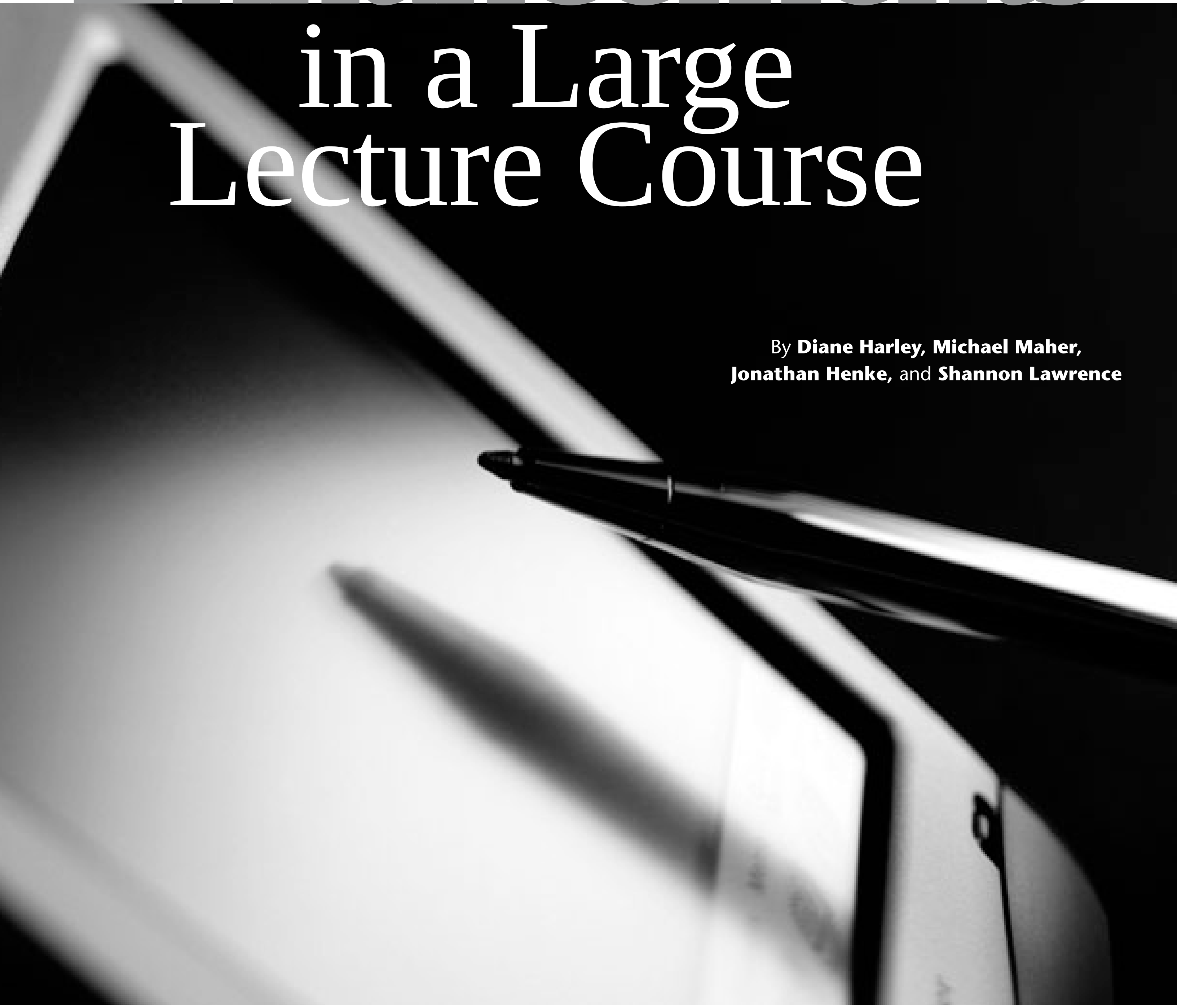
An Analysis of Technology Enhancements in a Large Lecture Course



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An analysis showed increased student use of curricular resources, increased convenience, and a potential for cost savings

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.[1,2] The University of California 10-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.[3,4] Determining the effectiveness of technology enhancements in higher education settings is not a simple undertaking, however.[5,6]

This article 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, along with their potential to free up teaching staff time and possibly serve more students off site. Our primary goals were to determine if

- the use of online teaching materials results in significant restructuring of staff time in laboratories and lectures,
- teaching facilities can be used by more students, and
- the technology enhancements affect student performance and 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.[7] 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.

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,[8] 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 UC Berkeley Digital Chemistry 1A course[9] 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.

In the fall semester, one of three semesters in which the course is taught (fall, spring, and summer), one to two instructors (tenured faculty or lecturers) give nine lectures (three identical lectures on a given day, with lectures three days a week). These instructors are supported by approximately 50 teaching assistants (TAs). 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 carrying out miscellaneous tasks.

Lectures

One instructor, assisted by a demonstration expert, gives three identical one-hour lectures every Monday, Wednesday, and Friday. Students can attend any of the lectures on a given day, which provides them with scheduling flexibility. Beginning in fall 2000 (Year 1 of this study), all the material previously displayed on chalkboards was transformed into PowerPoint slides for projection in the lecture hall, posting on the Web site, and integration with the video of lectures available on the Web site. In the same semester, students could view the online lectures in two formats: live or on demand.

Laboratory Sections

Approximately 45 laboratory sections for Chemistry 1A are scheduled in four-hour blocks between 8 a.m. and 5 p.m. daily, Monday through Friday. The four-hour lab period allots one hour for discussion and administrative tasks, and three hours for the experiment. Each TA is responsible for leading discussion, answering questions, and overseeing student experiments for approximately 30 students during lab sections that meet weekly.

Chemistry 1A TAs are salaried academic employees who are expected to work 20 hours per week. Their weekly responsibilities include four hours of leading a lab section, three hours of lecture attendance, two office hours, participation in the one- to two-hour TA meeting, preparation for their lab sections, and grading weekly assignments. All TAs are also required to grade quizzes and exams. Most TAs are first-year graduate students, so the TA cohort changes from year to year.

Study Design

A grant from the Mellon Foundation allowed us to experiment with a wide range of data collection methods. We wanted 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 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 online—tasks that students in the control group performed in labs. 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.

Data Collection and Analysis

We collected data to evaluate faculty and TA time, course cost, student attitudes, and student performance.

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[10] and Erhmann and Milam,[11] we estimated the cost of resources used to teach Chemistry 1A using activity-based costing. 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.

We identified 50 activities necessary for offering Chemistry 1A. 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 were not necessarily the same as the resources acquired by the university for the course. For example, we found that TAs used 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, reassigns the teaching assistants to other productive tasks, or does nothing with the freed up TA time.[12]

Defining Technology Enhancements

It is important to note that Chemistry 1A is constantly changing and evolving. Technology enhancements were introduced to the course in an incremental fashion over the span of several years. Therefore, we could not directly observe a fully traditional or fully technology-enhanced course during Year 1. We compared three "versions" of the course: Traditional Year 1, Technology-Enhanced Year 1, and Technology-Enhanced Year 2. We distinguished between traditional and technology-enhanced costs only during Year 1 of the study.

In order to draw comparisons of costs between the traditional and technology-enhanced versions of the course in Year 1, we had to define a hypothetical traditional course. We did this with the aid of retrospective interviews of instructors and other staff. During Year 2, the course was fully technology enhanced and did not include a control group, although we were able to correlate patterns of technology use with individual student performance and attitudes through transaction log analysis.

Teaching Staff Time and Attitudes

We were interested in redistribution of staff time in response to technology enhancements to the course. 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 detailed student demographic and other background data.

Student Attitudes

We used a combination of pre- and post-course surveys and focus groups to measure other possible changes in student learning, such as student access to, use of, and opinions about the technology used in the course. We also explored whether or not the students believed the technology impacted their learning and how it affected their attitudes toward the course and learning.

Student Use of Technology

We collected usage statistics for both years of the study through transaction log analysis. Analysis of usage statistics included the following online features: lecture Webcasts, lecture slide presentations, quizzes, the 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.

Results

The study results summarize cost data, student performance and attitudes, and prospects for reuse of space and time.

Overview of Cost Data

Although the technology enhancements increased the cost of Chemistry 1A in the pilot year, the technology costs were 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.

When instructors reused the technology-enhanced products created for Year 1 in the subsequent year, the course development cost decreased 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). Table 1 summarizes the results of our cost analysis.

Development costs (Web site, lecture slides, online quizzes) would decrease in future years if instructors revise or reuse existing digital or multimedia products in their courses. The two largest development and revision costs were for the preparation of the course Web site and the lecture slides. 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 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. Each faculty member has a distinct philosophy, strong preferences,

Table 1

Comparison of Course Costs

	Year 1 Traditional	Year 1 Technology-Enhanced	Year 2 Technology-Enhanced	Year 2 Savings*
Development/ revision:				
Staff:				
Faculty	$736	$40,094	$10,916	($10,180)
TAs	$0	$0	$1,387	($1,387)
Support staff	$2,108	$30,141	$10,332	($8,224)
Supplies and equipment	$87	$848	$554	($467)
Facilities	$50	$630	$330	($280)
Total, Development/ revision	$2,981	$71,713	$23,519	($20,538)
Delivery:				
Staff:				
Faculty	$152,204	$91,972	$64,036	$88,168
TAs	$619,887	$598,366	$518,582	$101,305
Support staff	$95,046	$119,069	$135,931	($40,885)
Supplies and equipment	$48,680	$54,059	$63,627	($14,947)
Facilities	$38,607	$38,720	$37,722	$884
Total, Delivery	$954,423	$902,186	$819,898	$134,525
Total	**$957,405**	**$973,899**	**$843,417**	**$113,987**
Total 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

and considerable flexibility in how to teach the class.

Faculty and TA Time

We observed several types of time savings for instructors and TAs as a result of technology used in the course.

- *Instructors spent less time doing repetitive tasks in the technology-enhanced version of Chemistry 1A.*

Specifically, our data show that instructors spent considerably less time preparing for class following 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 lecture day 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. We should note that students were particularly fond of the online lecture slides as study aids, and this was reflected in heavy use of these resources.

- *Instructors spent less time answering routine questions in the technology-enhanced course because students could find the necessary information online.*

Instructors spent approximately 50 percent less time answering routine questions about the course, including time spent in office hours. More than 60 percent of students reported visiting the Web site rather than attending teaching staff office hours to get answers to questions at least some of the time. Rather than spending less time on the course overall, instructors reported spending the saved time on other activities related to instruction and course development.

- *TAs were relatively inexperienced teachers and spent 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.*

The cost savings are considerable and can be captured each year with only minor revisions in subsequent years.

Few of the TAs had graduate-level teaching experience. Although the majority of TAs came into Chemistry 1A with access to and experience using educational technologies (aside from online office hours and lecture Webcasts), few found that the technologies were central to their teaching. TA surveys indicated that, by some measures, they were more comfortable with the technologies and the benefits provided as the semester progressed (for example, Webcasts and the 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 was saved in class because of the online pre-lab resources. Based on our observations, TAs in the treatment group did fewer administrative tasks during lab. There appeared to be a significant time-savings in grading as well. The availability of automatically graded online quizzes reduced time spent by TAs grading, which is a task most of them found 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 lab sessions. Most students in the treatment group also 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 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 the classroom. For example, newly available time appeared to result in more time for other activities (such as conducting the experiment or increasing 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.

Student Performance and Attitudes

Analysis of student performance and attitudes revealed a variety of trends.

- *Student performance was not significantly affected by the technology enhancements in the Year 1 experiment.*

We found no significant difference between students in the treatment and control groups in grades, retention, or 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 self-reported (and those who were observed in Year 2) using Webcasts the most frequently had poorer final grades. Multiple hypotheses might explain this result (for example, low-performing students are more likely to rely on Webcasts as backup, or Webcasts actually impede performance). Year 2 data indicate that student use of the Webcast as a replacement for the in-person lecture attendance resulted in poorer final grades, but Webcast use for other reasons did not have the same negative effect. Students who used the course Web site more often tended to have better course grades.

■ *Students found 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" (that is, what do students perceive as benefits and costs of the technology). Student 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 used the online enhancements

—on an as-needed basis;

—as a significant resource in their study strategies, especially when preparing for exams; and

—as safety nets for their individual circumstances (for example, compensating for disabilities, lack of English proficiency, and 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 was 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 groups 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,[13] although good data suggest lectures serve many useful purposes for students and faculty.[14] Our findings from Chemistry 1A show that excellent lectures presented by a 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.*

Although somewhat contradictory with the finding above, at no time was full lecture hall capacity (capacity = 523 seats × 3 lectures = 1,569) approached in our attendance counts (actual attendance range = 762 to 1,024). In Year 2, 31 percent of survey respondents reported attending lecture less than three times per week, and 25 percent reported replacing the lecture with Webcasts. Attendance data on another introductory science course, which did not use Webcasts, indicate that Webcasts alone were 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[15] and Year 2 suggest that the degree to which students opted out of attending lectures might be heavily influenced by time of day (for example, early morning) and the style of lecture delivery.

Prospects for Reuse of Space and Time in Lectures and Labs

The cost and time savings achieved from technology enhancement of Chemistry 1A suggest possibilities for restructuring of the course.

■ *The availability of 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 used the online lectures primarily as study aids, and the majority (more than 80 percent) would not substitute remote viewing for attending lectures. Students still reported, and we observed, however, that they did not attend lecture the "required" three days per week, but closer to an average of two days per week.

Our data on actual lecture attendance confirm what many instructors already know—a large number of students do not attend every lecture. 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 and 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 opted out of attending lectures or if a lottery system were devised so that students were required to view a certain number of lectures per semester online.

■ *Time spent in laboratory sections hypothetically could 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. Some students always 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 additional 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 also formal discussions and informal one-on-one interaction among students and TAs.

Discussion

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.

Challenges to Conducting 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, and so on). There are many obstacles to navigate:

- 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 in different formats, distributed among many units on campus.
- The merging of key technology support units in Year 2 of the study, which compounded the difficulty of getting reliable cost data.
- Inconsistencies and performance problems in commercial learning management system software (for example, the quizzing tool).
- Campus cultures and habits 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.

Importance of Convenience and Choice for Students

Perhaps our most important finding about student behavior and the technology was the degree to which students embraced the multiple opportunities technology provided for curricular resource access and for scheduling flexibility. Large lecture courses have a reputation among educators as being poor learning settings, especially among educators who advocate a predominantly student-centered approach to learning. On the other hand, our data show that students were both exceptionally enthusiastic about the lecture component of the course and engaged with the online materials. Attendance data indicate, however, that although students valued lectures, they also frequently opted out of attending them.

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 at lectures.

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 (for example, 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, and 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.

Implications of University Culture for Sharing and Reuse

Campus culture will have a significant impact on the likelihood that online teaching materials will be shared and reused by other faculty.[16] Our findings suggest that some cost-savings could be realized under certain circumstances, which might or might 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 paints a picture of a research university community 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. There simply was no appreciable adoption of electronic materials by other faculty.

The sharing of teaching materials in a research university environment might 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 might not be 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 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 (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; or (3) if the materials can be made available to off-site student populations at other institutions.

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