The Development of the Studio Classroom

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Introduction

The roots of the Studio Course model at Rensselaer can be found in the research in physics education and the calculus reform movement of the 80’s. We became convinced that there had to be a better way to teach than the various lecture models that dominated the education systems, especially at the large universities. The pressures of advances in computing, communication, and cognitive science both mandated change and enabled that change. Computing tools were advancing such that the power was doubling every 18 months, but little had been done to use that power in education. New forms of communication through networks, email, and the World Wide Web were revolutionizing communication and could do the same for education. We were learning more and more about how students learn, obstacles to learning, and techniques to improve learning from the research in the cognitive sciences, particularly as applied to physics teaching.

Background

New learning environments needed to be designed to allow students to become far more engaged with one another, with the instructor, and with newly created technology based materials. In the 1980’s the author and his collaborators were involved in the reanalysis of the introductory physics curriculum to determine how it needed to change to prepare students for the information world. In the M.U.P.P.E.T. project, Redish and Wilson called for an entirely new, technology based, approach to physics.[1] As they developed the M.U.P.P.E.T. curriculum they became more and more familiar with the research in physics education and it’s implications for course design. During the 80’s an active community developed that was interested in the application of technology to physics education and also interested in the developing understanding of student learning. Some worked on the creation of microcomputer based laboratories, some on video disks and digital video, others were interested in physics simulations, still others focused on modeling and numerical approaches to problem solving.

Driven by the conviction that there were a host of excellent ideas being developed, but that the overall implementation of those ideas suffered from their lack of integration, Redish and Wilson formed the CUPLE consortium, short for the Comprehensive Unified Physics Learning Environment.[2] It was comprehensive because it made an effort to include many of the approaches that had developed independently. It was unified because it was designed around a set of standards for collecting materials and having them work together with a common user interface on a common hardware and software platform. The CUPLE project received its initial funding from the Annenberg CPB project, quickly followed by an IBM Corporate grant. Later funding from the National Science Foundation allowed the completion of the project. Many of the modules were deployed in the traditional physics course at Rensselaer as laboratory modules, homework, or in class activities.

At the same time as this ferment in physics, the mathematics community was undergoing it's own re-examination. Their projects were driven by two issues, the incorporation of technology into the curriculum and creation of a better introductory course in calculus. "A Pump and not a Filter" was the subtitle of one of the Calculus conferences. The Calculus for a new Century conference pulled this all together into a clear call fro reform in Calculus. William Boyce of Rensselaer attended that conference and returned to campus convinced that Rensselaer should help lead the change. Boyce was one of the authors of one of the most popular Calculus texts at the time and was an ideal person to lead the charge. He began the Rensselaer Computer Calculus project in 1988. By 1991, this had been deployed to all 1100 calculus students in the freshman class.

Very soon thereafter, Joe Ecker, then Chair of Mathematics and the author began to feel that the revised courses were exciting, but not yet right. Technology had been grafted onto traditional courses. Problems had been changed and curriculum revised, but there had not really been a fundamental redesign of the course. We then decided to undertake a "zero based budgeting" approach to the course redesign. In doing this we decided not to be bound by past practice, existing facilities, or present personnel. Instead we asked ourselves just what an ideal physics or mathematics course might look like. We had always been envious of our brethren at the liberal arts colleges that could experiment with smaller class sizes. We particularly liked approaches like the Workshop Physics approach of Priscilla Laws.[3] We also knew that we wished to incorporate cooperative learning techniques[4],[5] throughout the course. We asked ourselves if we could design an interactive learning course that would take advantage of these techniques and yet be possible to operate economically in the context of a large research university that educates over 1000 students in calculus and 600 students in physics each semester.

Thus was born the studio classroom. The name and some aspects of the pedagogy were borrowed from the architects and artists who are known for their studio programs. The classroom climate was modeled on the interactive courses, often in humanities, found at the liberal arts colleges. This all had to be done while meeting the need for the rigor and coverage of the technological research university.

What makes a Studio Classroom?

I am often asked what makes a studio classroom. Is it a prescriptive approach? Are all studios the same? The answers to the last two are certainly no, but the answer to the first question is more difficult. Putting oneself in the place of a student can help you see the key difference. If you (as a student) go to lecture, what do you expect to do? Many answer "listen," "take notes," or "read the blackboard." Those who may not have been as diligent in their studies answer "read the paper," "talk to friends," or "study for another course." A few will give what is perhaps the most correct answer: "Oh, I would cut." Attendance in introductory lecture classes is notoriously poor in the major universities.

If the same people are asked what they would do in a studio, they might answer "draw," "sculpt," "paint," or "design."

The difference is in who is the actor. In the lecture, the lecturer is the actor and the students are the audience. In the studio, the student is the one active and the professor becomes the audience.

Of course, it is never quite that simple. Sometimes I try to explain the difference with a joke: "If you walk into a classroom and find the professor working hard while the students rest (sleep?), you must be in a traditional class. If you find the students working while the professor rests, it must be a studio class!" Any faculty member who has worked in the studio knows that to be a joke, because the activity of the professor is critical to the success of the studio classroom, but it highlights the importance of the student becoming active and engaged.

The studio classroom demands more of the student than the traditional lecture and that fact is not lost on the students. One student noted on his class evaluation form "Professor XXXX, for years students have been able to sign up for this class, cut the lectures, read the text, study the back tests in the files, and get a passing grade. You forced me to learn this material. I'll never forgive you for that."

Recognition

The Studio Course has been recognized as a significant breakthrough in providing high quality cost effective courses in articles in Newsweek (April 29, 1996), the New York Times (January 8, 1995), the Wall Street Journal (November 13,1995) and the ASEE Prism. The RSVP Distance Learning Program at Rensselaer won the 1993 US Distance Learning Association Award for best University Distance Learning Program and the 1996 US Distance Learning Association award for its cooperative engineering and management distance learning program with General Motors.. The Studio Course model won the 1995 Theodore Hesburgh Award from TIAA/CREF. The *Hesburgh Award* was presented at the 1995 annual meeting of the American Council on Education. Richard Riley participated in the presentation of the award at the meeting, which was keynoted by President Clinton. Rensselaer was the recipient of the first annual *Boeing Outstanding Educator of the Year Award*. From 37 nominees, Rensselaer was selected to honor its achievements in undergraduate education in the engineering, manufacturing, computing, mathematics, physics, and chemistry disciplines. In 1996, Rensselaer was honored with the Pew Charitable Trust Prize. Rensselaer is the only university to have been awarded this "triple crown" of higher education awards.

In the spring of 1999, the Pew Charitable Trust formed a program, headed by Carol Twigg (former VP of EDUCOM), that will invest $8.8 million in universities that wish to restructure along lines similar to those discussed here. The program is located at Rensselaer as the Center for Academic Transformation.[6]

Detailed Design of the Studio Classroom

Pedagogical Considerations[7]

As noted earlier, the design of the studio course draws heavily on the research in science education and particularly that in physics education. The introductory science and mathematics courses at many of our large universities around the world can be an intimidating experience for the new student. It is not only the difficulty of the material, but also the experience of sitting in the large non-interactive lectures with a lecturer who is mathematically unapproachable even when personally approachable.

Shiela Tobias, in "*They're not dumb, they're different*!" provides one of the best chronicles of student reactions in the introductory course.[8] This format of large lecture, smaller recitation, and separate laboratory continues to be the dominant method of instruction at the larger universities. The faculty usually does the lectures and the laboratories are done by teaching assistants. Often, the recitations are taught by mixtures of teaching assistants and faculty, with that mix varying widely from university to university.

Most physics, chemistry, or calculus learning takes place in the recitation or problem sessions, in spite of the uneven quality. Most laboratories are not well taught and not well integrated with the courses. Taught by teaching assistants with minimal or almost no training, the laboratories are universally panned by the students. Because of this perception of low quality and the resources required to run laboratories, several of the larger universities have abandoned them altogether.

Faculty and staff at the major universities, aware of the shortcomings of this system, have undertaken many reform efforts. The meetings of the American Association of Physics Teachers have devoted decades to ideas for how to improve the lecture. One recurring theme is the use of lecture demonstrations that range from the spectacular to the humorous. Faculty, students, and even the general public love and remember the best demonstrations and the best demonstrators. Books have been written on how best to do demonstrations and which demonstrations might be done. We have also tried audio, video, and now computers to make the lectures more interesting and more instructive. Unfortunately, later interviews with the students often reveal that the memory of the demonstration is often not accompanied by an understanding of the physics of that demonstration.

Many efforts to improve the introductory course work from an assumption that there are "good lecturers" and "bad lecturers," and that students can learn more from the "good lecturers." The strategy then is to improve the "bad" or replace with the "good." Even many applications of technology are efforts to improve or replace the lecturer with electronic forms of lecture. Many institutions have used videotaped materials to replace the traditional pre-laboratory lecture with videotapes of good lecturers who can articulate in clear English the goals and procedures for the laboratories. Others (including the author) have created computer-based pre-laboratories[9] toward the same ends. With the creation of the "Mechanical Universe" this approach of using technology to replace the lecturer may have reached its highest form. Each video opens with a scene of students filing into a large lecture hall and then listening attentively to the opening remarks of a truly outstanding lecturer. Today, we are seeing the same kind of approach on the web. The lectures are videotaped, digitized, and them made available as streaming video. The lecture notes are converted into PowerPoint and sometimes made available over the network.

These are all worthy efforts toward noble goals, but a more serious re-examination of our assumptions and our approaches was required. Evidence has been pouring in from those doing research in science education, but it seems to have had little effect on physics or the other sciences in most of our largest universities. Hestenes' "Force Concept Inventory" and later tests have been applied across the country in a variety of institutions with equivalent results.[10],[11] Eric Mazur (Harvard) felt that his students were really learning in his lectures until he gave them Hestenes' test. The disappointing result inspired him to develop innovative interactive techniques for use with large enrollment courses.[12]

There are, of course, some notable exceptions. Ron Thornton's (Tufts) article[13], "Learning Physical Concepts with Real-Time Laboratory Measurement Tools," is particularly interesting, because it compares more interactive methods using microcomputer based laboratories to traditional lecture approaches and shows that the interactive methods can reduce student error rates spectacularly.

Eric Mazur's article provides an honest personal anecdote illustrating the statistical evidence amassed by Hestenes[14], Laws[15] [16], Sokoloff[17], and Thornton[18] that even a "good lecturer" does not directly improve student learning. Certainly there are significant differences in the affective domain showing that students enjoy the course more, appreciate the subject, and come away with improved attitudes to the discipline. This can probably be linked to student retention and recruitment of majors, and perhaps even to increased learning through the other areas of course such as reading, problem solving, and laboratories. Providing good lectures is obviously superior to providing poor lectures, but still does not lead directly to increased learning.

A standard counter argument is that "lectures must work, because students have been learning that way for centuries." The problem with this approach is that it neglects to take into account the many other ways that students learn, such as reading, problem solving, discussion with other students, discussion in the recitations, performing laboratories, and so on. Frequently it is based upon a generalization from the speaker’s own experiences, which are (by definition) atypical.

We decided that we wished to de-emphasize (but not eliminate!) the lecture, increase the number of hands-on activities, keep problem solving at about the usual level, and use collaborative learning and team approaches.

Development

At one critical point in 1993, we convened a panel of nationally prominent educators, architects, and representatives of industry to review the status of our programs and to plan for future programs. We expected such a diverse group to provide a diverse perspective, but never expected to reach any kind of a consensus. We were surprised at the strong consensus to reduce the emphasis on the lecture, to improve the relationship between the course and the laboratory, to scale up the amount of student activity while scaling back the watching, to expand the team and cooperative learning experiences, to integrate rather than overlay technology into all of the courses, and above all to do so while reducing costs!

Our goal for the studio courses was to bring the interactivity often found in small enrollment interactive courses into the large enrollment courses. We combined lecture, recitation, and laboratory were into integrated sessions hosted in one studio facility. A team comprised of a faculty member, graduate student, and in some cases, an undergraduate student, taught the classes. We were also exhorted to try to design a course that cost no more than the alternatives.

Facilities

Over the years there have been a number of variation on the facilities design. Some have used clusters and others have used a “theater in the round” configuration. In the “theater in the round” configuration in physics there are 2 m. long worktables, each designed for two students, with open workspace and a computer workstation. Often the tables also contain the equipment for the day's “hands-on” laboratory. The tables form three concentric partial ovals with an opening at the front of the room for the teacher's worktable and for projection. The workstations are arranged so that when students are working together on an assigned problem, they turn away from the center of the room and focus their attention on their own small-group workspace. The instructor is able to see all workstation screens from the center of the oval, and thereby receives direct feedback on how things are going for the students.

In any course, when the teacher wants to conduct a discussion or give a mini-lecture, he or she is able to ask the students to turn back toward the center of the room. This removes the distraction of having a functioning workstation directly in front of the student during the discussion or lecture period, yielding a classroom in which multiple foci are possible. Students can work together as teams of two, or two teams may work together to form a small group of four. Discussion as a whole is facilitated by the semicircular arrangement of student chairs. Most students can see one another with a minimum of swiveling of chairs. This is particularly important since only about 20-40 percent of the time spent in the classroom is actually on the computers; the remainder is devoted to group activities, hands-on laboratories, and discussion.

This type of classroom is friendly even to those instructors who tend toward the traditional style of classroom in which most of the activities are teacher-centered rather than student-centered. Projection is easily accomplished, and all students have a clear view of both the instructor and any projected materials. As a facility in which the instructor acts more as a mentor/guide/advisor, the classroom is unequaled. Rather than separating the functions of lecture, recitation and laboratory, the instructor can move freely from lecture mode into discussion, and can assign a computer activity, ask the students to discuss their results with their neighbors, and then ask them to describe the result to the class. Laboratory simply becomes another one of the classroom activities that is mixed in with everything else. This course uses the latest in computing tools and incorporates use of cooperative learning approaches. We have created a powerful link between the lecture materials and the problem-solving and hands-on laboratories.

Equipment

The first studios were equipped with networked desktop computers with two to four students sharing a computer. A 64 student classroom might typically have 32 desktop systems installed with a typical price of $2000-3000 per networked desktop. This classroom could host roughly ten to twelve sections of a course per week. This means that it could serve 640 students per semester. Although we would have liked to change them more frequently, we were actually using the computers for five years before replacing them. Amortizing the cost of the computer over 10 semesters (a conservative choice, since we also used them in summer) yields a cost of $20-30 per student. This cost was tiny in comparison to the cost of personnel. It was, in fact, the smallest cost of the course.

In the middle of the decade, we began a pilot project to convert from university owned desktops to student owned laptops. A faculty committee led by Mark Holmes, Chair of Mathematics, and John Kolb, Dean of Computing and Information Services, led a four year pilot program that developed the courses, supported the faculty, and created the plan for full implementation.[19] The last obstacle to overcome was to have the overall cost be lower in the laptop models and to provide for the financial aid required for many of our students. We are now one year into the full implementation phase of the project, and are delighted with the results.

Cost Considerations

The traditional physics course met in three different kinds of facilities: a modern 500 seat lecture hall, a typical 30 seat recitation or discussion room, and a 25 seat laboratory. The introductory calculus course used a similar lecture hall, the same 30 seat discussion rooms, and a 30 seat computer laboratory. Scheduling 600-1000 students through these facilities was an art in itself. In physics there were two lecture sections, 25-30 recitation sections, and 30-40 laboratories to be scheduled each week. These 57-72 events were staffed by faculty and graduate students, and required a lecture demonstration support staff and a laboratory support staff. If the studios were sized from 48 to 64 students each, the same number of students per week could be accommodated in 12-15 sections. It was thus possible to meet the cost constraints.[20]

Many of the courses met for 4-6 hours per week with approximately 2 hours devoted to lecture, two to recitation, and two to laboratory. In the studio we collapsed all of this into 4 hours. This could be done in two two-hour sections or in three sections. The reduction from six to four contact hours is an important aspect of stewardship of both student and faculty time and resources. In spite of the 1/3 reduction in contact hours, the evaluations demonstrated that students learn the material faster and as well or better than the traditional course.[21] Zemsky and Massy cited the Rensselaer Studio Courses for their focus on constraining costs while enhancing quality.[22]

Calculus, Physics, and Chemistry were the three largest introductory courses at Rensselaer in the early 90's. They each had a model that educated 600-1100 students in lecture, recitation, and laboratory. The laboratories were quite different with Chemistry requiring wet labs with the usual safety equipment, physics using laboratories with much less stringent requirements, and mathematics using computer laboratories. They also differed in their use of faculty. Chemistry used all faculty in their recitations, physics was a mix, and mathematics used nearly all graduate students. Each of these could be redesigned to be economically competitive to alternatives.

Studio courses developed later, particularly in Electrical Engineering replaced primarily lecture-based classes with studios. These require additional resources to add the laboratory experiences that were not present in the traditional course, and are likely to be more expensive.

Whether the studio courses are more expensive or less than the alternatives depends upon the alternative model. If one is willing to put 500 students in a lecture hall and dispense with both discussion sections and laboratories, there could be no cost savings from studios, but the quality of such teaching would be unacceptable to most institutions. There are always "cheaper" alternatives, but the compromise in the quality of the student experience may be just too great.

The "cheaper" alternative may not actually be the least expensive when all costs are taken into account. As a number of universities prepared their proposals to the Pew Charitable Trust program administered through the Center for Academic Transformation at Rensselaer, they discovered that alternatives that did not look immediately cost effective became so when "rework" was considered. "Rework" occurs when there is a large failure rate in an initial course and students must repeat the course at least once. This has the effect of increasing the number of students who take a particular course. If one third (33.3%) of the students fail to complete a course and then take that course over, it has the effect of increasing the enrollment by 50% in the steady state. This increase of 50% in enrollment requires more faculty, facilities, and support staff and can increase cost up to 50 % for those models that are linear in cost!

Deployment

In the fall semester 1993, Professor Joe Ecker, taught the first full Studio course in Calculus. In the spring of 1994, Professors Wayne Roberge and Jack Wilson followed with the first Physics Studio. At about the same time, professor Frank DiCesare designed the new Engineering Lab to have many of the characteristics of the studio. This course came to be called LITEC or Laboratory Introduction to Electronic Control.[23] During the Fall 1994 semester, the CUPLE Physics Studio was expanded to full deployment in all Physics I sections and Physics III sections and a pilot deployment in Physics II. In 1995 the Physics department voted unanimously to end the traditional course in favor of the full deployment of the Studio.

The studio quickly spread into other disciplines with each model adapting the studio philosophy to that of the faculty of that discipline. The first Studio Chemistry courses at Rensselaer used very little technology while adopting most of the logistical and pedagogical innovations of the other studios. Professors R. Spilker and J. Brunski created a freshman studio, Introduction to Engineering

Analysis, for the engineering students. Studios were used in writing courses, genetics, economics courses, engineering courses, and many others.

The Electrical, Computer and Systems Engineering (ECSE) department has developed five of the most advanced Studio classrooms on campus. The facilities are currently being used for the following courses:

- Electric Circuits
- Electronic Instrumentation
- Analog Electronics
- Digital Electronics
- Fields and Waves
- Microelectronics Technology
- Computer Components and Operation
- Computer Architecture, Networks, and Operating Systems
- Laboratory Introduction to Embedded Control
- Control Systems Engineering

This represents all of the introductory level courses in electrical and computer engineering and has created an entirely new learning experience for our students. The Studio facilities are being used to integrate the learning of fundamental concepts and the professional practice skills that are so important to an engineering education. Combining all of these learning activities into the new Studio courses has eliminated separate theory and lab courses.

The ECSE Studios use computer video projection(two per room), high-speed networked computers, and the equipment normally found in electrical/computer engineering laboratories such as scopes, logic analyzers, multi-meters, power supplies and prototyping materials. A key ingredient in these Studios is the creative use of lighting and audio to stimulate student-student and student-instructor interactivity.

Corporations such as Hewlett Packard, IBM, Intel, and Sun have been significant contributors to the creation of these studios.

Of course the artists and architects remind us that they have always taught studios!

In 1996 a number of campus wide process teams were created to look at our programs. The campus-wide team on the introductory curriculum, “The Crossing the Threshold Team,” recommended that all introductory courses move into these interactive formats over the next few years. The Curriculum Reform Implementation Team, chaired by then Dean of Engineering, Richard Lahey, ratified that recommendation and prepared the implementation plans. Although implementation is not yet complete and likely never will be, the result was pervasive use of the studio model.

A Typical Course Day

It is difficult to describe a typical studio course, since there is quite a bit of variation from discipline to discipline, campus to campus, and professor to professor. Although the details differ, there are enough common characteristics to make such an effort worthwhile. Here I will describe a specific studio, Physics I, that has been taught by the author on several occasions and shares most features with the studios taught throughout the physics department. In an effort to achieve some uniformity the Physics I and II sections have a course manager and the syllabus and activities are jointly decided by a committee of faculty.

In most classes, students come to class with a homework assignment of three to six problems to turn in. The first portion of the class is devoted to a discussion of these problems and is much like a recitation. The problems are quite similar to those used in the traditional class except that there are more problems that might use the symbolic mathematics software (Maple, Matlab, or Mathematica), a spreadsheet, or even an object oriented modeling tool. As we go over questions that they have about the problems, we often call on the students to present the solutions. Other students then comment on the problem. We try to hold the problem discussion to within 20 minutes

The students then move into some kind of laboratory or group problem solving activity. In the first class of the semester that activity is adapted from the well known work of Ron Thornton and Laws using the motion detector to measure and graph the motion of students.[24],[25]

Next we present a topic with a five minute discussion followed by a laboratory on that topic. For example, we set up a video camera and had a student throw a ball. The video was directly digitized into the computer and made available over the network to each work area. Students then analyzed the motion using the CUPLE digital video tool, and created a spreadsheet containing the position versus time data. The analysis proceeds in the usual fashion resulting in graphs of position versus time, velocity versus time, and acceleration versus time for each component. The final laboratory report remains in electronic format, although we often have the students record observations on a written worksheet.

The laboratories (22 per semester in the specific case) are performed entirely at each work area. When we introduced Newton's Second Law, we had the students calibrate a force probe and then hang a spring and mass from the probe with an ultrasonic range finder under the mass to measure the position. From this the students can calculate the acceleration versus time and compare to the force divided by the mass.

You may notice that this experiment foreshadows the introduction of Hookes' Law and the topic of oscillations, both of which come later in the course. There are questions on the worksheet that ask the students to observe and comment upon each of these phenomena, but we do not attempt to name them or introduce theory at this time. We try to introduce and explore the concept prior to naming it.

In both examples given above, the computer based laboratory data acquisition and analysis tools are embedded into a hypermedia text that introduces the topics, links the students to related materials, and poses questions for the students to answer with the tools. A consortium of schools led by Rensselaer and the University of Maryland created these hypermedia activities through the CUPLE project. Funding has come from the Annenberg/Corporation for Public Broadcasting, the IBM Corporation, and the National Science Foundation. Teams of faculty and students working together created most of these materials. The student involvement has added a fresh approach to many of the material that is appreciated by the students taking the course. Today, many of these materials have been supplanted by materials developed later or by commercially available materials.

Hands-on activities are an integral part of the Physics Studio. In fact, the number of hands-on laboratories is over twice as large as the traditional course. Each activity is shorter than the traditional laboratory, but it is tightly integrated with both the homework and class discussion. The laboratory portion of the class ranges from 20-40 minutes and is often combined with a computational activity.

Lab activities fall into three major categories: microcomputer based laboratories (MBL) as described above, video laboratories, and modeling and simulation projects. The video laboratories allow the students to take live video of an event (from a handi-cam) directly into their computer and then play that event back as video on each student's computer screen as shown in figure 4. They bring up a graphical overlay on the screen and place points on the graph directly over the object as it moves.

Those of us old enough to have done this with spark marks on waxed tape or with a Polaroid camera will recognize that this is conceptually quite similar and leads to the same kinds of data analysis that we performed. On the other hand, the relationship between the marks and the moving object is far more obvious to the student than it was in the earlier cases. Since we use pretty much the same equipment each week, set up for this lab is limited to bringing in the handi-cam and plugging it into the network. This is also far less cumbersome and less expensive than the specialized equipment that we used to do the spark tapes or strobed Polaroid pictures.

The class ends with a discussion of the material assigned for the next class. At this time we often call attention to the "fore-shadowing" that has occurred in the problem solving and laboratories and pull this together to introduce the next topic. This part of the class is often referred to as the mini-lecture. I prefer to introduce the formalism after the phenomenon rather than before the phenomenon.

Results

We focused on a variety of metrics for success. These are some of the metrics that we looked at:

- Student performance on traditional tests
- Student attendance
- Student performance on cognitive tests
- Student performance on problem solving
- Student attitudes toward the courses
- Student retention
- Faculty attitude toward the courses
- Student success in later classes

Our experiences with the Studio Courses have been very encouraging. Student response is particularly satisfying. They have been quite enthusiastic about the courses as measured by responses on the end of semester surveys. In the Calculus Studio, nearly twice as many students agree that they enjoyed the studio course as compared to the traditional lecture/recitation/lab format.

One question on an external survey conducted by the Dean of the Undergraduate School last semester stirred quite a bit of interest in the administration and faculty. When students were asked whether they would cite a particular course as "a positive reason to attend Rensselaer," over 90% of the students agreed! This compares to 63% who agreed with this proposition in the other mathematics courses that had been downsized but did not abandon the traditional lecture approach. When student responses were controlled for popularity of the teacher and course, there were significant (actually spectacular) gains in students' satisfaction.

Our experiences indicate that instructors are rated far higher in the teaching evaluations in the studio courses. There was one exception to that, a brilliant lecturer who was comfortable with his slightly lower evaluations, because he believed so deeply in what he was doing. This is a significant issue at institutions like Rensselaer where student evaluations and research results play equally major roles in salary, promotion, and tenure decisions. More and more of the research universities are revamping these criteria to re-emphasize the teaching aspects of the professor's role.

Student performance has been a more difficult metric to measure. We saw a variety of results in the various studios. Some showed no significant difference, others showed significant improvement. For example students in the physics studio performed as well as or better than students in the traditional courses in spite of the 33.3% reduction in class contact time. This was demonstrated by student performance on tests matched in difficulty, length, and content to tests from previous years and those given in the same year in the traditional course. In both mathematics and physics, more topics were covered in the studio courses than in the lecture courses.

With the support of an anonymous donor, we undertook a longitudinal study of student performance and attitude that is following the students through their undergraduate career.

Maintaining those improvements does take some vigilance. Later studies of the Physics studio under different instructors showed that learning gains on a focused test of mechanics learning were not improved over traditional alternatives and that the average size of the sections had slipped to just over 30 students.[26] The size of the sections was increased back toward the design goal of 48 to restore the economic efficiency and interactive learning techniques based upon educational research have since lead to further learning gains.[27]

Once most departments introduced Studio classes they retained those models. The department of Mathematics is a notable exception to that. Mathematics involved far fewer of their faculty in the introductory course than did Chemistry, Physics, or Biology. The conversion to the studio did require more faculty involvement and less graduate student involvement, and as a result, the mathematics models evolved in a slightly different direction.

Professor Harry Roy has done some comparison of recitation and computer assisted learning sections in his Studio Genetics classes. While the students received each favorably, neither by itself improved performance compared with the other. However, by combining lecture, laboratory simulations, and problem solving together, student satisfaction improved dramatically.[28]

Roy also reported increased satisfaction as an instructor "*As a teacher I like the studio method far better than lecturing. I feel I have a much better grasp of what my students' difficulties are, and how to relieve those. I get much better interactions with the students and a much more intense involvement of students in the class. Although it is difficult to prove the superiority of one teaching method over another due to the lack of simultaneous control sections, and the small numbers of students, I feel that the students are better able to solve problems in genetics now than when I first started teaching the course with more traditional methods and tools. I have little hesitation in asking them difficult mapping questions on tests - questions that previously I would not have dared to ask them*."

The Studio at Other Universities

The Studio classroom has been deployed at a variety of different kinds of universities and in a variety of disciplines. I am often asked if the studio classroom is something that can only work in large universities, or technological universities, or in technical classes. Nothing could be further from the truth. The challenge was to make these work within the confines of the large technological universities. These kinds of pedagogical models are far more prevalent in the Arts and Humanities and at the Liberal Arts Colleges. Making them work in the environment of the technological university took great care with both the design and the implementation.

When other universities deploy the studio classroom, they invariably put their own spin on the model. Some will acknowledge the relationship to the Rensselaer Studio classroom and others will not. That is not important. What is important is that creative faculty are developing and deploying learning environments that are better for students and better for faculty.

Some of the other Universities that have deployed studio style classrooms include:

- Penn State University (http://www.science.psu.edu/facaffairs/strategic.htm) (http://www.psu.edu/ur/archives/news/GE.html) (http://dps.phys.psu.edu/about.htm)
- Arizona State University (http://www4.eas.asu.edu/phy132/)
- Indiana State Univ. (http://physicsstudio.indstate.edu/)
- Cal Poly San Luis Obispo (http://www.cob.calpoly.edu/Evan/polyplan/polyplan.htm) (http://chemweb.calpoly.edu/phys/)
- Ohio State University (http://www.physics.ohio-state.edu/~ntg/26x/2064_pictures.html)
- The University of Amsterdam (http://www.wins.uva.nl/research/amstel/)
- The University of New Hampshire (http://einstein.unh.edu/academics/courses/)
- The Curtin Univ. of Tech. (Australia) (http://www.physics.curtin.edu.au/teaching/studio/)
- The Univ. Of Mass. –Dartmouth (http://www.aps.org/meet/CENT99/BAPS/abs/S3455002.html)
- The Colorado School of Mines (http://einstein.mines.edu/physics100/frontend/main.htm)
- Acadia Univ. (Canada) (http://ace.acadiau.ca/math/boutilie/)
- Santa Barbara City College (http://www.cs.sbcc.net/physics/redesign/final_report/reportb.html)

The breadth of these efforts makes it impossible to cover each of the programs, and the scale of the dissemination is even more impressive when one considers the many descendents of the “Workshop” courses developed by Priscilla Laws and collaborators. In many respects the Workshop and Studio models share the same intellectual roots.

Going the Distance: The Virtual Studio Classroom[29],[30]

Distance learning is no longer the province of the “correspondence schools” or “diploma mills.” It has become the focus of nearly every great university. Schools like Rensselaer and Stanford have been heavily involved for over a decade through their large programs in engineering education.

In 1999 MIT signed a cooperation agreement with Cambridge University that created a joint venture in technological university education and research. The British government agreed to provide $109 million and to raise $26 million from private sources to create the new center to be based in Britain.[31],[32] MIT has also arranged to provide Singapore with higher education services,[33] and received a $25 million gift from Microsoft to enable the distance-learning portion of the relationship.[34]

New York University has gone so far as to spin off their distance learning program as a for profit venture called "NYU On-line." Their plan is to augment the $1.5 million investment from NYU with capital raised from private venture capital sources.[35]

The Wharton School of Business at the University of Pennsylvania, Johns Hopkins University and Teachers College at Columbia University created a joint venture with Caliber, in turn a joint venture of MCI and Sylvan Learning systems, to offer their programs at a distance. These are all top ranked programs. Although these programs did not evolve in the way that they were expected to by their proponents they remain clear evidence that distance learning has entered the top tier mainstream.

In the rush to the distance learning markets, universities have not always been careful to take into account the lessons learned from the centuries of higher education. Many of these programs are driven by technology and not pedagogy. Technology is a powerful driving force that must be reckoned with, but centuries of history and the recent research coming out of the cognitive sciences on how human beings learn will have much to say about where this technology will take us.

For the virtual university to be successful, it will have to replace the traditional modes of distance learning such as satellite video, tele-training keypad response systems, and interactive video conferencing with a much more robust educational model. Our goal is to provide the distant learner with as much of the studio experience as possible. In this model of interactive multimedia distance learning, one creates a virtual studio with students connected together over a network that carries data, voice, and video to the students' computers. Each student has access to multimedia materials created for the course and delivered from CD-ROM or across the network. In short, we plan to take the studio classroom to the distance!

Part of any virtual classroom will be synchronous activity in which the students and instructors interact through live voice and video while working together with a synchronous collaborative software package. Part of any virtual classroom will be asynchronous activity, or activities done at the students' own time and pace. The actual mix of synchronous and asynchronous activity will be adjusted to suit each course and audience. The more of the course that is conducted asynchronously the more flexible the course can become.

What is to prevent the course from becoming fully asynchronous? If we are to fulfill the desire for anytime/anyplace education then a fully asynchronous course sounds quite desirable. Why should students be bound to a particular time, if not a particular place? There are many efforts underway to do just that. The Sloan Foundation has a program that is funding universities to develop Web or Lotus Notes based courses that are taken at the students' convenience. Interactivity is included through asynchronous use of email, news groups, or other electronic discussion modalities.

Once again history and experience provides a cautionary note. There is a rather long record of efforts to break the constraints of place and time. Some of these were based upon text delivery and others on computing. The completion rate for students in these self-paced courses is often less than can be tolerated. If the education experience is not critical to the student's progress or if the student is well motivated, this may not be a problem. If there are alternative approaches available, then the self-paced models will work very well with the highly motivated. Michigan State has long offered their students a modularized and self-paced physics program, called PhysNet, that was designed along the lines of a Keller Plan course. When the students are not highly motivated or when there is a desire to move large percentages of a group through certain educational experiences, an asynchronous approach might not work. A Ford Motor Company Vice President concerned with education and training tells a story of creating a CD-ROM to introduce a new technique to certain Ford employees. The CD-ROM was designed to support about 15 hours of instruction, but the users were only averaging 1.5 hours. The results were disappointing.

In the tradeoff between synchronous and asynchronous time, we will have to strike a careful balance. Certainly there is a place for asynchronous techniques, but there will also be a need to incorporate a structure of continuous feedback and interaction that insures a satisfactory success rate. The more we are able to move instruction in the asynchronous direction, the more flexible the environment will be and the greater will be the gains in economic efficiency. When the balance is struck it is unlikely to be 100% asynchronous or 100% synchronous.

Our work indicates to us that a course in which most of the activity is asynchronous but which includes regular synchronous meetings might be effective, flexible and efficient. Perhaps 10-20% of the course activity could be synchronous. The synchronous activity also allows one to incorporate the discussion, small group projects, and role playing that are so important to student learning. This model is often referred to as **the 80/20 Model.**

In our experience an effective interactive multimedia distance learning environment (figure 4) will have the following characteristics:

- Delivery on standards based multimedia PC's equipped for live video/audio interactions and connected to a robust ip multi-casting network.
- A mix of synchronous and asynchronous activity.
- Use of Web and/or CD-ROM based multimedia materials.
- Use of professional quality software tools for CAD, symbolic math, spreadsheets, word processing, etc.
- Live audio and/or video interactions among the students and with faculty.
- Email interactions among the students and faculty.
- Small group discussions.
- Collaborative software for application sharing over the network.
- Access to rich resources on the network.
- Ability to "pass the floor" to students to allow them to lead the class through an activity.
- Course administration software to track student progress.
- Classes with a mix of students in traditional and workplace settings.
- Classes with a global perspective and global audience.

In partnership with AT&T, we created a prototype of such a system, which was tested in the AT&T University of Sales Excellence. A follow-on architecture was spun off as the ILINC LearnLinc system, which uses ip multicasting, and agents to reduce bandwidth scaling from n^2 to nearly flat as n (the number of interacting sites) increases.[36]

Each year since 1995 LearnLinc has been put into use in an NSF Chautauqua Program that linked Rensselaer Polytechnic Institute and the School of Engineering at the University of Pittsburgh into linked virtual classrooms. Faculty from around the nation (and Asia and Europe) attend the three-day workshop on multimedia in science, mathematics, and engineering education. The instructor often alternates teaching from Pitt and Rensselaer. Students report that they felt that the instructors were in the room with them no matter where the actual location. Observers noted that the students at a local site would often communicate to one another while making eye contact through the system rather than trying to do so across the room!

In the spring of 1997, Professor Chun Leung used this to teach a graduate course in Astrophysics that teamed a classroom at Rensselaer Polytechnic Institute with a classroom at Hong Kong City University. The course was taught in the early morning in New York and in the early evening in Hong Kong. Students met each day (often enjoying different meals together!) in the paired classrooms. Students made presentations from each site and came to know and work with counterparts that they had never met.

Kent State University has deployed this system to teach nursing, business, and English to branch campuses across the state of Ohio. Our Center for Integrated Electronics and Manufacturing has delivered a short course in Chemical Mechanical Planarization to semiconductor fabricators like Intel, Matsushita, Applied Materials, and others. One of the sites reached was in Osaka, Japan.

Professor Bradford Lister, Director of the Rensselaer Anderson Center for Innovation in Undergraduate Education, has developed two innovative distance learning courses for the National Technological University.[37] *Hands-On Multimedia* and *Hands-On World Wide Web*, combine satellite broadcasts with synchronous web-based tutoring sessions and asynchronous hands-on exercises conducted via the Internet. *Hands-On Multimedia* was restricted to 100 students at six sites, while *Hands-On World Wide Web* attracted over 8000 participants at 500 sites in the United States and Asia. These virtual studio courses used WebCT, ILINC LearnLinc, Citrix Winframe server, and MS Internet Information Server. Lionel Baldwin, the President of NTU described this course as “the future of distance learning.”

Conclusion

The studio model has been adopted broadly across Rensselaer in situations where it fits with the academic objectives and resource availability. Although a faculty process team had called for a complete conversion of introductory courses to the studio model, that has not been accomplished. As we looked more carefully at doing that, it did not make sense to make it a mandatory goal. We now have many advanced level courses that are taught in the studio style and even a few graduate courses. We expect that mixture to continue to be in place indefinitely. There is no need or desire to convert all courses.

The studio model has also been adopted outside of Rensselaer, although each model is different, as the model is adapted to local circumstances and culture. The ability to adapt is one of the strength of the Studio classroom. It is not a prescriptive approach that defines rigid standards and specific activities. It is more of a collection of philosophical goals and pedagogical practices that can be used to design a course to be an effective and efficient learning environment in which the student is active, engaged, and collaborating with other students.

There seems to be no obstacle to use of the model in distance learning environments and our experience shows that it can be an environment that is friendly to student and faculty and conducive to learning.

There will be many new variations on the studio theme and many other models deriving from the same research and experience base. That is good news for the students and the faculty of the future. It will be a good place to learn and a good place to teach.

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