the end of the semester whereas their Year 1 counterparts reported weekly in time logs.

Table 18: TA Weekly Time, Self-Reported in hh:min, Mean ± SD

	Year 1 TA Time Logs			**Year 2 TA Survey**
	All N=467 N=31/wk average	**Control Group** N=347 N=23/wk average	**Treatment Group** N=120 N=8/wk average	**All** N=28
Required *lecture, office hours, TA meeting*	5:39 ± 1:29	5:43 ± 1:24	5:28 ± 1:42	6:19 ± 1:24
Lab Section	3:28 ± 1:16	3:30 ± 1:18	3:22 ± 1:13	4:12 ± 0:48
Grading *includes exam proctoring*	5:37 ± 4:36	5:45 ± 4:43	5:11 ± 4:14	4:20 ± 2:04
Preparation	2:04 ± 1:40	2:02 ± 1:44	2:08 ± 1:29	2:04 ± 1:30
Miscellaneous	1:16 ± 2:28	1:21 ± 2:49	1:01 ± 0:54	1:41 ± 1:16
Total time spent on Chemistry 1A	18:05 ± 6:09	18:23 ± 6:22	17:13 ± 5:27	18:43 ± 4:47

Time logs from TAs in the treatment group also suggest a savings of time in three areas outside of lab: grading (34 minutes on average), required activities[11] (15 minutes on average), and miscellaneous activities (20 minutes on average). TAs in the treatment group, however, reported spending more time preparing for lab section meetings (16 minutes) and conducting the experiment (7 minutes). In weeks when there were homework quizzes implemented in the control group, TAs in the treatment group were observed spending more time assisting students in conducting the experiments.

Year 1 TA Time: Observations, Control vs. Treatment Groups

Observed Time in Labs, Year 1. Table 19 summarizes the results of the data we collected on the time TAs spent in lab section meetings. Year 1 observations revealed that TAs and students in the treatment group appeared to spend slightly more time on the Discussion and Experiment (four minutes on average per activity) than those in the control group. In summary, observations and surveys indicate that TAs spent less time on administrative tasks in the classroom, such as administering quizzes, in Year 1 as a result of the technology.

[11] TAs are required to attend three lectures and the TA meeting, and conduct office hours each week. As requirements were not different for the TAs in either group, we suspect that this timesavings is an anomaly due to the specific group of TAs sampled.

Table 19: Year 1 and Year 2 TA Time, Observed, Reported in hh:min

	Year 1 Full Observations						Year 2 Full and Partial Observations	
	All Lab Sections		Control Group		Treatment Group		All Lab Sections	
	Mean ± SD	N	Mean ± SD	N	Mean ± SD	N	Mean ± SD*	N
Total TA Time in Lab	3:12 ± 0:38	16	3:13 ± 0:30	8	3:12 ± 0:47	8	3:32 ± 0:34	68
Total Class Time[1]	2:44 ± 0:39	16	2:43 ± 0:37	8	2:45 ± 0:43	8	2:37 ± 0:42	43
Classroom Activities:								
Homework Quiz[2]	0:15 ± 0:03	4	0:15 ± 0:03	4	*n/a*		*n/a*	
Discussion[2]	0:46 ± 0:12	12	0:44 ± 0:16	6	0:48 ± 0:08	6	0:48 ± 0:16	23
Experiment [2†]	1:38 ± 0:25	16	1:36 ± 0:18	8	1:40 ± 0:33	8	2:15 ± 0:46	63
TA Behaviors:								
Administration	0:15 ± 0:07	8	0:21 ± 0:05	4	0:09 ± 0:04	4	*n/a*	
TA instructional time	0:58 ± 0:38	16	1:02 ± 0:41	8	0:54 ± 0:33	8	*n/a*	
One-on-one student interaction	1:22 ± 0:41	16	1:09 ± 0:20	8	1:36 ± 0:53	8	*n/a*	

* Most conservative estimate.
[1] In Year 1, Class Time is calculated as the time from TA arrival to the time the last student completed experiment whereas in Year 2, it is calculated as the time from the first official class activity to the time the last student completed the experiment.
[2] Individual activities in the lab section meeting do not necessarily represent a breakdown of "class time" for either students or TAs because of additional time spent in other types of activities.
[†] SD in experiment time shows difference between experiments more than difference between TAs.

In addition to recording duration of class time devoted to the Discussion and Experiment, we were also able to observe the quality and duration of interactions among TAs and students in Year 1. These observations revealed that TAs in control and treatment groups allocated time differently in the classroom. TAs in the treatment group spent more time in class interacting one-on-one with students. In fact, they appeared to spend more than half of the lab section meeting (50%, 1 hour and 36 minutes on average) working individually with students while TAs in the control group spent only slightly more than one-third of their time (36%, 1 hour and 9 minutes on average) in similar activities.

Observations in Year 1 also showed that TAs in the treatment group saved an average of 20 minutes in instructional and administrative time. The savings came from less time spent: lecturing or at the chalkboard, conducting the check-in question or the homework quiz, and performing other administrative functions.

Year 2 TA Time: Observations

Based on Year 1 lab observations, we concluded that labs could be shortened from four to three hours (with some changes to the curriculum, such as limiting the unpopular Discussion). The Department agreed to explore the idea of a shorter lab section meeting in Year 2 for all lab sections. This was accomplished with a minimum of disruption by keeping the four-hour time slot, but designating the first hour as optional for students. Interim surveys administered three weeks into the semester during Year 2 indicate that approximately half of TAs felt time constraints with a three-hour lab section meeting. Some TAs reported that the reduced time limit for lab section meetings negatively affected their ability to answer questions and explain concepts to students. As a result, course staff gave TAs the option to allocate time at their own discretion and many TAs opted to return to the scheduled four-hour time.

Our Year 2 observations of 68 lab section meetings, however, indicate that most lab section meetings were under four hours, with many taking less than three hours (Table 19). Depending on the assigned Experiment for that day, the total time spent in necessary class activities ranged anywhere from 32 minutes to three hours and 51 minutes. The Experiment made up the bulk of the lab period.

2c. Year 1 Student Time: Self Reports

To expand on our observations of TA time in labs, we collected survey data on student time both in and out of lab section meetings in Year 1. A complete description of the student surveys can be found in Section D (Student Attitudes About the Course).

Overall Student Time

According to self-reported data collected in the on-line post-survey, students in Year 1 reported spending an average of 14.8 hours per week on activities related to Chemistry 1A overall. Students reported spending an average 7.3 hours per week in activities related to lecture. There were only slight differences between control and treatment groups for the mean values. Students reported in the on-line post-survey in Year 1 that they spent an average of 7.6 hours per week on activities related to lab. There was no real difference between control and treatment group self reports regarding the total number of hours spent on activities related to lab.

Student Time in Labs

Respondents to the Year 1 on-line post-survey generally felt that there was enough class time during their lab sections to ask questions about lecture (58% responding "most of the time" or "always"). Of those respondents, students in control group (57% responding "most of the time" or "always") were somewhat less likely to feel this way than were students in treatment group (60% responding "most of the time" or "always").

Although most (59%) of the on-line post-survey respondents said that they "never" felt that there was insufficient time during their lab section to complete the experiment, 41 percent did state that at least "some of time" there was not enough time to complete their experiment. This difference becomes more apparent when viewed by section type: many more students in the control group (50%) said that at least "some of the time" they had problems completing in-section tasks than did students in the treatment group (22%). This difference is statistically significant (χ^2= 14.8, p = 0.0001).

In looking at student time observed in labs in both control and treatment groups in Year 1, it appears that students enrolled in sections in the treatment group did not spend as much time on administrative tasks. On average, administrative tasks occupied 21 minutes of class time in control group sections and only 9 minutes of class time in treatment groups. However, during these observed weeks, students in the treatment group spent approximately the same amount of time in section as students in the control group, indicating that students and TAs reallocate time from administrative duties to other activities.

2d. Instructor Time

Staff Interviews. Section A (Measuring Cost Effectiveness) reports on much of the data we collected regarding teaching and non-teaching staff time. The relevant findings related to instructor time in particular are summarized here. A total of nineteen interviews with teaching and non-teaching staff were recorded and transcribed. Interviews were conducted with faculty and staff from the College of Chemistry as well as from campus units involved in technology support and implementation. We also interviewed others associated with the College of Chemistry, such as the dean and instructors of Chemistry 1A during other semesters.

Instructor Time and Attitudes

Before discussing results, it must be noted that the introductory chemistry course at UC Berkeley is taught by tenure-track faculty who are active researchers. This is in contrast to many Research One and other institutions where a dedicated teaching staff of lecturers or adjuncts has the primary responsibility for teaching large introductory courses. At UC Berkeley, each faculty member has a distinct philosophy, strong preferences, and considerable flexibility in how to teach the class.

The lead instructor for Chemistry 1A estimated an overall time-savings of 53 percent per week due to technology enhancements to the course in Year 2 as compared to the traditional version of the course. Rather than spend less time on the course overall, the instructor reported that he spends the saved time on other activities related to improving instruction and course development.

In particular, our data show that the lead instructor spends considerably less time (35%) preparing for the technology-enhanced class as a result of the lecture slides. The bulk of these savings can be attributed to the eliminated need for extensive chalkboard preparation prior to lectures. (Although the lead instructor saved considerable time on chalkboard preparation, three times as much time was spent in Year 1 by the second instructor and an additional student assistant on the initial development of the digital lecture slides.) While some time is still spent in Year 2 on revising and preparing lecture slides, much less time is spent (87% less overall) in Year 2 than in Year 1. Savings were also noted by both instructors in lecture preparation and organization. Both instructors noted that time spent consulting about revisions to each lecture's total scope and sequence was facilitated by the electronic format of the slides. Collective time spent on these preparatory activities was reduced by an additional 10 percent.

The lead instructor spent less time answering routine student questions about course administration in office hours or by email. He reported that student contact time was reduced by more than half in the technology-enhanced course, which is an additional weekly time-savings of six percent. Student survey responses confirm this. We found that 69 percent of Year 1 students and 62 percent of Year 2 students stated that they have used e-mail to ask questions of instructors instead of going to office hours in person either always, most, or some of the time. Additionally, thirteen and eight percent, in Year 1 and 2 respectively, reported that they consulted webcasts instead of seeking assistance from a TA or Instructor.

Information provided by other chemistry instructors suggested that the distribution of development and delivery time varies from instructor to instructor because of personal teaching styles and philosophies. The role of educational technology in particular is not viewed in a uniform way by either instructors or by administrators. For example, sophisticated electronic chemistry modules developed some years ago by another faculty member in the department are not used by many other chemistry instructors. Additionally, some of the on-line resources (quizzes) that are the subject of this report were adopted in a subsequent semester of Chemistry 1A, but were abandoned the second year because of significant implementation problems and lack of support staff necessary to ensure success. So far, the lecture slides have not been adopted by other instructors. We should note that administrators were generally unaware of the ways in which technologies might be used to reconfigure space and time. Instead, most view technology as having the potential to improve course pedagogy (e.g., tutorials, simulations, data sets); issues of cost-savings and/or increasing convenience for faculty or students are rarely mentioned as reasons for investing in educational technology.

C. Student Background, Performance, and Retention

1. Data Collection

1a. Background Information

In both years, demographic data, such as age, gender, race/ethnicity, and socioeconomic status, as well as descriptive measures from college and high school, such as GPA, units completed, college major, and SAT scores, were collected from individual consenting students' university records. Additionally, the same aggregate data were collected for all students who completed the course. Table 20 provides a profile of students taking the course.

Table 20: Summary of Student Demographics and Background Data, Year 1 and Year 2

		Year 1 (N=1,331*)		Year 2 (N=1,135**)	
		Frequency (%)	**Mean ± SD**	**Frequency (%)**	**Mean ± SD**
Demographic Measures					
Gender:	Male	591 (44%)		506 (45%)	
	Female	740 (56%)		623 (55%)	
Ethnicity:	White	363 (27%)		295 (26%)	
	Black	36 (3%)		19 (2%)	
	Hispanic	83 (6%)		81 (7%)	
	Asian/Pacific islander	687 (52%)		605 (54%)	
	Other	25 (2%)		20 (2%)	
Age			18.5 ± 1.6		18.8 ± 0.63
First Learned Language:	English only	593 (45%)		476 (42%)	
	Another language only	322 (25%)		269 (24%)	
	English & another language	398 (30%)		379 (34%)	
Socioeconomic status					
Father's education:	No high school	77 (6%)		66 (6%)	
	Some high school	45 (4%)		35 (3%)	
	High school grad	103 (8%)		92 (9%)	
	Some college	115 (9%)		92 (9%)	
	2-year college grad	43 (3%)		43 (4%)	
	4-year college grad	312 (25%)		283 (27%)	
	Post-grad	538 (44%)		448 (42%)	
Mother's education:	No high school	104 (8%)		83 (8%)	
	Some high school	40 (3%)		37 (3%)	
	High school grad	159 (13%)		130 (12%)	
	Some college	155 (12%)		110 (10%)	
	2-year college grad	96 (8%)		84 (8%)	
	4-year college grad	406 (32%)		369 (34%)	
	Post-grad	307 (24%)		266 (25%)	
Parental income			\$81,748 ± \$82,412		\$90,024 ± \$83,202
Educational Background					
SAT I :	Verbal score		638 ± 90		632 ± 91
	Math score		686 ± 79		686 ± 78
	Total score		1324 ± 145		1318 ± 147
SAT II (Achievement Test)			2002 ± 224		2006 ± 226
High school GPA			4.26 ± 0.33		4.27 ± 0.28
First semester of college		1,114 (87%)		966 (86%)	

* Year 1: includes students enrolled in the course at any point during the semester.
** Year 2: includes students who completed the course.

1b. Student Performance

We examined the impact of the technology enhancements on three aspects of student performance and attitudes: 1) student learning as measured by exam performance and a carry-forward experiment, 2) course retention rates, and 3) student attitudes regarding the course. The discussion below covers student learning and retention in the Year 1 control and treatment groups. A similar comparison was not possible in Year 2. Student attitudes in Year 1 and Year 2 are reported in Section D (Student Attitudes About the Course). We also looked at the relationship among certain types of on-line behavior, performance, and attitudes in both years. Those results are in Section E (Student Use of Technology Enhancements).

Students' Grades and Coursework. Course grades were determined by a number of measures, including final exam, mid-term, and final course grades. We measured student performance through scores on course exams (midterms and finals), and other coursework. All students completed the same lab assignments and took the same exams.

Carry-Forward. In addition to the direct comparisons described above, during Year 1 we worked with faculty in the succeeding course ("Chemical Structure and Reactivity") to measure student understanding of core concepts from both classes. This method, a "carry-forward" experiment (Seymour, 1999), can help identify how the on-line tools help students learn and retain knowledge. Data collection for the carry-forward experiment started in the fall semester of Year 1 with the follow up data collected in the spring semester of that same academic year. A total of 272 students completed the subsequent chemistry course and consented to release their course information.

1c. Course Retention Data

Data regarding course completion were collected at the end of the semester and compared across the control and treatment groups. Detailed information on course enrollment transactions was collected from the University Registrar for all students in Chemistry 1A. Because most students continue to adjust their class schedules during the first three weeks of the semester, we defined the enrollment baseline as the end of the third week.

2. Results

2a. Year 1, Student Performance

<u>Exam Scores</u>

We measured student performance in Year 1 by examining total course points earned out of 1,000 possible points. We looked specifically at the final exam scores (350 points possible) as the best measure of student performance. We chose this option because final exam scores have a large impact on the final grade, they focus on specific learning outcomes, and they are reflective of a consistent and standardized grading process.[12]

Of the 1,190 students who completed the course in Year 1, 672 (56%) consented to provide access to their course grades. No significant differences were found among treatment and control groups (Table 21), and we can assume that different experiences among the two groups had no effect on their performance in the course.

Table 21. Comparison of Control and Treatment Groups by Final Exam Points (max = 350), Year 1 Mean ± SD

	All (N=671)*	Treatment Group (N=168)	Control Group (N=503)*	Effect size
Year 1 fall semester	236.5 ± 51.8	234.2 ± 53.4	237.3 ± 51.2	–0.059

*Missing value = 1

[12] TAs scored exams as a group under the supervision of course instructors, and each TA was responsible for a specific question for all students. Other measures, such as overall course grades, included multiple, uncontrolled variables, such as lab grades (which were inconsistent across lab sections because TAs grading practices varied significantly among TAs).

Carry-Forward

We were interested to know if specific learning outcomes differed among students in the control and treatment groups in Chemistry 1A, and if any difference persisted in the following semester (when there was no differentiation between the groups). Two outcomes were identified by instructors as important to a student's success in the follow-up course: 1) Student demonstrates knowledge of the fundamentals of how molecules interact, and 2) Student demonstrates ability to apply the concept of equilibrium by describing how acids and bases interact to form stable/unstable molecules.

Instructors also identified corresponding final exam questions from both Chemistry 1A and the subsequent course that addressed these learning outcomes. We compared student scores on exam questions to determine if there were any differences in conceptual understanding between the control and treatment groups. In order to identify possible differences between groups within each course and over time, we looked at the individual and combined scores of selected exam questions corresponding to identified learning outcomes (Table 22).

These findings suggest that, for the two identified learning outcomes, the different experiences of students in the control and treatment groups did not have a significant impact on the students' learning in Chemistry 1A. In the following semester of Chemistry, while results for individual questions varied, the overall means of the two groups indicate that students who had been in the Chemistry 1A treatment group performed slightly better, although the total effect size was still only 26 percent.

Table 22: Comparison of treatment and control groups, by selected final exam question scores corresponding to learning outcomes

Mean ± SD

Course	Learning Outcome	Question	Possible Points	All (N = 272)	Treatment Group (N = 66)	Control Group (N = 206)	Effect size
Chemistry 1A	1	1	13	10.6 ± 2.7	10.2 ± 2.8	10.7 ± 2.7	–0.18
		2	5	4.0 ± 2.0	3.9 ± 2.1	4.0 ± 2.0	–0.02
		3	5	4.0 ± 2.0	3.9 ± 2.1	4.0 ± 2.0	–0.02
	2	4	5	2.6 ± 2.5	2.5 ± 2.5	2.6 ± 2.5	–0.03
		5	5	2.0 ± 2.5	2.2 ± 2.5	1.9 ± 2.4	0.10
		6	5	2.6 ± 2.5	3.1 ± 2.4	2.5 ± 2.5	0.27
	Combined	**Total**	**33**	**21.7 ± 6.4**	**22.0 ±6.4**	**21.7 ± 6.4**	**0.05**
Subsequent Course	1	1	2	1.9 ± 0.5	1.8 ± 0.6	1.9 ± 0.5	–0.13
		2	2	1.3 ± 0.9	1.4 ± 0.9	1.3 ± 0.9	0.05
		3	2	1.1 ± 1.0	1.2 ± 1.0	1.1 ± 1.0	0.11
	2	4	2	1.0 ± 1.0	1.1 ± 1.0	0.9 ± 1.0	0.19
		5	2	0.9 ± 0.6	1.0 ± 0.6	0.9 ± 0.6	0.06
		6	3	0.6 ± 1.2	0.9 ± 1.4	0.5 ± 1.1	0.28
	Combined	**Total**	**13**	**6.8 ±2.6**	**7.3 ± 2.7**	**6.6 ± 2.6**	**0.26**

2b. Student Retention

Table 23 summarizes retention data. Retention rates between Year 1 and Year 2 did not differ significantly. Additionally, there was no significant difference in completion rates between students in the control and treatment groups in Year 1. Of students in the control group, 94 percent completed the course; in the treatment group, 97 percent completed the course.

Table 23: Course Retention Rates for Chemistry 1A, fall semesters only

	Year 1			Year 2
	All Students	**Control Group**	**Treatment Group**	**All Students**
Number of students enrolled on Day 1	1,215	*n/a*	*n/a*	1,116
Number of students enrolled after Week 3	1,258	971	287	1,202
Number of students who completed the course	1,190	913	277	1,135
Percentage of students who completed the course	94.6%	94.0%	96.5%	94.4%

D. Student Attitudes About the Course

1. Data Collection

To measure other possible changes in student learning, we examined the issues associated with learning that are not outcomes oriented (Erhmann, 1998). These issues included student access to the technology used in the course, their use of it, their opinions regarding using it, whether or not the students believe it impacted their learning, and how it affected their attitudes towards the course and learning. These issues were examined by using a combination of pre- and post-surveys and focus groups.

Student Surveys. Table 24 summarizes the number of students responding to the surveys. Surveys addressed students' perceptions of technology enhancements in the course. The on-line surveys also provided the opportunity for students to report about time spent on activities related to lecture and lab as well as some time spent on-line. All surveys included both close-ended and open-ended questions; responses to open-ended questions were later categorized and coded.

Table 24: Chemistry 1A Student Survey Response Rates

	Year 1		Year 2	
	%	N	%	N
On-line pre-survey*	16%	198	*n/a*	
In-class post-survey**	76%	904	*n/a*	
On-line post-survey** †	20%	243	57%	643

*Total number of students enrolled at the time the pre-survey was administered in Year 1=1,258
**Total number of students enrolled at the time the post-surveys were administered in Year 1=1,190
† Total number of students enrolled at the time the post-surveys were administered in Year 2 =1,135

Course Evaluations. We examined departmental course evaluations from Chemistry 1A over the two years of the study and the previous year. We also examined departmental course evaluations from another popular large lecture course, Introduction to General Astronomy, whose instructor frequently over-enrolls the course and encourages students to watch lecture webcasts instead of attending class. These data provide us with some measure of comparison in student opinion regarding alternative uses of technology in large lecture courses.

Student Focus Groups. A small number of focus groups in Year 1 were conducted for formative purposes, but had low student participation (N=13).

2. Results

2a. Year 1, Student Perceptions of Technology Enhancements

Students provided feedback about the technology enhancements in Chemistry 1A including the on-line quizzes and assignments, in-class lecture slides, lecture webcasts, and the course website. A selection of student responses from Year 1 are presented in Table 25. Findings for Year 1 and Year 2 are differentiated. A summary of select student responses to the various surveys can be found in Appendix C.

<u>Year 1, On-line Quizzes & Assignments—Control vs. Treatment Groups</u>

Students in the treatment group had the opportunity to take each quiz three times[13] and keep their highest score. These students received immediate feedback on each attempt, including their score for each question. There were some differences between the opinions of students in the treatment group (who had experience with on-line quizzes) and students in the control group (who did not) regarding doing activities on-line. According to the on-line post survey, students in the treatment group were pleased with their experience of taking quizzes and turning in pre-laboratory assignments on-line, and found these activities beneficial to learning chemistry. The majority of the students in the treatment group felt that completing assignments and quizzes on-line helped them

[13] Each quiz attempt randomly generated a new set of questions.

perform the tasks required in lab (70%) and made their lab time more productive (79%). Most (85%) also said that completing quizzes and assignments multiple times helped them learn Chemistry 1A concepts (Table 25).

Responses from the Year 1 on-line post-survey also suggest that students generally liked the idea of doing more on-line work regardless of whether they were in the control or treatment group (Table 25). Most of the students (71%) would be willing to do more work on-line in order to spend less time in lab, with students in the treatment group (75%) more in favor than students in the control group (69%). A majority of students (70%) also said that they would be willing to do all of their homework on-line. Students in the treatment group (90%), who already had experience with completing quizzes and assignments on-line, were much more enthusiastic (significantly so with $\chi^2 = 18.0$, $p < 0.0001$) about this prospect than were students in the control group (61%), who did not have the same experience. Students in the treatment group (87%) were also significantly ($\chi^2 = 19.6$, $p < 0.0001$) more in favor of recommending courses with on-line assignments and quizzes than students in the control group (56%).

The in-class post-survey, when compared to the aggregated responses in the on-line post-survey, showed a slightly higher positive response to these questions. Eighty-two percent of students responded that they would be willing to do more activities on-line and 75 percent indicated that they would be willing to do homework quizzes and pre-lab assignments on-line.

Table 25: Student Attitudes about Chemistry 1A Technology Enhancements
"Yes" Responses from Selected Year 1 On-line Post-Survey Questions

	All (N=218)		Treatment Group (N=67)		Control Group (N=151)		
	%	N	%	N	%	N	
"Would you be willing to do more activities on-line (e.g., quizzes, homework, discussion) so that you could spend fewer hours in the lab?"	71%	154	75%	50	69%	104	χ^2= 0.74, p= 0.39
"If you had the choice, would you complete your homework quizzes and pre-lab assignments exclusively on-line?"	70%	152	90%	60	61%	92	χ^2= 18.0, p= <0.0001*
"I would recommend that other students take courses like Chemistry 1A that use…on-line quizzes or assignments."	65%	142	87%	58	56%	84	χ^2= 19.6, p= <0.0001*
"Did completing the pre-lab assignments and homework quizzes on-line help you perform the tasks required in lab?"**			70%	47			
"Did taking quizzes or pre-lab assignments multiple times help you learn concepts about Chemistry 1A?"**			85%	56			
"Do you think your time spent in lab was productive because you took the quizzes or pre-lab assignments on-line?"**			79%	53			

* Statistically significant at the 99% confidence level
** Questions specifically related to on-line quizzes and assignments were asked only of students in treatment groups

Lecture Webcasts, Year 1 and Year 2

We were particularly interested in student use of lecture webcasts and their relationship, if any, to attendance patterns and study habits. We report the survey results here. Detailed webcast usage statistics are reported in Section E (Student Use of Technology).

In Year 1, students indicated through comments in the in-class post-survey that they watched the lecture webcasts because of the convenience and the ability to rewind and pause the lecture (e.g., "I can always rewind to listen to explanations if I didn't understand the first time."). In Year 2, as in Year 1, the majority of students who watched lecture webcasts did so after missing a lecture. The second most popular reason was to study and review materials prior to exams. Only about one-quarter of students who responded to the on-line surveys in both years chose to watch lecture webcasts instead of attending the lecture in person. Table 26 shows the distribution of responses.

Table 26: Reasons Students Watch Lecture Webcasts
Comparison of Responses to On-line Post-Surveys, by Year

	Year 1			Year 2
	All (N=232)	Control Group (N=164)	Treatment Group (N=68)	All (N=643)
After missing a lecture	66%	65%	69%	72%
To study and review material prior to exams	63%	65%	56%	41%
In addition to reviewing notes/handouts	*n/a*	*n/a*	*n/a*	31%
Instead of attending live lecture	27%	27%	25%	26%
Instead of reviewing notes/handouts	10%	10%	10%	*n/a*
Instead of seeking assistance from a TA or professor	13%	15%	6%	8%
To prepare for lab	4%	3%	6%	*n/a*
After attending a live lecture	15%	16%	12%	*n/a*
Other	7%	7%	7%	5%

Year 1 students who completed the on-line post-survey found the lecture webcasts useful, but preferred to attend lecture in person. Only a few students (12%) said that they would be willing to watch the lectures exclusively on-line; a majority (59%) indicated that they would never want that type of a class. Of the 904 students who responded to the same question on the in-class post-survey, more than 80 percent said they would not want that type of class. In Year 2, 86 percent of students reported they would not want to entirely watch lectures on-line instead of going to class.

When students whose first language was not English (approximately 22% of the enrolled students) were asked about the utility of the on-line lectures, a large number (93%) responded that on-line resources were useful for a variety of reasons, such as the option to review difficult parts of the lecture on-line.

2b. Year 1 and Year 2, Student Perceptions of the Course, Technology Enhancements, and Lectures

It is an article of faith among educators and students alike that the large lecture format is not the best learning environment for students (e.g., Boyer Commission, 1999), although there are good data that suggest lectures serve many useful purposes for students and faculty (e.g., McKeachie, 1999). We were interested in learning: 1) whether students have negative attitudes about the lecture experience, and 2) if the technology enhancements were correlated with positive perceptions students might have about the course.

Student Perceptions of the Course. We first looked at the College of Chemistry's course evaluation data. Students rate the course and the instructor on a scale from one to seven, with seven as the highest ranking. These data show that students' ratings of Chemistry 1A in Year 1 and Year 2 were similar to the ratings given by students in the year prior to the beginning of the study, and consistently higher than the overall averages for lower-division courses within the Department (Table 27).

Table 27: Student Course Evaluation Ratings for Chemistry 1A, by Year (fall semesters only)

	Previous Year	Year 1	Year 2
Overall Course Rating, Chemistry 1A	5.81	5.63	5.61
Average Rating for Lower Division Courses in the Department	5.17	5.17	5.09
Total Responses to Course Evaluations	1,137	1,215	1,159

***Student Perceptions of the Technology Enhancements*.** Chemistry 1A students also responded very positively to the technical enhancements in our surveys and focus groups. One focus group participant commented, "I think I speak for a lot of people when I say that we're glad we have this resource available to us." Year 1 focus group discussions and survey comments revealed additional student perceptions of technology enhancements. One recurring theme was a reduction in student stress due to the availability of on-line resources. One student commented, "It took away a lot of the anxiety I had about the class, like if I would miss anything." Another agreed, "It's kind of like this little safety net."

In Year 2 we had a significant increase in the proportion of students responding to surveys.[14] When Year 2 students (N=643 responses) were asked whether their experience with the technologies offered in Chemistry 1A affected their overall satisfaction with the course, 87 percent said "yes." Of the 473 students that chose to explain their answer, 98 percent made positive comments about the technologies. Of those respondents with positive comments (N=467), 27 percent thought that the use of technology increased the availability and access to resources and helped them prepare for class. Nineteen percent felt that the implementation of the technologies improved the course. Another nineteen percent indicated that the technologies promoted learning and understanding of the course material. The remaining 32 percent (N=157) found the technologies generally helpful, useful, or convenient.

As noted above, the majority of Year 1 student survey respondents would recommend that other students take a course that used technologies such as those offered in Chemistry 1A. Year 2 students were also asked if they would recommend that their peers take a course like Chemistry 1A that used various technologies such as the course website, lecture slides, on-line quizzes and pre-labs, lecture webcasts, and on-line office hours. A large majority (range 67–94% for all technologies except on-line office hours and lecture browser[15]) said that they would recommend technology enhancements (Table 25). One hundred and seven students responded with detailed comments to this question. Of these, thirty-six percent commented that the technology was helpful and useful. Twenty-one percent either found that the use of technology in the course was an improvement or found that it increased their access to the resources in the course. Sixteen percent reported that the technology was convenient and accommodated their schedules more easily. Ten percent had general positive comments about the course and considered the technology a good supplement to their educational experience.

Student Perceptions of the Lecture Experience. Overall, Year 1 and Year 2 students expressed the opinion that lecture webcasts were a valuable resource, but they considered webcasts most useful as a supplement to in-person lectures, rather than a substitute. Positive comments about the in-person lecture experience centered in three areas: interactivity (e.g., "easier to ask questions and talk to other students in the classroom."); chemistry demonstrations (e.g., "I like to feel the heat from the demonstrations rather than feeling the heat from my monitor."); and students' personal discipline and concentration (e.g., "I concentrate better in lecture halls than my room"). The importance of interactivity of the in-person lectures may reflect the instructor's uniquely engaging lecture style, and the use of the "ChemQuiz,"[16] a pedagogical technique for encouraging content-based peer-to-peer interaction. Table 28 outlines the details of student preferences.

Table 28: Students' Reasons for Attending Lecture in Person
Year 2 Survey Comments, Coded (N=577)

Student Comments	Frequency %	N
Going to the lecture fosters personal discipline and concentration	33%	192
The live lecture is interactive and facilitates conversations with other students	23%	135
Attending lecture aids comprehension and learning	15%	85
Prefer viewing the demonstrations in-person at lecture	9%	52
Prefer attending lecture in person (no reason given)	15%	77

[14] High survey response rates in Year 2 can be attributed to a number of factors: the inclusion of minors in the study design, increased incentives for participation in surveys, or the fact that all students were required to complete weekly assignments and quizzes on-line (and therefore, had more opportunity to complete the survey).
[15] The BMRC Lecture Browser was not offered in Year 2, although archived lectures from Year 1 were available but not advertised.
[16] The "ChemQuiz" is an adaptation of a technique known as "Peer Instruction," pioneered by Professor Eric Mazur, Department of Physics, Harvard University. Mazur's technique is a method for teaching large lecture classes interactively.

E. Student Use of Technology

1. Data Collection

Website User Logs. We collected usage statistics for both years of the study. During Year 1 and Year 2, transaction logs were automatically generated by servers handling on-line materials in the following areas: on-line quiz taking patterns, general web page usage, and lecture webcast viewing.[17] In Year 1, we examined anonymous website usage for the most frequently used files. In Year 2, we were able to track the identity of each student along with other access statistics, and therefore have more detailed data on website usage because of authentication and a larger number of student consents.[18] We performed a transaction-log analysis for the following on-line materials:

- Lecture webcasts, available live or as on-demand replays
- On-line versions of slide presentations from lecture
- On-line quizzes
- On-line lab manual
- Exam preparation materials, such as sample exams and exam solutions
- Homework solutions
- Communication tools, such as a bulletin board and chat tool
- Course information, including the course lecture, laboratory, and exam schedule; homework assignments and due dates; grading rubrics; office hour times and locations; and contact information for instructors and TAs

In analyzing website usage data, we selected two different metrics: the number of page hits (successful requests for non-image files) and the number of sessions ("a series of page requests by a visitor without 30 consecutive minutes of inactivity"). Because we authenticated all website users by requiring a login name and password in Year 2, our definition of sessions is even more robust than the industry standard.[19]

Lecture Webcasts. We examined the number of webcast views and the total time viewed by looking at transaction logs for the lecture webcasts. For comparison, we also collected statistics on general webcast usage patterns for other large lecture courses at UC Berkeley.

Student Attendance. In an effort to better understand and compare patterns in student attendance for courses in which lecture webcasts were offered, we sampled the number of students present in the lecture hall, Pimentel Auditorium, for three courses in Year 2: Chemistry 1A (fall and spring semesters) and Introductory Physics (spring semester). See Table 29. While both chemistry courses offered lecture webcasts, the physics course did not.

Table 29: Attendance Sampling by Course

Course	Year 2 Term	Days lectures offered	Days attendance taken	Percent sampled	Students enrolled*	Webcasts
Chemistry 1A	Fall	41	11	27%	1,202	Yes
Chemistry 1A	Spring	41	12	29%	506	Yes
Introductory Physics	Spring	41	12	29%	171	No

* Enrollment calculated at the end of the third week of classes.

[17] Due to a server logging error, for a three-week period during the middle of the Year 1 fall semester, the time of webcast views was not logged. For these missing data points, we imputed a value of time viewed based on the number of bytes transferred (which was successfully logged) and the average bytes-to-viewing-time ratio for other views from that IP address.
[18] We limited our analysis to students who completed the course, eliminating usage data from course staff and instructors, and from students who subsequently dropped the course.
[19] The Internet Ad Bureau (1997), which defines the industry standard for web usage measurement, suggests several different metrics.

2. Results

Unless otherwise noted, we will report general website usage patterns for Year 2. (A detailed analysis of transaction logs, student background, student performance, and student attitudes is the subject of another paper.) Details of webcast statistics, and their relationship to other measures, are reported at the end of this section.

2a. Website Usage Patterns

Year 1 General Website Usage

In Year 1, when the website was accessible to the general public, the main course website received 690,916 page hits for the semester—an average of 581 page hits per student. The bulk of the overall website usage was by UC Berkeley users; more than 85 percent of page requests originated from users in the berkeley.edu domain. Seventy-eight percent of requests came from computers in the campus residence halls. Because so much of the traffic originated on-campus, and in the residence halls in particular, it is reasonable to assume that a vast majority of the website usage resulted from students enrolled in the course.

Year 2 General Website Usage

Students who completed the course showed a higher level of website use than in Year 1 for both required (e.g., weekly quizzes and assignments) and optional portions of the website. Table 30 shows the level of usage per week of different resources on the website. Table 31 further breaks down usage to show the distribution of number of sessions for each type of resource. It is interesting to note that some resources (such as exam materials) were used relatively uniformly by many students, while the usage of other materials (such as lecture slides) varied much more between students.

Table 30: Summary of Year 2 Web Usage by Type of Resource (N=1,135 students who completed the course)

	Page hits per student	**Sessions per week, per student**	**Percentage of students who used the resource at least once per week** (>15 sessions per semester)
Total website	**2,745.52**	**8.65**	**100.0%**
Course information	292.71	6.38	99.9%
Quizzes	701.15	2.16	98.0%
Lecture slides	795.53	1.33	49.7%
Exam materials	142.92	1.32	61.9%
Lab manual	68.83	1.08	43.7%
Communication tools *(bulletin board, chat)*	73.62	0.78	18.3%
Homework solutions	36.89	0.49	16.0%
	Views per student	**Average length of each view** (hh:mm:ss)	**Percentage of students who viewed webcasts at least once per week**
Lecture Webcasts	13.02	00:22:28	25.37%

Table 31: Summary of Year 2 Website Usage, Total number of sessions for each type of resource (N=797 students who consented and completed the course)

	0 Sessions	1–5 Sessions	6–10 Sessions	11–15 Sessions	16–20 Sessions	21–25 Sessions	25+ Sessions
Total website	**0 (0%)**	**0 (0%)**	**0 (0%)**	**0 (0%)**	**0 (0%)**	**0 (0%)**	**797 (100%)**
Course information	0 (0%)	0 (0%)	0 (0%)	0 (0%)	1 (0.1%)	6 (0.8%)	790 (99.1%)
Quizzes	0 (0%)	0 (0%)	3 (0.4%)	8 (1.0%)	29 (3.6%)	106 (13.3%)	651 (81.7%)
Lecture slides	3 (0.4%)	150 (18.8%)	121 (15.2%)	93 (11.7%)	98 (12.3%)	69 (8.7%)	263 (33.0%)
Exam materials	0 (0%)	19 (2.4%)	95 (11.9%)	153 (19.2%)	156 (19.6%)	126 (15.8%)	248 (31.1%)
Lab manual	0 (0%)	54 (6.8%)	175 (22.0%)	195 24.5(%)	131 (16.4%)	88 (11.0%)	154 (19.3%)
Communication tools[1]	31 (3.9%)	387 (48.6%)	153 (19.2%)	48 (6.0%)	38 (4.8%)	34 (4.3%)	106 (13.3%)
Homework solutions	113 (14.2%)	282 (35.4%)	157 (19.7%)	104 (13.0%)	77 (9.7%)	39 (4.9%)	25 (31%)
Webcasts[2]	25 (3.1%)	350 (43.9%)	117 (14.7%)	97 (12.2%)	49 (6.1%)	33 (4.1%)	126 (15.8%)

[1] bulletin board, chat
[2] number of views

Website usage over time. Website usage varied a great deal at different points in time. Figure 1 shows usage of different on-line resources, except lecture webcasts,[20] over time in Year 2. Lecture webcast usage is displayed in Figure 2. Overall, the most noticeable pattern is a weekly cycle, with the heaviest use on Sundays and Mondays, and little to no use on Fridays and Saturdays. In addition, total usage peaks near the dates of midterm and final exams.

Different on-line resources have different patterns of use. Usage of lecture slides, exam materials, webcasts and course information are closely related to the exam schedule. Usage of communication tools, lab manual, and homework solutions, on the other hand, hold relatively constant throughout the semester. Usage of on-line quizzes follows a weekly cycle, with peaks just before the Monday deadline for homework quizzes and no connection to the exam schedule.

2b. General Lecture Webcast Usage

In Year 1, seven percent of requests for videos were for live lectures, and the remainder (93%) were for archived videos. Each Chemistry 1A lecture webcast was viewed approximately 0.355 times per enrolled student. Duration of each play was short. Over 60 percent of replays lasted less than ten minutes, and only ten percent of replays lasted for the entire lecture. Webcast usage peaked during the 4th, 8th, 12th, and 16th weeks of the semester, corresponding exactly to the course's midterm and final exams. In general, students accessed the archive beginning around 10:00 a.m. in the morning, building to a peak around noon. Usage continued heavy throughout the afternoon and evening with a short drop around dinnertime. Usage continued until 2:00 a.m. when it fell off rapidly until it picked up again later that morning.

In Year 2, five percent of requests for videos were for live lectures; each Chemistry 1A lecture webcast was viewed approximately 0.317 times per enrolled student, and each Chemistry 1A student viewed an average of 7 hours and 26 minutes of webcasts during the semester.[21] Most webcast views were short; for Chemistry 1A, 43 percent of all views were shorter than 10 minutes. Only 20 percent of views were 50 minutes or longer (the length of an entire lecture). Similar to Year 1 data and student survey comments, these observations of webcast usage suggest that students in general are not using webcasts to view entire lectures, but instead are using them on an "as-needed" basis, to review or study specific segments of the lecture. Figure 2 shows that in Year 2, webcast usage peaks in weeks 4, 8, 12, and 16—immediately prior to each of the four exams. This pattern clearly indicates that students use webcasts, along with lecture slides and exam materials, primarily to study and review for exams.

[20] Webcast statistics were in a different metric.
[21] Webcast usage for Year 2 was lower than Year 1. This may have been related to the fact that the BMRC Lecture Browser was not implemented.

Figure 1: Website Usage Over Time
(Chemistry 1A, Year 2)

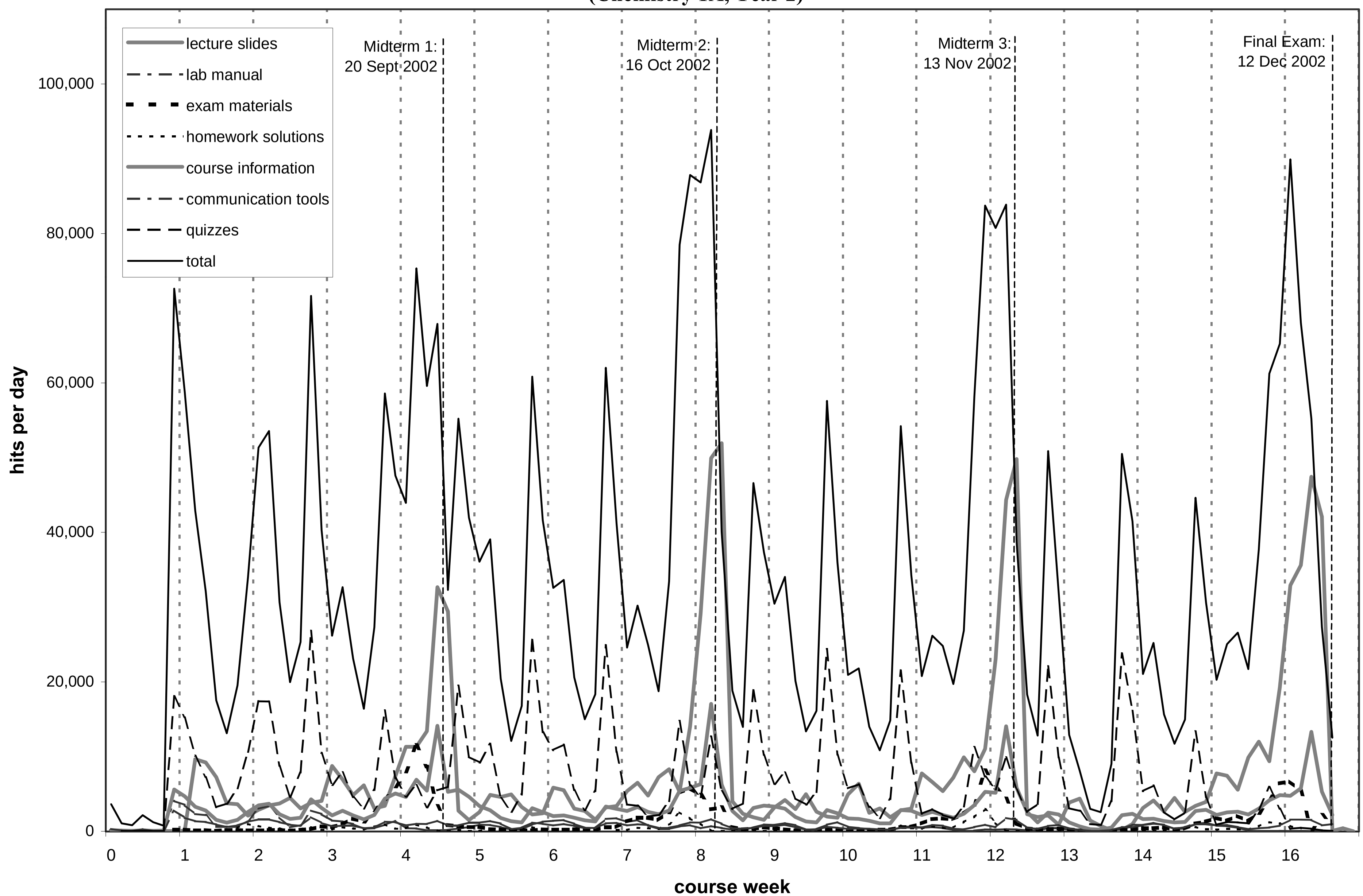
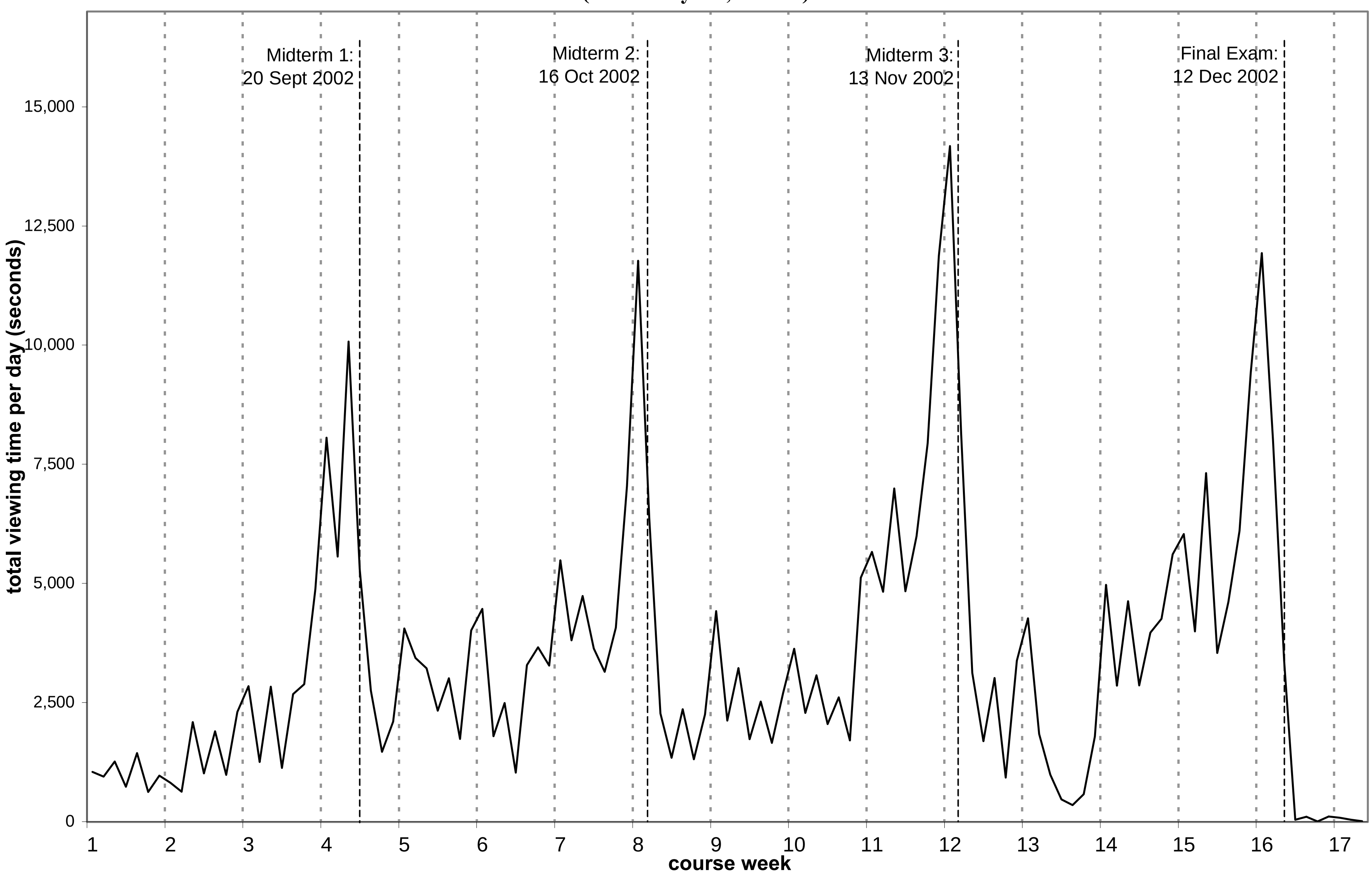


Figure 2: Webcast Viewing over Time (Chemistry 1A, Year 2)

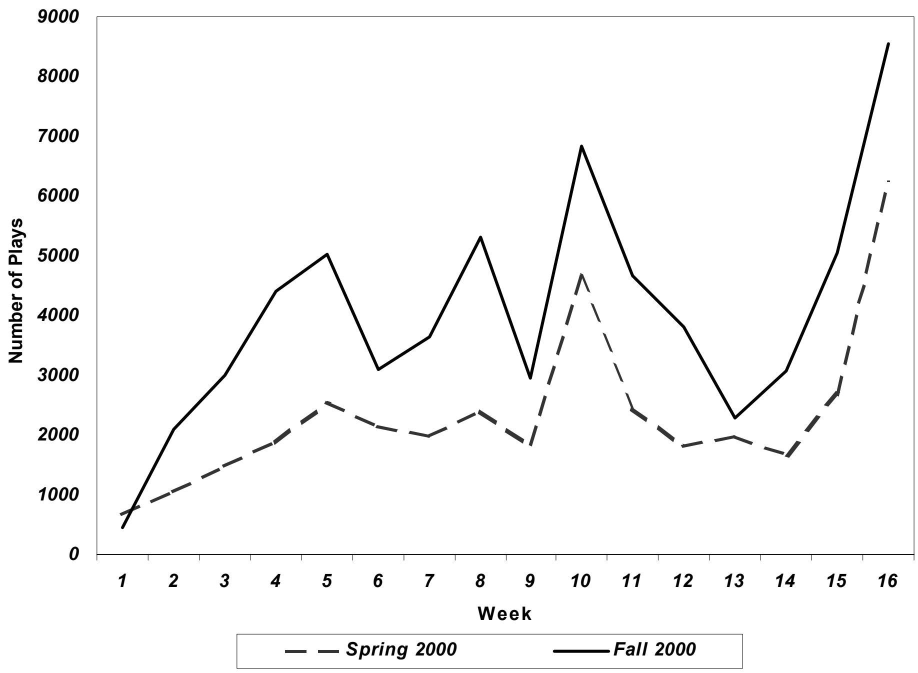


Lecture Webcast Usage: Chemistry 1A Compared to Other Courses

Year 1. Our data support the observation that students use webcasts primarily for on-demand study, rather than replacing attendance during live lectures. These observations paralleled trends in other courses using the lecture webcast service in the Year 1 fall semester (N=21) and spring semester of the previous year (N=13).

Figure 3 shows the number of plays of all webcast lectures each week during Year 1 at UC Berkeley. A class with two midterms typically schedules them during weeks five and ten, and a class with one midterm typically schedules it between weeks eight and eleven. Week sixteen corresponds to the final examination period on campus (Rowe et. al., 2001).

Figure 3: Plays Per Week of all UC Berkeley's Webcasted Courses, Year 1

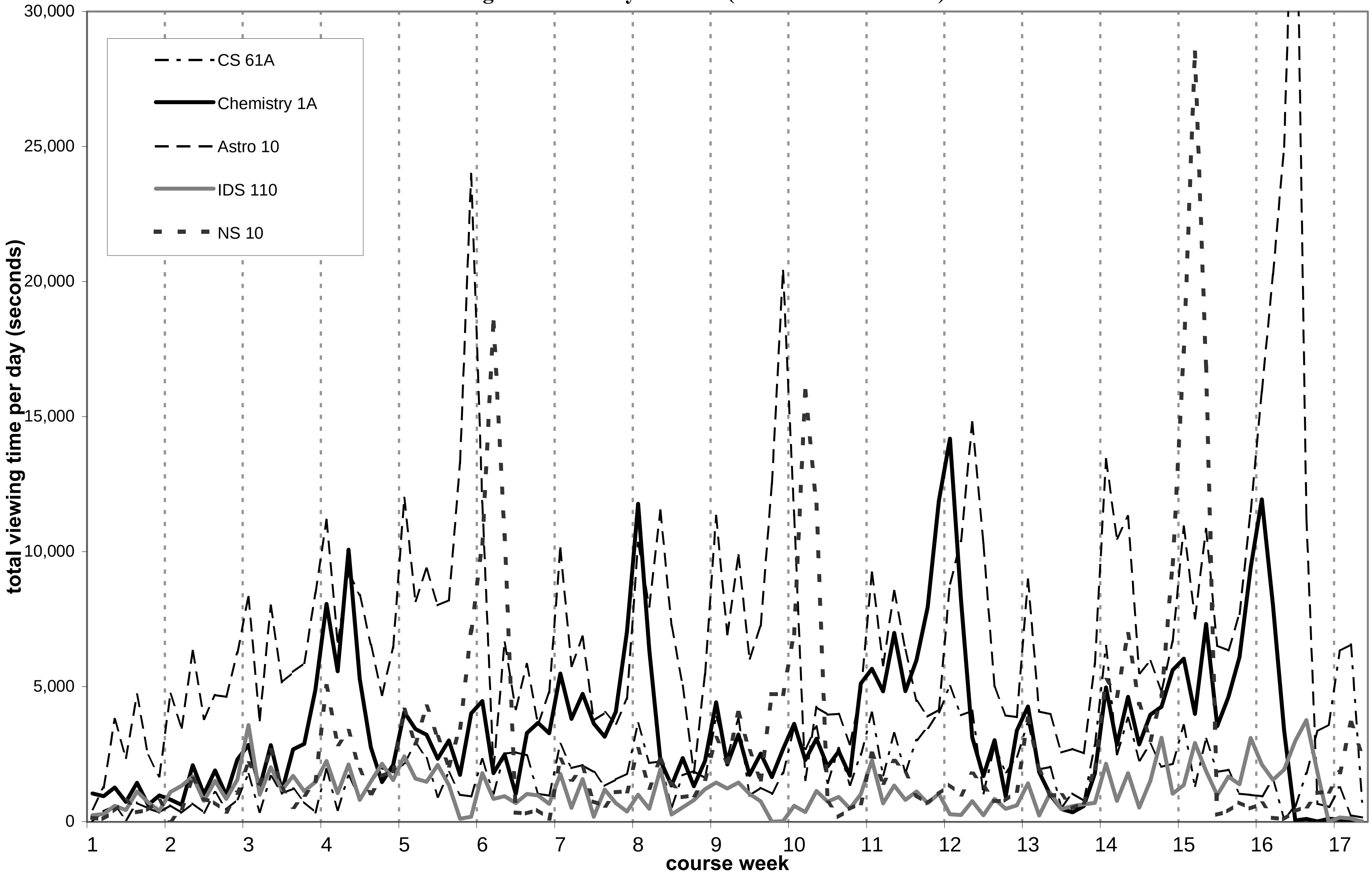


Year 2. In comparison to webcast viewing in other large introductory lecture courses in both the fall and spring semesters of Year 2, students taking Chemistry 1A had a slightly lower lecture webcast usage per student than some other courses (Table 32). It is interesting to note the large variation in webcast usage levels between different courses. It is also interesting that usage in some courses is more closely related to exam schedules than in other courses (Figure 4). Because webcasts are available to the general public and are accessed anonymously, it is difficult to know whether these differences are due to enrolled students or to non-student access.

Table 32: Lecture Webcast Viewing, Large Lecture Courses, Year 2

Course	Year 2 Term	Enrollment	# of lectures	Total # of views	% of live views	# student views per lecture	Viewing time per student
Introduction to General Chemistry (Chem 1A)	**Fall**	**1135**	**41**	**14,734**	**4.8%**	**.317**	**7:26**
Introduction to Computer Programming (CS 61A)	Fall	414	42	9,039	3.6%	.520	11:57
Introduction to General Astronomy (Astro 10)	Fall	990	40	25,736	3.3%	.650	18:19
Introduction to Computers (IDS 110)	Fall	426	37	5,487	11.1%	.348	6:12
Introduction to Human Nutrition (NS 10)	Fall	670	24	10,693	3.6%	.665	9:50
General Biology (Bio 1B)	Spring	467	42	33,249	1.4%	1.695	31:03
Introduction to General Chemistry (Chem 1A)	Spring	506	41	8,070	2.8%	.389	10:16
Introduction to Computer Programming (CS 61A)	Spring	311	44	10,295	8.1%	.752	21:40
Introduction to Computers (IDS 110)	Spring	388	36	14,931	2.9%	1.069	8:11
Introduction to Human Nutrition (NS 10)	Spring	695	44	19,750	1.7%	.646	14:25

Figure 4: Webcast Viewing over Time
Large Introductory Courses (Year 2 Fall Semester)



Viewing over time. The most notable trend for the majority of the courses we examined is spikes in lecture webcast viewing immediately preceding exams (Figure 4). For many courses, viewing jumped to three- to four-times the typical daily usage in the days immediately preceding exams. Viewing then dipped to almost zero in one to three days following the exam. This post-exam dip is noticeable even in courses without a pre-exam spike. The strong correlation with exam schedules reinforces our interpretation that students use the webcasts primarily as a tool for studying and review, rather than as a regular substitute for in-person lecture attendance.

Pre-exam spikes, and webcast viewing in general, tended to increase over the course of the semester (in spite of the fact that course enrollment tends to erode slightly, as students drop the course over the course of the semester). Since most of the students in these courses are first-year students at the university, or at least new to the subject matter of the course, these trends may mean that students are adjusting to their first year of college and learning how to use the technology resources available.[22] As the semester progresses, more students may become comfortable with the webcast technology or find it a useful tool for their own study habits.

2c. Lecture Webcast Viewing and Attendance

There has been some consternation on campus that the presence of lecture webcasts results in decreased in-person classroom attendance. Although the majority (>80%) of students in Chemistry 1A reported that they would not substitute remote viewing for attending lecture in person, but prefer to use webcasts as a study aid, other data suggest that students are opting out of attending all three lectures per week. Thirty-one percent of students report in the Year 2 on-line post-survey (N=243) that they attend lecture less than three times per week and 25 percent stated that they replace the lecture with webcasts.

In Year 2 we conducted student attendance counts for a random sample of lectures in the fall and spring semesters. Attendance at the sampled lectures in the fall semester ranged between 90 percent (near the beginning of the semester) to 68 percent (near the end). In the spring semester, attendance at Chemistry 1A lectures ranged from 82 percent to 60 percent.[23] In comparison, student attendance at lectures for a section of Introductory Physics in the spring semester showed a similar trend (Table 33), but a much larger drop-off in attendance. For this course, where webcasts were not used, attendance was high in the first half of the semester but dropped steadily, from approximately 90 percent of enrolled students attending lecture in the fourth week of the semester to approximately 60 percent attending by the seventh week. In the second half of the spring semester, however, student attendance dropped dramatically, averaging about 45 percent of enrolled attending lectures in the last few weeks of the semester.

Table 33: In-person Attendance at Lectures, Comparison Across Courses, Year 2

Chemistry 1A, fall semester (Enrollment = 1,202)				**Chemistry 1A, spring semester** (Enrollment = 506)				**Introductory Physics, spring semester** (Enrollment = 171)			
Week	**Lecture**	**Attendance**	**%**	**Week**	**Lecture**	**Attendance**	**%**	**Week**	**Lecture**	**Attendance**	**%**
3	7	1,024	85%	6	13	426	82%	6	13	157	92%
3	8	930	77%	6	14	393	78%	6	14	138	81%
4	Mid-term 1			6	15	370	73%	6	15	123	72%
7	19	913	76%	8	Mid-term 1			7	Mid-term 1		
7	20	894	74%	9	21	367	73%	9	21	116	68%
8	21	949	79%	9	22	322	64%	9	22	100	58%
8	Mid-term 2			9	23	249	49%	9	23	61	36%
9	24	875	73%	11	27	339	67%	11	27	101	59%
11	31	813	68%	11	28	365	72%	11	28	79	46%
11	32	762	63%	12	Mid-term 2			12	Mid-term 2		
12	Mid-term 3			12	30	365	72%	13	34	74	43%
14	36	769	64%	14	35	332	66%	14	35	76	44%
14	37	794	66%	14	36	335	66%	14	36	77	45%
15	39	800	67%	14	37	312	62%	14	38	77	45%

[22] The on-campus Student Learning Center, which works with approximately 35 percent of Chemistry students in the fall course, reported that since the implementation of the technology enhanced course, students often ask how they can develop strategies for navigating all of the on-line resources available.

[23] With the exception of March 22, 2002—the day before Spring Break—which had approximately 50 percent attendance.

The similarity in attendance patterns between the two chemistry courses, where webcasts were available, and the physics course, where webcasts were not available, suggests that the drop in attendance throughout the semester is not an unusual phenomenon. Anecdotal reports from other courses also support this conclusion. The steep attendance drop-off in the physics course—steeper than in the two chemistry courses with webcasts—indicates that student absences are the result of a more complicated interaction of factors than simply the existence of webcasts, such as time of day and style of lecture.

Finally, it should be noted that in the fall semester of Year 2, the total lecture hall seating capacity for Chemistry 1A was 1569 (3 lectures/day x 523 seats). In fact, at no time was that capacity approached in our attendance counts (N=11 counts; range=762 to 1024). Apparently all students attending lectures could have been accommodated in two lectures instead of the three that were allocated.

<u>The relationship between webcast viewing and lecture attendance</u>

For the two courses for which lecture webcasts and attendance counts were available (the fall and spring semesters of Chemistry 1A in Year 2), we performed a correlation analysis to determine if there was any relationship between attendance at a specific lecture and viewing of that lecture's webcast. For the fall semester course, lower attendance for a lecture was correlated with greater webcast viewing of that lecture, although this correlation was not quite statistically significant ($R = -0.58$, $p = 0.060$). For the spring course, there was no significant correlation between lecture webcast viewing and attendance ($R = 0.15$, $p = 0.65$). This suggests that students are not using webcast viewing as a substitute for in-person attendance in a consistent, large-scale way. In both cases, the date of the lecture relative to exam schedules was a much stronger predictor of attendance, with a steady decrease in attendance observed throughout the semester.

It should be noted that an exceptionally popular course on campus, Introduction to General Astronomy, over-enrolls by approximately 90 percent of the seat capacity in Pimentel Auditorium. The instructor allows all interested students to enroll, and encourages them to substitute lecture webcast viewing for in-person attendance. A review of departmental course evaluations for this course indicates that the overall ratings for the course and the instructor are remarkably high, and very few students complain about the lack of seating capacity. Transaction log analysis indicates that this course gets an exceptionally high level of lecture webcast viewing (see for example, Figure 4 and Table 32).

2d. Web site and webcast usage in relation to student performance and attitudes

In Year 1 and Year 2, we had the opportunity to further investigate the relationship between usage of on-line resources and both observed and reported student behaviors such as grades and attitudes about study habits.

<u>Student Lecture Webcast Viewing and Performance, Year 1</u>

Although we were unable to track actual webcast viewing of individuals in Year 1, we were able to identify self-reported webcast viewing, individual attitudes, and student performance for a group of students. As reported above, Year 1 students reported their use of on-line lecture webcasts on the on-line post-survey (N=243). Of these students, 147 also consented to provide access to their course grades. We performed simple regression analyses to model the effect of webcast viewing and reasons for viewing on students' course grades. Overall, self-reported webcast usage was related to lower course grades (although this relationship was not statistically significant). Students' reasons for using on-line webcasts showed a weak relationship with student grades in this sample. Students who reported using lecture webcasts as a replacement for the in-person lecture had lower scores in the course overall. Since webcast users were a self-selected group, students who used webcasts as a replacement for in-person lecture attendance may simply have had poor study habits. Table 34 illustrates our regression analysis of how student webcast usage and reasons for usage (according to self-reports on Year 1 survey) affected their overall course grades.

Table 34: Students' Reasons for Watching Lecture Webcasts, Year 1 On-line Post-survey Responses (N=243)

	Mean ± SD	**Correlation to overall course grade***
Frequency of webcast usage (self report)	1.2 ± 0.8 views per week	β= –25.7, R^2=0.02 per view per week
	Frequency % (N)	**Correlation to overall course grade***
To study and review material prior to exams	76% (N=136)	β= –20.7, R^2=0.007
To prepare for lab	5% (N=9)	β= –41.3, R^2=0.008
Instead of going to lecture (live)	33% (N=59)	β= –55.5, R^2=0.06**
After missing lecture (archived)	79% (N=146)	β= –46.7, R^2=0.03**
After attending live lecture	18% (N=31)	β= 22.0, R^2=0.006
Instead of reviewing notes/handouts	12% (N=21)	β= 31.2, R^2=0.01
Instead of seeking assistance from TA or professor	15% (N=26)	β= –31.9, R^2=0.01

* a negative β indicates that the factor contributes to a reduced point total
** statistically significant at p = 0.05

Student Lecture Webcast Viewing, Website Usage, Background, and Performance, Year 2

In Year 2, the high participation rate of consenting students allowed us to analyze variables that might link use of on-line resources, performance, and background. We collected an immense amount of data on student web usage, not all of which is reported here. In brief, a multiple regression analysis found that four background variables are significantly related to performance: females score lower than males in the course, and higher SAT I math scores, SAT II scores, and high school GPAs are associated with higher course grades. No other background variables were statistically significant. We also found that usage of the course website was significantly related to higher course grades. Webcast viewing, on the other hand, had no significant effect on course grades. Students' *reasons* for viewing webcasts, however, had a large effect on course grades; students who used webcasts as a replacement for live lectures on average scored lower in the course. Details of this analysis are below.

We performed a multiple regression analysis to estimate the effect of students' usage of on-line resources on their course grades. Course grades were measured on a 1,000-point scale, with the difference between a B and an A equal to about a 120-point increase and the difference between a B and a B+ equal to about a 60-point increase. In our regression model, we included students' amount of website usage (excluding webcasts), measured as the number of sessions per week; and their amount of webcast viewing, measured as the number of hours of viewing per week. We also included students' self-reported reason for viewing webcasts, as indicated on the on-line post-survey: those who viewed webcasts instead of attending live lecture (referred to as "replacers") versus those who did not.

We also included in the model measures of students' demographic background (gender and ethnicity), socioeconomic background (parental income and education), and educational background (SAT I and II scores and high school GPA), to control for their effects. The total R^2 of this model was 0.51, indicating that these variables together account for more than half of the variability in course grades. The adjusted R^2 of the model decreases from 0.50 to 0.46 with the removal of the "replacer" variable and to 0.44 with the removal of the usage measures, indicating that each of these provides appreciable additional predictive power.

In the total model (Table 35), four background variables were significant at the 95 percent confidence level: females scored twenty points lower than males in the course, and higher SAT I math scores, SAT II scores, and high school GPAs were associated with higher course grades. No other background variables were statistically significant.

Student usage of the course website was significantly related to higher course grades: an increase of one session per week was related to a 3.8-point increase in course score. Lecture webcast viewing, on the other hand, had no significant effect on course grades. Interestingly, students' reasons for viewing lecture webcasts made a big difference in course grades: students who used webcasts as a replacement for live lectures on average scored 31 points lower in the course—half the difference between a B+ and a B.

We also repeated this regression breaking out the usage of individual portions of the course website. The adjusted R^2 of the model increased by less than one percent. Usage of only one portion of the website was statistically significant: the use of on-line exam materials was associated with higher course grades (β= 15.8 ± 6.3 course points per session per week; p= 0.013).[24] Trends in the other variables remained unchanged.

Table 35: Predicting Student Course Points: Ordinary Least Squares Regression
R^2 =0.51, N=483 students with all data available

Variable	Parameter Estimate (β) *(estimate ± std err)*	p-value
* Female gender	–20.4 ± 7.1	0.004
White ethnicity	–0.05 ± 7.5	0.995
Parental education	–0.18 ± 1.3	0.89
Parental income *(logarithm)*	–1.0 ± 3.4	0.77
SAT I verbal score	–10.1 ± 5.8 *per 100-point increase*	0.08
* SAT I math score	41.4 ± 7.4 *per 100-point increase*	<0.0001
* SAT II combined score	18.3 ±3.3 *per 100-point increase*	<0.0001
* High School GPA	51.2 ±14.4	0.0004
Website usage *(sessions per week)*	3.8 ±0.8	<0.0001
Webcast usage *(viewing hours per week)*	1.3 ±4.7	0.78
* "Replacer"**	–30.6 ±8.0	0.0002

** Statistically significant predictor of course grade (p < 0.05) at the 95% confidence level.*
*** Students who self-reported that they viewed Chemistry 1A webcasts instead of attending live lectures.*

[24] Two other variables were significant at the 90 percent confidence level: increased usage of lecture slides predicted higher course grades (β= 5.9±3.3; p= 0.076) and increased usage of the on-line lab manual predicted lower course grades (β= –9.2±5.3; p= 0.080).

IV. DISCUSSION

A. Overview of Cost Data

Although the technology enhancements increased the cost of Chemistry 1A in the initial pilot year, these costs are a relatively small percentage of the total cost of the course. In the first year, developing technology-enhanced materials added $68,731 (7.1 percent of total course costs) to the development/revision costs. Three-quarters of that additional development cost was recovered in course delivery cost savings in the first year that the technology-enhanced course was offered. If instructors reuse the technology-enhanced products created for Year 1 in subsequent semesters, then the course development cost will decrease substantially. In fact, we found that the cost of developing technology-enhanced materials dropped to less than three percent of total course costs in Year 2, and that the investments in technology-enhanced materials paid for themselves in reduced course delivery costs over the two course offerings (one offering each in Years 1 and 2).

Development costs (web site, lecture slides, online quizzes) would decrease in future years if instructors were to revise or reuse existing digital or multimedia products in their course. The two largest development and revision costs were for the preparation of the course web site and for the preparation of the lecture slides for the lectures. Development costs decreased in Year 2 by almost 70 percent and we expect the same in future years, with instructors revising or reusing existing digital or multimedia products in their course. The degree to which reuse of the technology enhancements by other faculty will occur is not clear, as the introductory chemistry course at UC Berkeley is taught on a rotating basis by tenure-track faculty who are active researchers. The result is that each faculty member has a distinct philosophy, strong preferences, and considerable flexibility in how to teach the class.

B. Faculty and Teaching Assistant Time

Instructors spend less time doing repetitive tasks in the technology-enhanced version of Chemistry 1A. Specifically, our data show that instructors spend considerably less time preparing for class since the introduction of the lecture slides. The lead instructor for Digital Chemistry 1A estimated an average time-savings of 53 percent overall due to technology enhancements to the course. This estimate included 35 percent time-savings in lecture preparation. The cost savings are considerable, and can be captured each year with only minor revisions in subsequent years. In the traditional course, instructors spent several hours each day of lecture creating the chalkboards. In the technology-enhanced course, instructors are freed from this time-consuming task because they have created the lecture slide presentations before the beginning of the semester. It should be noted that students were particularly fond of the online lecture slides as study aids, and this was reflected in the heavy use of these resources.

Instructors spend less time answering routine questions in the technology-enhanced course because students are able to find the necessary information online. Instructors spend approximately 50 percent less time answering routine questions about the course, including time spent in office hours. More than 60 percent of students report that they go to the web site rather than teaching staff office hours to get answers to questions at least some of the time. Rather than spend less time on the course overall, instructors report that they spend the saved time on other activities related to instruction and course development.

Teaching Assistants are relatively inexperienced teachers and spend a large amount of their time at the start of the semester negotiating the varied responsibilities of being a TA, not using technology to enhance their teaching. Few of the TAs had graduate level teaching experience. Although the majority of TAs come into Chemistry 1A with access to and experience using educational technologies (aside from online office hours and lecture webcasts), few find that the technologies are central to their teaching. TA surveys indicate that, by some measures, they were more comfortable with the technologies and the benefits provided as the semester progressed (e.g., webcasts, perception that technologies saved time and freed up time in lab).

The TAs in the treatment group spent less time grading, and appeared to spend less time on administrative tasks both in and out of the classroom. TA administrative time is saved in class because of the online pre-lab resources. Based on our observations, TAs in the treatment group did fewer administrative tasks in lab. There appeared to be a significant time-savings in grading as well. The availability of online of quizzes that were automatically graded reduced the time that TAs spent grading, which is a task most of them find menial. More than 80 percent of TAs surveyed were willing to migrate these tasks online. An interesting finding was that TAs and students in the treatment group appeared to spend more time on the Discussion and Experiment in laboratories, and that most students in treatment groups felt that they were never rushed.

Because TA salaries and benefits are 60 percent of all course costs for Chemistry 1A, reducing, or at least reallocating, TA time presents opportunities for saving money, serving more students, and/or redistributing TA time to allow for richer interactions with students. By freeing TAs of tasks that they considered menial and burdensome, the technology enhancements allowed TAs to increase the time they spent doing other instructional activities both inside and outside of the classroom. For example, newly available time appeared to result in more time for other activities (e.g., conducting the experiment or increased TA-student interaction) rather than in less time spent in lab section meetings. Year 2 data confirmed that TAs, especially after they had gained familiarity with the technology enhancements, saw the technology more as a time-saver than as a way to foster increased student understanding of the course material.

C. Student Performance and Attitudes

Student performance was not significantly affected by the technology enhancements in the Year 1 experiment. We have found no significant difference between students in the treatment and control groups in grades, retention, or their conceptual understanding in the following semester of chemistry. However, the intention behind introducing technology enhancements to Chemistry 1A was to do no harm, not necessarily to raise course grades. Both years of data indicate that those students who used webcasts the most frequently (based on self-reported or observed data) had poorer final grades. Multiple hypotheses may explain this result (e.g., low-performing students are more likely to rely on webcasts as back-up, webcasts actually impede performance). Year 2 data indicate that student use of webcasts as a replacement for the in-person lecture attendance results in poorer final grades, but that webcast usage for other reasons does not have the same negative effect. Students who used the course web site more often, on the other hand, tended to have better course grades.

Students find the technologies to be an exceptionally positive component of the course. A little explored topic in cost-effectiveness studies is the impact on student "costs" (i.e., what do students perceive as benefits/costs of the technology?). Our attitudinal data collected over two years suggest that students perceived the suite of enhancements as a significant contributor to their overall satisfaction with this large lecture course. web usage data, when triangulated with performance and attitudinal data in Year 2, suggest that students use the online enhancements: 1) on an "as needed" basis, 2) as a significant resource in their study strategies, especially when preparing for exams, and 3) as safety nets for their individual circumstances (e.g., disabilities, English proficiency, personal schedules). Of the almost 500 students who wrote in comments on surveys, 98 percent thought that the use of technology increased the availability of and access to resources, helped them prepare for class, improved the course, promoted learning and understanding of the course material, and/or were either helpful, useful, or convenient. By a significant amount, students in the treatment group responding to the online survey in Year 1 wanted more online assignments and were more likely than their counterparts in the control group to recommend this type of course to other students.

Lectures can be a positive draw for students. It is an article of faith among educators and students alike that the large lecture format is not the best learning environment for students (e.g., Boyer Commission, 1999), although there are good data that suggest lectures serve many useful purposes for students and faculty (e.g., McKeachie, 1999). Our findings from Chemistry 1A and an introductory astronomy course show that excellent lectures presented by dynamic teaching staff are a huge draw for students. In Chemistry 1A, reported reasons for attending the lectures included interacting with other students and the instructors, experiencing live demonstrations, and encouraging personal discipline and concentration. Many students alluded to the positive social benefits of participating in an "event" with large numbers of other students.

A large number of students regularly do not attend lectures. At no time was full lecture hall capacity (N=1569) approached in our attendance counts (range=762 to 1024). In Year 2, 31 percent of survey respondents report attending lecture less than three times per week and 25 percent report replacing the lecture with webcasts. Attendance data on another introductory science course, which did not use webcasts, indicate that webcasts alone are not the reason for decreased student attendance at lectures. Comparative attendance and viewing data from other courses that used online video lecture archives at UC Berkeley in Year 1 (Rowe *et. al*., 2001) and Year 2 suggest that the degree to which students opt out of attending lectures may be heavily influenced by time of day (e.g., early morning) and the style of lecture delivery.

D. Prospects for the Reuse of Space and Time in Lectures and Labs

The availability of the on-demand replays of lectures has the potential to allow a larger number of students to be enrolled in the course. Our data indicate that most students in Chemistry 1A use the online lectures primarily as study aids, and the majority (>80 percent) would not substitute remote viewing for attending lecture. However, students still report, and we observed, that they do not attend lecture the “required” three days per week—but rather closer to an average of two days per week. Our data on actual lecture attendance confirm what many instructors already know, that a large number of students do not attend lecture on a daily basis.

Reduction in the number of lectures given each day from three to two (or one)—perhaps by requiring some students to attend lectures virtually—could realize appreciable saving in faculty time devoted to lecture as well as free up lecture hall space for other courses. Because the same lecture is given three times per day, staff and facilities costs could be saved if a portion of students either opted out of attending lectures, or a lottery system were devised so students were required to view a certain number of lectures per semester online. Our data indicate that the lecture hall is not filled to capacity, and one lecture per day could easily be eliminated.

Time spent in laboratory sections could hypothetically be reduced. Based on our observations, average time spent on experiments and discussion combined was approximately three hours instead of the four hours allotted for these activities. There were always students who straggled in lab, however, and filled up the full time allotted for the lab. If a time reduction proves practical, Chemistry 1A could add approximately 20 lab sections per week and accommodate approximately 600 students without acquiring new space for labs. While more TAs would need to be hired to teach additional sections, no additional costs would be incurred for new facilities in this scenario. Although our observations and TA self-report data show that a reduction of lab time from four to three hours is possible, it is not probable. After providing the opportunity to conduct labs in three hours, we found that the four-hour section seems to be the desired interval for the activities that take place in lab, which include not only the experiment but formal discussions and informal one-on-one interaction among students and TAs.

V. CONCLUSION

Our study provides some intriguing data on both the costs and utility of the current technology enhancements in a large lecture course at a major public research university, which we discuss below.

A. CHALLENGES TO ROBUST RESEARCH

The challenges associated with executing a robust research analysis of a "fast-running" experiment of this scope are substantial. The size and complexity of the Chemistry 1A teaching and learning environment and its placement within an even larger and more complex public research university cannot be overemphasized. Implementation and evaluation of large-scale experiments of this sort require not only robust campus technology support structures, but the gathering of different types of data (costs, learning outcomes, transaction log statistics) from disparate campus units and individuals (institutional, faculty, staff, students, etc.). There are many obstacles to navigate. For example:

- Maintaining a balance between good research design and not disrupting the teaching of a large introductory course;
- Gathering consents from more than 1,000 students per semester (25 percent of whom were under 18);
- Ferreting out Activity Based Cost data that were distributed among many units on campus and in different formats;
- The merging of key technology support units in Year 2 of the study compounded the difficulty of getting reliable cost data;
- Inconsistencies and performance problems in commercial LMS software (e.g., quizzing tool).
- Campus cultures and habits that were not always sympathetic to the demands of experimentation and research in real time, large introductory courses;
- Constant editing of the course by faculty and staff, which ultimately benefits student learning and is the *sine qua non* of good teaching, but makes controlling variables in an experiment of this sort exceptionally difficult.

B. THE IMPORTANCE OF CONVENIENCE AND CHOICE FOR STUDENTS

Given that large lecture courses have a reputation among educators as being poor learning settings, especially among those who advocate a predominantly student-centered approach to learning, our data show that students were both exceptionally enthusiastic about the lecture component of the course and engaged with the online materials. Survey responses and transaction log analysis showed that the course web site in general, and the lecture slides posted on the web site in particular, were popular and well-received. Transaction log analysis of lecture webcasts showed clearly that students used lecture webcasts primarily as a study tool and a supplement to in-person attendance. Attendance data indicate that, although students valued lectures, they frequently opted out of attending them.

We suspect that the positive reception of the Chemistry 1A course and the associated technology enhancements is related to a number of factors:

- The enhancements were minimally disruptive to the teaching style and pedagogy of the teaching staff;
- The enhancements increased convenience for both students and faculty;
- The enhancements were "generic" and pedagogically neutral enough that students could use them flexibly and on their own terms (e.g., as a "safety net," reviewing lectures online for exam study and replacement of missed lectures, repetition of difficult sections by non-native English speakers, downloading lecture slides for preparation and review, taking quizzes multiple times);
- The overall quality of this large lecture course, as with many others on the UC Berkeley campus, is exceptionally high. The instructors in charge are dedicated to providing the best experience possible for students, and are constantly integrating student and TA feedback into course improvements; and

- The instructors are charismatic lecturers who can make a large lecture hall intimate through a number of devices that encourage student participation in lectures.

C. The Implications for Sharing, Reuse, and University Culture

Campus culture will have a significant impact on the likelihood that online teaching materials will be shared and reused by other faculty (Harley 2002). Our findings suggest that some cost-savings could be realized under certain circumstances, which may or may not carry over from semester to semester at UC Berkeley or other campuses that pride themselves on having active research faculty teach introductory courses. For example, although the campus is in theory supportive of "introductory course redesign," our knowledge of administrator and faculty attitudes about educational technologies paint a picture of a research university community that is not yet ready to embrace the reuse of space and time in a systematic way. Interviews indicated that faculty and administrators at various levels of the campus were unaware of the potential cost savings in space and time that might be possible through the careful use of educational technologies.

Moreover, our knowledge of Chemistry 1A faculty behavior suggests that the successful wholesale adoption of technology enhancements from one semester to the next cannot be assumed. In reality, the sharing of teaching materials in a research university environment may be complicated by multiple factors such as faculty idiosyncrasies and the continuity of underlying support structures for technology enhancements. Replicating support mechanisms and customizing materials to one's own course require investments of time and energy by teaching staff. We should note that the experience at UC Berkeley is probably not directly comparable to institutions where non-research, non-tenured faculty are responsible for teaching large introductory courses. In fact, the sharing of electronic teaching materials among faculty may occur more readily in institutions where introductory course curricula are standardized and where research faculty cede course development and delivery to lecturers or adjuncts.

Given a change in campus culture and thinking, there is certainly the possibility that several instructors, or even instructors on other UC campuses, might be able to share online lecture materials. Hypothetically, the availability of a variety of online materials to every Chemistry 1A instructor could eliminate the need for 'reinventing' the course and thus allow time-savings in preparing, organizing, and updating the course materials. Additionally, a rethinking of the time faculty devote to repetition of the same lectures multiple times in a week could potentially free instructors to creatively use the lecture time as a more student-interactive experience and/or reallocate space for other purposes. This rethinking seems particularly relevant given that students have independently found ways to integrate technology enhancements into their time management and study strategies.

Finally, we suspect that any large scaling benefits will come either (1) when newly hired faculty, who might be more adroit with new technologies, enter the department, (2) if the course can be "modular" so that faculty can select materials that fit their learning goals, should their learning goals differ from the developers' intentions, and/or (3) if the materials can be made available to off-site student populations at other institutions.

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APPENDIX A: LIST OF ACTIVITIES INVOLVED IN CHEMISTRY 1A

Development/Revision	Preparing lecture graphics and overheads Creating and updating lab manual Revising discussion handbook Preparing and programming questions for on-line quizzes and assignments Designing and preparing of course website

Delivery: Lectures	Delivering the lecture, including demos and in-class video display
	    Delivering the lecture
	    Preparing and performing chemistry demonstrations
	    Originating and displaying lecture hall video
	Encoding, streaming, archiving lecture webcasts
	Preparing for lecture (instructor)
	Setting up lecture browser presentation

Delivery: Labs	Supplying chemicals for experiments
	Attending TA meetings and lectures
	    Attending weekly TA meetings
	    Attending lectures
	    Attending daily pre-laboratory check-in meetings
	Teaching and administering lab sections
	Preparing for laboratory teaching (TAs)
	Recruiting, training, and monitoring teaching staff
	    Recruiting teaching staff
	    TA training
	    Monitoring labs

Delivery: Quizzes, Exams, and Grading	Grading homework quizzes, check-in quizzes, and pre-lab exercises
	Grading lab write-ups
	Creating homework quizzes (traditional version)
	Grading (instructor)
	Setting up and maintaining on-line pre-lab exercises and quizzes
	    Setting up on-line quizzes and assignments
	    Maintaining on-line quizzes and assignments
	Writing, proctoring, and grading exams
	    Writing exams (Head TAs and instructors)
	    Proctoring midterms
	    Grading midterms
	    Proctoring final exam
	    Grading final exam

Delivery: General	Course-level administration and scheduling
	    Pre-course lecture and lab scheduling
	    Faculty-staff weekly meeting
	    Course administrative duties
	    Administration
	Office hours (instructor)
	    Holding office hours and communicating with students
	    Communicating and meeting with TAs
	Maintaining and hosting website
	    Maintaining website content
	    Hosting website
	Tutoring and other out-of-class student support
	Out-of-class teaching activities
	    Preparing for and teaching scholars sections
	    Office hours (TAs)
	    Weekly review sessions
	    Other out-of-class teaching activities
	Student enrollment, account, and database management
	    Managing student enrollment
	    Managing on-line accounts
	    Setting-up student grades database
	    Maintaining student grades database
	Updating, editing, and publishing the syllabus
	    Updating the syllabus
	    Editing and publishing the syllabus

APPENDIX B: BREAKDOWN OF COURSEWORK AND TOTAL COURSE POINTS

		Year 1 Points	**Year 2 Points**
Final Exam points (total)		350	350
Mid-terms 1, 2 & 3 (combined total)		400	375[A]
Laboratory Points (total)		200	198
Homework Quiz Points (10 each)		30[B]	35[C]
Check-in Question/Discussion		20[D]	14[E]
Pre-lab Assignments		**	27 [B]
Lab Write-ups		**	**
Total Points		**1,000**	**999**
Extra Credit Points Possible (estimated)		9	9
Grading Scale	A =	870 – 1,000	900 – 1,000
	B =	730 – 869	750 – 899
	C =	470 – 729	500 – 749
	D =	350 – 469	350 – 500

[A] The two best midterms were worth 150 points each, but lowest midterm score was weighted less (75 points).
[B] 3 points each
[C] 2.5 points each
[D] 2 points each x 10 assignments
[E] 1 point each x 14 assignments
** Points included in laboratory points total

APPENDIX C: SELECTED STUDENT SURVEY RESPONSES, COMPARED BY YEAR

Question	Y1 On-line Post Treatment Group N= 69	Y1 On-line Post Control Group N=174	Y1 On-line Post All N= 243	Y1 In-class Post Treatment Group N=219	Y1 In-class Post Control Group N=685	Y1 In-class Post All N=904	Y2 Post All N=643
How often do you visit the Chem 1A course website, or other Chem 1A on-line resources?							
3+ times per week	83%	73%	76%	67%	54%	57%	85%
1–2 times per week	15%	24%	21%	31%	32%	32%	14%
less than once per week	2%	3%	2%	2%	13%	10%	1%
never				1%	0%	0%	1%
How often do you watch lecture webcasts?							
3+ times per week	3%	9%	7%	9%	7%	8%	9%
1–2 times per week	23%	29%	30%	23%	21%	21%	19%
less than once per week	53%	43%	46%	46%	45%	45%	50%
never	21%	19%	19%	22%	27%	26%	23%
I watch Fall 2001 Chem 1A lecture webcasts for the following reasons: (check all that apply)							
Instead of attending live lecture	25%	27%	27%				26%
To study and review material prior to exams	56%	65%	63%				41%
After I miss a lecture	69%	65%	66%				72%
Instead of reviewing notes/handouts	10%	10%	10%				n/a
In addition to reviewing notes/handouts	n/a	n/a	n/a				31%
Instead of seeking assistance from a GSI or professor	6%	15%	13%				8%
To prepare for lab	6%	3%	4%				
After attending a live lecture	12%	16%	15%				
Other	7%	7%	7%				5%
I would be willing to watch lecture webcasts entirely on-line instead of going to the lecture hall.							
Yes				16%	17%	17%	14%
No				83%	82%	82%	86%
Both				1%	1%	1%	
Did completing the on-line homework quizzes or pre-lab assignments in advance help you perform the tasks required in lab?							
Yes	70%	n/a	70%				52%
No	30%	n/a	30%				48%
Did taking [on-line homework] quizzes or pre-lab assignments multiple times help you learn concepts about Chem 1A?							
Yes	85%	n/a	85%				71%
No	15%	n/a	15%				29%
Would you be willing to do more activities on-line (e.g. quizzes, homework, discussion) so that you could spend fewer hours in the lab?							
Yes	75%	69%	71%	85%			
No	25%	31%	29%	15%			
Since Chem 1A began, how often have you...completed an on-line pre-lab assignment or homework quiz with a group of other students?							
Always	2%	4%	3%				9%
Most of the time	2%	10%	7%				15%
Some of the time	21%	55%	45%				34%
Never	76%	31%	45%				42%
Since Chem 1A began, how often have you...studied with other students for quizzes and/or examinations for Chem 1A?							
Always	10%	14%	13%				18%
Most of the time	19%	27%	25%				25%
Some of the time	37%	36%	36%				39%
Never	33%	23%	26%				18%

Since Chem 1A began, how often have you...used email to ask questions of your GSI or professor instead of going to office hours in person?							
Always	14%	11%	12%				6%
Most of the time	23%	16%	18%				13%
Some of the time	38%	40%	39%				43%
Never	26%	33%	31%				39%
On average how many hours PER WEEK have you spent in *activities related to lecture* for Chem 1A.							
Total (average) hours per week	7:02	7:22	7:16				6:55
Standard Deviation	3:53	5:16	4:55				4:33
On average how many hours PER WEEK have you spent in *activities related to lab* for Chem 1A.							
Total (average) hours per week	7:53	7:34	7:40				6:54
Standard Deviation	2:37	3:01	2:54				2:48
In general, did you have difficulty completing lab experiments in the time allotted?							
Yes							13%
No							87%
How do you most often access Chem 1A on-line materials through the Internet? (Choose one)							
Phone modem	15%	3%	7%	10%	8%	8%	6%
Cable modem	3%	4%	4%	5%	4%	4%	5%
DSL	10%	5%	7%	5%	3%	3%	7%
Campus ethernet	72%	87%	82%	83%	86%	86%	82%
Other		1%	1%	1%	0%		1%
Did your experience with the technologies offered in Chem 1A affect your overall satisfaction with the course?							
Yes							87%
No							13%
I would recommend that other students take courses like Chem 1A that use: (check all that apply)							
Course websites	100%	95%	97%				94%
Lecture slides	88%	88%	88%				83%
On-line quizzes or assignments	87%	56%	65%				67%
Lecture webcasts (video broadcast over the internet)	76%	75%	75%				80%
Lecture browser (archived lecture webcasts w/ search function)	94%	90%	91%				44%
Accessing grades on the web			n/a				92%
On-line office hours			n/a				41%
Do you have a learning disability, or are you physically challenged or differently abled?							
Yes	8%	3%	5%				1%
No	92%	97%	95%				99%
Is English your first language?							
Yes	68%	44%	72%				78%
No	32%	26%	28%				22%

REFERENCES

Boyer Commission on Educating Undergraduates in the Research University. *Reinventing Undergraduate Education: A Blueprint for America's Research Universities.* New York: State University of New York, Stony Brook, 1998. Available online, see: <http://naples.cc.sunysb.edu/Pres/boyer.nsf/>

The California Postsecondary Education Commission. *Providing for Progress: California Higher Education Enrollment Demand and Resources into the 21st Century (Report 00-1)* Sacramento, California: The California Education Commission, February 2000. Available online, see: <http://www.cpec.ca.gov/Publications/ReportSummary.ASP?968>

Creswell, J.W. *Qualitative Inquiry and Research Design: Choosing Among Five Traditions*. Thousand Oaks: SAGE Publications, 1998.

Ehrmann, Stephen C. "What Outcomes Assessment Misses." Cincinnati, OH: AAHE Assessment Conference, American Association for Higher Education, June 14, 1998. Available online, see: <http://www.tltgroup.org/programs/outcomes.html>

Ehrmann, Stephen C., and John H. Milam, Jr. *Flashlight™ Cost Analysis Handbook: Modeling Resource Use in Teaching and Learning with Technology*. Washington, DC: The Teaching, Learning, and Technology Group, 1999.

Fisher, Saul, and Thomas Nygren. "Experiments in the Cost-Effective Uses of Technology in Teaching: Lessons from the Mellon Program So Far." Cost-Effective Uses of Technology in Teaching (CEUTT) Initiative, Andrew W. Mellon Foundation, March 2000. Available online, see: <http://www.ceutt.org/ICLT%20CEUTT.pdf>

Harley, Diane. "Planning for an Uncertain Future: A U.S. Perspective on Why Accurate Predictions About ICTs May Be Difficult," *Journal of Studies in International Education* 6, no. 2 (2002).

Juster, Thomas, and Frank Stafford, eds. *Time, Goods, and Well-Being.* Ann Arbor, MI: Survey Research Center, Institute for Social Research, University of Michigan, 1985.

Levin, H. M., and P. J. McEwan. *Cost-Effectiveness Analysis: Methods and Applications,* 2nd Edition. Beverly Hills, CA: Sage Publications, 2001.

Maher, Michael, Barbara Sommer, Curt Acredolo, and Harry R. Matthews. "Costs and Effects of On-line Education Compared to the Large Lecture Hall." University of California, Davis, April 22, 2002.

Massy, William F., and Robert Zemsky. *Using Information Technology to Enhance Academic Productivity*. National Learning Infrastructure Initiative (NLII) and Educom, 1995. Available online, see: <http://www.educause.edu/nlii/keydocs/massy.html>

McKeachie, W. J. *Teaching Tips: Strategies, Research, and Theory for College and University Teachers,* 10th Edition. New York: Houghton Mifflin, 1999.

Media and Measurement Task Force. "Metrics and Methodology." Internet Ad Bureau, September 15, 1997. Available online, see: <http://www.iab.net/advertise/metricsource.html> (18 July 2002).

Office of Student Research. *Berkeley's 1999 New Undergraduates: A Statistical Profile.* Berkeley, CA: University of California, Berkeley, February 2000. Available online, see: <http://osr.berkeley.edu/Public/STAFFWEB/DC/SoNS-99.html>

"The Pew Grant Program in Course Redesign." Pew Charitable Trusts. Accessed: July 18, 2002. Available online, see: <http://www.center.rpi.edu/PewGrant.html>

"The Pew Grant Program in Course Redesign Round 1 Grant Awards: University of Wisconsin–Madison (Introductory Chemistry)." Pew Charitable Trusts. Accessed: July 18, 2002. Available online, see: <http://www.center.rpi.edu/PewGrant/rd1award/UWM.html>

Phipps, R., and J. Merisotis. "What's the Difference? A Review of Contemporary Research on the Effectiveness of Distance Learning in Higher Education." Washington, DC: The Institute for Higher Education Policy, April 1999. Available online, see: <http://www.ihep.com/Publications.php?parm=Pubs/Abstract?9>

Rowe, Lawrence A., Diane Harley, Peter Pletcher, and Shannon Lawrence. *BIBS: A Lecture Webcasting System*. Berkeley, CA: Berkeley Multimedia Research Center, June 2001. Available online, see: <http://www.bmrc.berkeley.edu/research/publications/2001/160/>

Seymour, E. "Implementation of 'Carry Forward' knowledge retention experiments," personal correspondence, May 1999.

Strauss, A., and J. Corbin. *Basics of Qualitative Research: Techniques and Procedures for Developing Grounded Theory*. Thousand Oaks: SAGE Publications, 1998.

Twigg, Carol A. *Improving Learning and Reducing Costs: Lessons Learned from Round I of the Pew Grant Program in Course Redesign.* The Pew Learning and Technology Program, 2003. Available online, see: <http://www.center.rpi.edu/PewSym/mono1.html>

University of California Office of the President. "UC Enrollment Growth to 2010," *News and Communications Fact Sheet.* Oakland, CA: University of California Office of the President, January 2000. Available online, see: <http://www.ucop.edu/ucophome/commserv/FS000302Enroll.pdf>

Ver Ploeg, Michele, Joseph Altonji, Norman Bradburn, Julie DaVanzo, William Nordhaus, and Francisco Samaniego, eds. *Time-Use Measurement and Research: Report of a Workshop.* Washington, DC: National Academy Press, 2000.