BioCalc:
A Model for Teaching Calculus to Biology Students
at the
University of Illinois at Urbana-Champaign

Presented by

*The Institute on Learning Technology*

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![National Institute for Science Education](image)

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READER’S GUIDE

Special terms appear in the Glossary. Terms featured in the glossary are hyperlinked the first time they appear in a section. (In printed text, hyperlinks appear underlined.)

All citations to which this case study refers are listed in the References.

Technical asides are indicated by numbered endnotes and appear to the online reader in a mouse-over box. (These asides also can be found in the Endnotes.)

Various topics introduced in the study are developed at greater length in Discussions (specified by number) to which the reader is referred at relevant points.

The reader is referred at relevant points to various other Resources (specified by letter). Among these is a short description of the Methods Used to Produce this Case Study (Resource B).

Of note for users of the web version: Clicking the “previous page” button will take you to the previous linear section of the case study, not necessarily to the page which you last visited. Clicking the “back” button of your web browser will return you to the section last visited.

We use pseudonyms for the students who appear in the quoted material. Pseudonyms used for non-student interviewees are marked with an asterisk (*) when used for the first time. To help avoid confusion, the researchers are identified as "interviewer" the first time their name appears in an interview segment.

The instructors and administrators who are identified in the case study read this document and gave us permission to use the quotes we attribute to them. The UIUC readers also affirmed that this case study conveys the essence of what they were doing in the spring of 2000.
INTRODUCTION

“Using the Mathematica notebooks, we could design a course in which students make their own observations and learn in much the same way researchers do: through discovery, visualization, and experimentation.”

--Jerry Uhl, Professor of Mathematics

Throughout the last decade, many math departments in U.S. colleges and universities have been quietly (and, in some cases, not so quietly) taking steps to improve introductory calculus courses. These courses have traditionally served students majoring in disciplines other than mathematics (e.g., engineering, biology, physics, chemistry, economics) who require competency in calculus for advanced study in their respective fields. The fact that students who are otherwise academically solid often struggle with learning calculus has fueled efforts to reform how calculus has been taught. To create a learning environment better suited to non-math majors, many reform courses have focused not only on teaching calculus but also on applying it effectively and meaningfully in other fields.

At the University of Illinois at Urbana-Champaign, Professor Jerry Uhl has been working to develop and implement reform calculus courses since the late 1980s. Well known for the Calculus&Mathematica courseware that he and colleagues developed at UIUC, Uhl has used his expertise and experience to assist the UIUC School of Life Sciences (SOLS) in the creation of an introductory calculus course offered specifically to life science students. The course, called BioCalc, is just one example of the efforts taking place across campuses to improve introductory calculus education for non-math majors.

What is BioCalc?

BioCalc is a special section of Math 120 (Calculus I), an introductory calculus course required of all life science majors at UIUC. Rather than lectures and textbooks, however, the instructional medium for this course is a sophisticated symbolic manipulation software program, Mathematica, that integrates text, lots of graphics, and commands into an electronic “notebook” format. The program is used to run the Calculus&Mathematica (C&M) courseware developed by Uhl, Horatio Porta and William Davis.

The idea for a BioCalc course was conceived when Uhl, already teaching a number of math courses with C&M courseware, was approached by a SOLS faculty member who was concerned because life science students were not performing as well as expected in traditional, lecture-based calculus courses. After pointing out that many of the examples and applications used in C&M courses were in fact drawn from the life sciences, Uhl suggested that a C&M calculus course could be designed specifically for life science students. Such a course would place a greater emphasis on the crucial connections between calculus and life sciences.

Jerry: Life science growth models reinforce the idea of the derivative [because] the derivative measures growth rates. [The C&M courseware lessons] include problems on modeling the growth of animals, predator-prey models, blood alcohol levels, cigarette smoking and lung cancer correlation, carbon dating, as well as data analysis of the U.S. population in historical context, including plots of yearly growth.

The new course would use the same format and instructional materials as the C&M Math 120 courses already being offered. The difference would be the greater emphasis on life science applications. BioCalc was soon being offered as the introductory calculus option for life science majors.

What happens in BioCalc on a typical day?

Students spend most of their class time working through C&M lessons on the computer. The basis of each lesson (roughly akin to a textbook chapter) is a section entitled “Basics,” which introduces students to the key concepts and ideas of the lesson, and another section entitled “Tutorial,” where students learn methods and applications through a series of interactive questions and answers. At the end of each lesson, students are asked to complete a section of questions called “Give It a Try,” which they then submit electronically for grading and review. Also included with each lesson is a “Literacy Sheet,” which students are required to complete by hand.

For an example of a C&M homework problem, see http://www-cm.math.uiuc.edu/homework_examples.html.

Students are encouraged to work together. Thus, in a BioCalc classroom there tends to be a good deal of conversation. The instructor often wanders about the room, checking on students’ progress and offering help in the problem-solving process. For the most part, however, students are engaged in learning from the interactive lessons and from one another.

“What’s calculus good for, anyway?”

Students in calculus courses frequently lament, “What’s this stuff good for, anyway?” It’s a question that’s being given serious consideration by biology departments, as well. Do students in the biological sciences really need calculus? If so, how can calculus education
be improved to more adequately serve their academic needs? Is there room in the curriculum—and the budget—for such efforts?

There’s little doubt that most life science students do need and will make use of calculus, especially as advances in fields such as genetics and bioengineering highlight the need for higher-level math skills. To keep pace with such advances, departments are beginning to require students to take more advanced math and computer courses. Additionally, the nature of undergraduate biology education is changing as departments attempt to keep pace with the demands of the workplace. Charles Miller, director of the School of Molecular and Cellular Biology, noted:

> There are many employment opportunities now for students in the biological sciences at all levels, from bachelor’s to master’s. Years ago, [the thing to do with a life science degree] was go to med school. But now there are many other opportunities, and biology departments have to respond to that. At UIUC, we’re trying to design a curriculum that allows students—those who aren’t pre-med, for example—to take advantage of the opportunities that are waiting for them when they graduate.

To be adequately prepared, students need to have the appropriate quantitative skills. Courses like BioCalc are part of the effort to better prepare these students for the challenges they’ll meet beyond the university.

**Is it working?**

An assessment conducted at UIUC on the BioCalc Math 120 course has concluded the following:

- BioCalc students receive higher grades in Math 120 than non-BioCalc students.
- BioCalc students are as well-prepared for Math 130 [the second semester of introductory calculus] as non-BioCalc students.
- BioCalc students are significantly more likely to take an additional math course than non-BioCalc students.
- BioCalc students are slightly more likely to remain in a biological science major than non-BioCalc students.

As Brad Edge, a graduate teaching assistant in the math department and a frequent BioCalc instructor, noted, “We’ve got students majoring in the life sciences who are finding that mathematics is something they enjoy—in some cases, enough to come work in our program [as classroom or lab assistants]. They don’t give up their interest in life sciences. If anything, the opposite happens: they find that mathematics is not as separate from what they’re doing [in life sciences] as they first thought.”
Wow. How can I get my students to respond like that?

The UIUC folks were quick to point out that improving student learning involves a lot more than simply adding a computer to the classroom. In the following sections, we offer you their story—how BioCalc was conceived and implemented, how it has been received and assessed in the academic community, and perhaps most importantly, the philosophies and principles behind this particular approach to teaching. It is our hope that this story may serve as a guide to others who are dedicated to improving student learning in SMET disciplines.

The Bricoleurs

Throughout the LT² case studies, we refer to the creators of new learning environments as *bricoleurs*. It’s a French term that roughly means “handyman.” We use it to describe a person who is adept at finding (sometimes disparate) resources that can be used to achieve this person’s goals, particularly as they pertain to creating learning environments that encourage student participation and interaction. In this case study, the *bricoleurs* are Jerry Uhl, Bruce Carpenter, and Brad Edge.

Uhl’s success with and enthusiasm for C&M courses has drawn interest and support from international, national, and local colleagues. In particular, at UIUC both Bruce Carpenter, a teaching associate, and Brad Edge, a graduate teaching assistant, have been instrumental in promoting BioCalc as a resource for life science students at UIUC.

Jerry Uhl is a professor of mathematics at the University of Illinois, Urbana-Champaign. Since the late 1980s, he has devoted much of his time to Calculus & Mathematica and other computer based courses in differential equations, linear algebra and probability. Uhl is also involved with NetMath, a distance education program that utilizes C&M courseware. He has just completed a term on the Mathematical Sciences Education Board of the National Research Council, and in 1998 he received an award for distinguished teaching from the Mathematical Association of America. Uhl has lectured across the country, as well as in England, Ireland, Germany, Greece, Egypt, Switzerland, Puerto Rico, Japan, Singapore and South Africa.

Bruce Carpenter is a teaching associate in the Department of Mathematics. He frequently teaches BioCalc and other C&M courses. In addition, he is instrumental in coordinating and teaching in the Calc & Chem Prime Program, a summer math and chemistry program for life science students who do not score high enough on placement tests to directly enroll in Math 120. Bruce has also developed interactive learning tools to be used with Mathematica and is a consultant with Math Everywhere, Calculus & Mathematica’s publisher.

Brad Edge is a graduate student in the Department of Mathematics and a frequent BioCalc instructor. Brad was thirteen years old when he had the sudden realization that he wanted to be a mathematician when he grew up and has spent much of his time since that moment working to become one.
While teaching a Calculus & Mathematica BioCalc section, he realized (somewhat to his surprise) that he was enjoying the process and involved himself more in C&M and teaching in general. Eventually, part of his graduate assistantship was acting as assistant director of the C&M program, handling many of the administrative details. He has since given up the job to pursue work toward his degree but remains interested in education and convinced of the effectiveness of the Calculus & Mathematica program. He is married, and has two young daughters.
THE SETTING

In the mid-1990s, two important trends in higher education coalesced at the University of Illinois at Urbana-Champaign. The first was increased enrollments in undergraduate life science programs; the second, the implementation of introductory calculus reform projects. The result was the development of an innovative calculus course created to meet the specific needs of life science students. In this section of our case study, we briefly examine those trends and how they played out at UIUC, ultimately giving rise to the learning environment featured here—BioCalc.

Increased Enrollments in Undergraduate Biology Programs

Between 1991 and 1997, undergraduate degree awards in the biological sciences at U.S. colleges and universities increased 49 percent (Snyder 2000). The dramatic increase in enrollments has had serious impacts for biology departments, leading to larger class sizes, decreased student-faculty interaction, and strained resources.

In order to control enrollments in particular areas, colleges and universities frequently use gateway courses. These large, impersonal introductory courses are used to “weed out” certain students in what is typically viewed in academia as a process of natural selection. Such practices, though not officially acknowledged, are widespread, especially in SMET disciplines.²

At UIUC, enrollment in the School of Life Sciences³ in the early to mid-90s reflected national enrollment trends. Enrollments jumped dramatically, then slowly leveled off.⁴ Despite the burdens of higher enrollments, however, faculty and administrators with whom we spoke attested that the aim of the school was to retain its students, not send them packing.

“Weeding out is not a philosophy here,” explained Susan Fahrbach, professor of entomology and faculty director of the Howard Hughes Program in Life Sciences. Instead, the school focuses many of its resources on creating programs and opportunities that help its students succeed. BioCalc is one such effort.

During our interviews, Jerry Uhl recounted to us how, in the early 1990s, Sandra Lazarowitz,⁵ at that time a faculty member in UIUC’s Department of Microbiology and director of the Howard Hughes Program, grew concerned over the struggle many life science students were having not with their entry-level biology courses, but with the introductory calculus courses that are prerequisite to earning a degree in Life Sciences at UIUC (Table 1). In particular, Uhl recalled, she was alarmed to find that nearly sixty percent of life science students were receiving grades of C or lower. After speaking to biology faculty with similar concerns, Lazarowitz decided to take up the issue with the math department. Someone there gave her Uhl’s name.
Calculus Reform

In the 1980s, there was a growing concern in higher education that calculus, as it was currently being taught, was not serving the needs of its students. Failure rates in typical, lecture-based calculus courses were sometimes as high as fifty percent. Students who did pass were able to do the calculations (i.e., “plug and chug”) but often seemed to lack a clear understanding of the concepts behind the work. The calculus reform movement, as it became known, aimed to help students learn not just calculations but concepts and applications, as well.

The National Science Foundation began funding calculus reform projects in 1988. One of the first projects funded was at UIUC, where Uhl and two math colleagues, Horacio Porta (also at UIUC) and Bill Davis (at Ohio State University), were developing a computer-based calculus course. Looking for a way to improve student learning, they had come across Mathematica, a technical computing system that combined the ability to perform calculations (both numeric and symbolic) with strong visual and text capabilities. Uhl was intrigued less by the program’s computing capabilities than by its ability to “mix texts with commands,” a feature that he saw as a potentially powerful learning tool.

Converging Trends at UIUC

By the time Professor Lazarowitz contacted him, Uhl had successfully implemented a number of courses using the Calculus & Mathematica (C&M) courseware (see Table 2 for C&M courses offered at UIUC). These courses, however, had been developed primarily for engineering students.

“I don’t know where she got my name,” Jerry recalled, “but she called me and said, ‘Do you have anything to offer?’”

I said, “We have a course that we’ve developed—for engineers—but it just so happens that many of the activities in this course use life science models.” After all, the derivative measures growth, and what grows? Populations, animals, etc. So I told her we had a course that we could pitch at life science students without really making any significant changes in the course itself.

In fact, very few modifications were needed to get this new course going. BioCalc, as it came to be known, was first offered to life science students in the fall of 1994. Though the content was introductory calculus, the examples and applications were drawn from the life sciences.
Table 1. Required Math Courses for UIUC Life Sciences Options (Spring 2000)

<table>
<thead>
<tr>
<th>LIFE SCIENCES OPTIONS</th>
<th>Required Math Courses</th>
<th>Recommended</th>
</tr>
</thead>
<tbody>
<tr>
<td>General Biology</td>
<td>120 (or 135)</td>
<td>130 (or 245)</td>
</tr>
<tr>
<td>Honors Biology</td>
<td>120; 130 (or 135); 242 (or 245)</td>
<td></td>
</tr>
<tr>
<td>Bioengineering</td>
<td>120; 130 (or 135); 242 (or 245); 285</td>
<td></td>
</tr>
<tr>
<td>Biophysics</td>
<td>120; 130; 242; 285</td>
<td></td>
</tr>
<tr>
<td>Cell &amp; Structural Biology</td>
<td>120; 130</td>
<td></td>
</tr>
<tr>
<td>Ecology, Ethology &amp; Evolution</td>
<td>120 (or 135)</td>
<td>130 (or 245)</td>
</tr>
<tr>
<td>Entomology</td>
<td>120 (or 135)</td>
<td></td>
</tr>
<tr>
<td>Microbiology</td>
<td>120 (or 135)</td>
<td></td>
</tr>
<tr>
<td>Molecular &amp; Integrative Physiology</td>
<td>120 (or 135); 130 (or 245)</td>
<td></td>
</tr>
<tr>
<td>Plant Biology</td>
<td>120 (or 135)</td>
<td>130 (or 245)</td>
</tr>
<tr>
<td>Teaching Major</td>
<td>120 (or 135)</td>
<td></td>
</tr>
</tbody>
</table>

MATH 120. Calculus and Analytic Geometry, I
MATH 130. Calculus and Analytic Geometry, II
MATH 135. Calculus (Alternate Sequence)
MATH 242. Calculus of Several Variables
MATH 245. Calculus II (Alternate Sequence)
MATH 283. Linear Programming
MATH 285. Differential Equations and Orthogonal Functions

Table 2. UIUC Math Courses Taught with C&M (with links to syllabi)

<table>
<thead>
<tr>
<th>Course Number</th>
<th>Course Title</th>
</tr>
</thead>
<tbody>
<tr>
<td>Math 120</td>
<td>Calculus I</td>
</tr>
<tr>
<td>Math 130</td>
<td>Calculus II</td>
</tr>
<tr>
<td>Math 135</td>
<td>Calculus I (Alternate sequence)</td>
</tr>
<tr>
<td>Math 225</td>
<td>Introductory Matrix Theory</td>
</tr>
<tr>
<td>Math 242</td>
<td>Calculus III</td>
</tr>
<tr>
<td>Math 245</td>
<td>Calculus II (Alternate sequence)</td>
</tr>
<tr>
<td>Math 285</td>
<td>Differential Equations</td>
</tr>
<tr>
<td>Math 315</td>
<td>Linear Algebra</td>
</tr>
<tr>
<td>Math 361</td>
<td>Probability and Statistics</td>
</tr>
</tbody>
</table>
LEARNING PROBLEMS AND GOALS

Well, the whole history of this started when I got a call from Sandra Lazarowitz [in the Department of Microbiology at the time], and she said that she and other life science faculty were very upset with the standard calculus course. She said she had talked with someone in the math department and had told him that biology students just weren’t tuning into this course—over sixty percent were getting Cs, Ds or Fs. The math professor said, “Well, we can’t help it if you have stupid students.”

--Jerry Uhl, Professor of Mathematics

We have high admission standards to the program. If you write ‘biology’ or ‘life sciences’ on your application, you will be subjected to greater scrutiny than in any other program in this University, with the possible exception of engineering.

--Charles Miller, director of the School of Molecular and Cellular Biology

In this section of our case study, we present the problems that provided the impetus to create this new learning environment, as well as the goals that our bricoleurs and others sought to achieve through its implementation.

Learning Problems

To learn about the problems that BioCalc was implemented to address, we talked with faculty and administrators in both the Department of Mathematics and the School of Life Sciences. In these discussions, two key problems were reiterated:

- First, what we call the “weed out” problem: students were unable to fulfill the math requirements of their intended life science major and, as a result, were leaving life sciences altogether.
- Second (to borrow a phrase from Jerry Uhl), the “preach and pray” problem: faculty in the life sciences assumed that even those students who had successfully completed the required math course(s) were unable to connect what they had learned in math to what they were studying in life sciences.

The Weed Out Problem

Many students—not just at UIUC, but across the country—identify introductory SMET courses as major barriers to fulfilling the requirements of their chosen majors (Seymour & Hewitt 1997). These “weed out” courses typically serve the dual purposes of curtailing enrollment while enabling certain types of students to proceed to advanced study in these fields.

No one with whom we spoke at UIUC specifically labeled Math 120 (Calculus and Analytical Geometry I) as a weed out course. Yet, the students we interviewed described their experiences

\( ^a \) Jerry: “Preach and pray. Preach in your math class, and pray they [the students] make the connection.”
in traditionally-taught introductory calculus courses as confusing, frustrating and overwhelming—experiences that Seymour and Hewitt note are common in “weed out” courses. As a student hoping to major in biochemistry told us,

"[My traditional calculus class] was so confusing and frustrating. I’d do homework for, like, 30 hours every night, and I’d still sit there and stare at the problems and not get it. And I really need this class. I can’t declare my major until this class is out of the way. So I was trying, but I was getting a D. I went to [the instructor] and asked for help and she said, “Well, if you don’t understand it, maybe you should be in another section or a different math course.” So I dropped it."

Elizabeth, another life sciences student who had previously enrolled in a traditional calculus course, related her frustration with the fast pace of the course. She commented that it seemed to her that most of the other students in the course had taken calculus in high school and that the professor had adjusted the pace to suit those who were already familiar with the material.

"He went through things really fast and assumed we all knew it, when we didn’t. So it was really hard to follow. He would just write things across the board—derivatives of this-and-that—and I would copy it down, but I’d be so busy writing that I wouldn’t have time to understand it. Then he would do the same thing in the discussion section, just write a bunch of problems. He wouldn’t really take the time to explain each step, just “It goes from here to here to here, and that’s that.” ...After a while I just stopped going. I didn’t understand it, so I didn’t want to do it."

Another student commented that the language used in his calculus course was off-putting and hard to understand.

"Mark: I don’t remember anything from that class. The teacher explained it in a way that was—well, I guess the other students had had a lot of math, because they talked in, like, math talk. And I did not understand the teacher at all."

Other students related that they were intimidated by the math, even before actually enrolling in the course.

"Steve: I’d say my biggest fear coming into the class was that, well, basically, it’s calculus and in high school I took honors trig precalc, but not calculus. So, you know, words like “derivative” and “integral” scared me."

Paul Weichsel, associate chair of the Department of Mathematics, told us that students from other disciplines often balked at having to take math courses, especially when their scores on the University’s math placement exam required that they enroll in pre-calculus courses.

"These students were told they’d have to [first] take algebra, and they were saying to their advisors, “I don’t want this. I want to study life sciences. Why do I need to take algebra?” And then they would say, “If you’re telling me that the only way I can study life sciences on this campus is to take those courses, I’m not going to do it. I’m either
In short, some students, for the reasons cited above, were either leaving or not enrolling in life science programs because of one course: introductory calculus.

**The “Preach and Pray” Syndrome**

While the life science students we interviewed described, in effect, being “weeded out” of traditional calculus courses, BioCalc advocates identified another key problem: Neither faculty nor students in the life sciences viewed calculus—as it traditionally taught—as relevant or applicable to the study of life sciences. To Jerry Uhl, this traditional, lecture-based approach to teaching calculus boils down to a “preach and pray” approach—“Preach in your math class and pray [the students] make the connection.”

At UIUC, students often did not see the connection between math and their own course of study. Ruth Wene, an advisor in the School of Life Sciences, told us that to many life science students, calculus “seemed entirely irrelevant to anything that they thought they were going to be doing in the future.”

As the students experienced it, required courses that seemed to them irrelevant were all the more uninteresting and difficult. One student with whom we spoke described the equations drawn on the board in his traditional calculus course as little more than scribbles: “I would sit in lecture, and the professor would just scribble on the board with chalk, just big scribbles everywhere. She would talk and talk and talk and scribble away on the board.”

Such attitudes may be reinforced by the fact that, as often happens, instructors in non-math disciplines do not depend on their students being able to transfer math skills to a non-math context. This, as Jerry put it, is a catch-22: “The instructors don’t expect their kids to know any calculus, even though the students have had calculus. So the instructors don’t use it.”

Faculty weren’t using calculus in their courses because they perceived that students were not learning skills that they could transfer to their life science classes. Because of this, Ruth noted that some life science students weren’t even taking the required introductory calculus courses until their senior year. And a student with whom we spoke told us he’d taken BioCalc two and a half years earlier and hadn’t “had to use much calculus since, in any classes. I was taking science classes, but really there’s no incorporation of math.”

It’s important to point out, of course, that the disconnect between math and other disciplines is not limited to life science students, nor is it merely a problem at UIUC. Rather, as Bruce explained, the problem stems from the fact that most math courses provide little or no connections to other disciplines.

*One of classic things that happens—and not just at this university (because this happened when I was an undergraduate in engineering)—is that [instructors in other disciplines] basically teach their students the math they’ll need to know in order to take their course. Even though they have math courses as a prerequisite, instructors don’t depend upon the students actually being able to use the mathematics as a tool to do, say, engineering.*
This stems from the fact that “there’s no real interdisciplinary approach to math courses,” Bruce told us. Brad Edge, a BioCalc instructor and graduate student in the Department of Mathematics, pointed out that this problem is prevalent in math education and is related to the way in which mathematicians experience their discipline—that is, as purely abstract. Consequently, mathematicians often teach it that way, as well.

**Brad:** It’s taught very abstractly. We’re getting now to problems that are endemic to the entire mathematics education system. Students are used to the idea that mathematics is symbols; it’s an abstract pursuit. ...Because we [mathematicians] don’t teach it well. We don’t successfully teach students mathematical concepts as tools that they can use in their future pursuits.

An abstract approach to teaching mathematics, while useful for students studying to be mathematicians, is problematic for those who need disciplinary application experiences.

**Goals for Improving Student Learning**

The UIUC *bricoleurs* expressed a variety of goals for student learning, all centering on remedying the deleterious effects of “weed out” courses and instilling in students not only a solid understanding of mathematical concepts, but also how those concepts apply outside the math classroom.

When asked about his goals for student learning, Jerry commented that his first goal “was for students to come out of our course not thinking it was a waste of time.” BioCalc, for example, uses real world problems and examples to emphasize the relationship between calculus and the study of life sciences. Students are more motivated to learn when they can see and understand this important connection.

Brad told us he wanted students to find the course useful, but also wanted them to enjoy it—to discover “the joy of mathematics itself.” Perhaps more importantly, though, he wanted students to discover that they can indeed “do math:"

*I want my students to come out of my classroom with some feeling that not only wasn’t it a waste of their time, but that there’s room to think of mathematics as if it could be fun. And I also want my students to believe that it’s something they can do. Because one of the things that we really impose on people in mathematics education in this society is the impression that they can’t do it. Now, I’ve taught a number of different classes. I’ve taught a number of different types of students. And I’ve not found anyone that just can’t do math, despite their own belief that that’s the case.*

Steve, a former student of Brad’s, clearly picked up on these goals:

*Brad was very enthusiastic about Mathematica. We all got a kick out of it because he told us how he owned it in high school and how he loved graphing functions and stuff. He was always upbeat about it. I could see it was one of his goals for us to really enjoy it and like
it. You know, for some people, math is just math, but Brad really enjoyed it. He really found it a fun challenge—doing hard problems—and I know he just wanted us to get what he had gotten out of it.

Bruce told us his goals were two-fold: “rescuing” students who’d had previous negative experiences with math, and instilling in students (as literate citizens and future taxpayers) an appreciation for math and math research:

The goals are slightly different when I’m speaking for myself personally than when I’m speaking as an educator. The personal thing that I would want students to get out [of my class] is related to the fact that I teach a lot of math refugees. I teach students, a lot of students, who are literally fleeing from past math experiences. So personally, I want to at least let the students know that what they’re fleeing from is not the mathematics. I want them to know that part of the joy is being able to understand mathematical concepts and use them and that [the negative experience] was more a function of how they were taught math. That’s my personal goal. As an educator, I want these students to develop a sufficient appreciation of mathematics so that when they grow up and have children, they are willing to pay taxes to keep things [like this going]. I mean, mathematical research is in jeopardy. It’s not seen as a vital activity.

Moreover, nearly everyone we interviewed wanted students to be able to bridge the gap between learning calculus in a math class and using it in a life science course.

Bruce: [Life science faculty] don’t really expect their students to know any math; they don’t use mathematics—they don’t use calculus in the courses—so it’s not really utilized. Jerry: Sandy Lazarowitz’s hope was that that would change.
CREATING THE LEARNING ENVIRONMENT

One of the things I've become convinced of in my reading and thinking on the subject is that in order to truly understand mathematical ideas, you have to be able to visualize them.

--Bruce Carpenter

In this section, we examine the learning environment that the UIUC bricoleurs have created to achieve their goals for student learning. Specifically, we will look at how BioCalc works—the tools that are used, the learning activities assigned, and the learning processes that are enabled by this type of environment. But first, the bricoleurs shared with us their thoughts and ideas about how students learn.

The Learning Process

In our talks with Jerry, Bruce and Brad, it became quite clear that the ideas informing their classroom practices do not focus on teaching per se, but on learning. They described to us a learning environment based on the principle that learning best occurs when participants are engaged in an active and contextual manner.

That explains why Jerry is so adamant about why the BioCalc and other C&M courses work: they are designed to, in his words, “actively engage the students in their own learning.” He believes that students don’t and won’t learn math by sitting passively and listening to lectures; effective learning depends on student engagement and interaction—with ideas and concepts, with instructors, and with each other.

The bricoleurs believe that the most effective way to engage students is to introduce mathematical ideas visually—through graphs and pictures—before lengthy and complex descriptions enter the picture. They call these visuals “math kitties,” in reference to an observation about learning by famous mathematician Ralph Boas:

Suppose you want to teach the “cat” concept to a very young child. Do you explain that a cat is a relatively small, primarily carnivorous mammal with retractile claws, a distinctive sonic output, etc.? I’ll bet not. You probably show the kid a lot of different cats, saying ‘kitty’ each time, until it gets the idea.

And the math kitties in the C&M courses are not just visual; they’re interactive, too. The math kitties, Jerry explained, “introduce an idea with graphics the student can play with before the technical words go on.”

“We give our students lots of math kitties,” Bruce reiterated, adding that “one of the things I’ve become convinced of, in my reading and thinking on the subject, is that in order to truly understand mathematical ideas, you really have to be able to visualize them.” He continued:
Half of our brain is devoted to processing visual information. In dreaming, for example, emotional reactions are intimately tied to visualization. You actually start responding emotionally to something you see before you consciously recognize it. There are good evolutionary reasons for that, of course: you need to gear yourself up emotionally to run long before a threat is actually cognized.

Bruce pointed out that this process is an important one to understand when thinking about how students learn.

The point is that students start responding—they have an emotional reaction—to the classroom situation long before they have a conscious reaction. So in order to understand mathematics, it has to tie into that visual processing center. It’s not just pictures—it’s also relationships. It’s connections. It’s sequencing. It’s logical planning. All those things are bound up in visualization, in the ability to imagine it. These pictures that the students see [in the C&M courseware] are triggers: they spark that visualization process. We actually provide an environment where students can get visualization triggers that they then complete in their minds.

In essence, the math kitties trigger the learning process; that is, they stimulate students to think about and interact with what they see on the screen. This powerful process, Bruce noted, is often not enacted in more traditional, lecture-based courses. As a result, students often do not retain what they’ve learned.

A typical lecture/discussion format does not take advantage of that visual processing at all. I’ve taught all the standard lecture sections, and in talking with students, it’s clear that they can mimic the words but there’s no gut reaction to what they’re talking about. There’s no visualization. They’re not actually carrying on any visual processing. It’s all in the fore brain, which is why it leaves.

We asked Bruce how he can tell when the visualization process has been enacted. He told us his first clue is laughter.

Frequently when students bring a plot up on screen, they’ll laugh. I look for the laugh. That’s a big trigger, because the laughter means that they’ve had an emotional response to what they’re seeing. Then they can come along and start processing it and explaining it. But the emotional reaction is primary—it’s first—and conscious awareness comes afterwards.

As Bruce acknowledged, this type of thinking about student learning focuses on process rather than product. Understanding how students learn, and taking advantage of that, will help to improve what (and how much) they learn. Moreover, as Jerry put it, the primacy of process more closely reflects the way in which mathematicians themselves learn to do math.

Jerry: We were all research mathematicians when we started [developing the C&M courseware], and we learned by working. So we said, “We want our students to go about math the way we go about math.” Which means you’re not necessarily operating on a
Susan (interviewer): Can you explain that?

Jerry: Can I have a piece of paper? See, conventional teaching says, “This is your course. On day one, we’re doing this. {Draws a straight line.} Day two, we’re doing this. {Draws another straight line.} Day three... and eventually we have a completed student product.” Now, that’s not the way people learn at all. I think people learn this way. {Draws squiggly lines on paper.}

The BioCalc bricoleurs believe that giving students a contextual environment in which to learn is important. Not only does it give them a better idea of “what this stuff is good for” but also helps them to gain a genuine understanding of the interconnectedness of ideas. As Bruce pointed out, “Understanding is more than just memorizing a collection of facts; it’s knowing how things relate to each other.” Yet, too often it seems students memorize facts without understanding the underlying concepts and connections.

An emphasis on relationships is central to the design of BioCalc and the other C&M courses because, as Bruce put it, knowing facts without knowing the connections is “sterile knowledge:”

I call it head knowledge versus gut knowledge. Head knowledge is where all the facts are stored, but it’s in my gut where all the relationships are stored. If you have one without the other, you have sterility. In fact, it’s like the connection between algebra and geometry. If you understand something algebraically and don’t understand the geometry, you’ve only got ten percent of the picture. And if you understand something geometrically but don’t understand it algebraically, you’ve only got ten percent of the picture. Eighty percent lives in the connections between the two. That’s where the really important stuff happens, in the connections. And one of the things that we emphasize strongly in this course is the interconnections between ideas.

The Learning Environment: Tools and Activities

Ideas about how students learn are an important foundation in the creation of a learning environment, but how do such principles translate into actual practice? Let’s take a closer look at the BioCalc learning environment to find out.

As stated earlier, BioCalc is a section of Math 120 (Calculus and Analytic Geometry I) offered specifically to life science students. It uses the Calculus&Mathematica courseware in conjunction with Mathematica software and heavily emphasizes life science examples and applications in order to help students learn calculus concepts in a meaningful context.

BioCalc classes meet in a computer lab four days in week, where students spend their time working through lessons presented in an electronic notebook format. One day a week, the class meets outside the computer lab for a discussion period and for practice doing hand calculations. (Class periods are 90 minutes each day.) All Math 120 students earn five credit hours. Students in BioCalc earn an additional credit for learning the Mathematica program.
Instructors (primarily graduate students) are responsible for assigning lessons, preparing exams, and conducting discussions. During class, they act as guides to the students, often walking about the room, discussing problems and helping students find the answers to their own questions. Tim Braun, a C&M student and lab technician who has observed many classes, described the role of the instructor in typical C&M courses:

*In the lab, the faculty are there to guide their students more, to make sure that they’re getting the basic concepts. The best instructors generally wander around the lab looking at what each group of students are doing. If they see students stuck, they try and help explain them through it without just handing them the answer. They’re there just to see how their students are doing—more than anything else, to just kind of guide them along. It’s a lot of calculus. Mathematica is self-discovered through the lessons, but you do need guidance. That’s what the faculty are there for. They keep you on the right track if you’re missing a concept or just not getting what the lesson is trying to teach and getting really frustrated. They’ll help get you right back on track.*

There is also a classroom assistant (a veteran C&M student) who is available to help students, as well. The CAs are equipped to handle the more technical questions about Mathematica but also field student questions that arise from the lessons. Brad explained:

*An undergraduate assistant is assigned to each class. The undergraduate assistant is someone who has experience with the Calculus & Mathematica program and with the mathematics for that course, so they can answer questions. They’re sort of a front-line resource for the students, who can ask them for help with the Mathematica code or with lower level mathematics questions.*

There are no textbooks in the BioCalc courses. Instead, students use the Calculus & Mathematica courseware, which features a series of electronic “notebooks.” The notebook format is a unique attribute of the Mathematica software; it allows the combination of text, commands and graphics to function in a single interactive electronic document.

The C&M notebooks are divided into discrete, thematic lessons. The lessons presented in BioCalc (as well as other C&M sections of Math 120), for example, include:

1. Growth  
2. Natural Logs and Exponentials  
3. Instantaneous Growth Rates  
4. Rules of the Derivative  
5. Using the Tools  
6. Differential Equations of Calculus  
7. The Race Track Principle  
8. More Differential Equations  
9. Parametric Plotting  
10. Integrals for Measuring Area  
11. The Fundamental Formula  
12. Measurement

*A C&M Math 120 syllabus is online at [http://www.cm.math.uiuc.edu/pages/syllabi/120/120syl.html](http://www.cm.math.uiuc.edu/pages/syllabi/120/120syl.html). A syllabus for a traditional, lecture-based section of Math 120 is online at [http://www.math.uiuc.edu/UndergraduateProgram/engineering/syl120s.html](http://www.math.uiuc.edu/UndergraduateProgram/engineering/syl120s.html).*
students uses those key concepts to explore problem-solving techniques and applications, working with interactive examples (the math kitties) as many times as they like. Answers are provided so that students can check their own progress. The third section, *Give it a Try*, presents problems that students solve on their own. Here, they not only work the problems and find numerical answers but often must give written explanations of their findings, as well.

*An example of a C&M homework problem is online at [http://www-cm.math.uiuc.edu/homework_examples.html](http://www-cm.math.uiuc.edu/homework_examples.html).*

The notebook lessons—the backbone of the C&M courseware—are designed to more fully engage students by communicating new ideas visually and experimentally. When students open the notebooks, they are immediately presented with graphic interpretations of mathematics concepts. In the *Basics* these are presented for students to view, but in the *Tutorials* students interact with and manipulate the data by varying expressions and input data to see how such changes effect output. In this manner, students “are forced to learn,” one teaching assistant told us, “because they have to look at the information on the screen and do something with it.”

The emphasis on visualization is a key feature of the C&M courseware. In every part of the lessons, mathematical ideas are presented in visual formats. Jerry explained that “instead of overwhelming students with definitions before solving problems, the notebooks are designed to take the student through a series of calculations and graphs, giving the student an actual feel for what the algorithm does before giving them a text definition” (Rhee 1994).

Typically, a class completes one notebook lesson per week. Students are free to work through the *Basics* and *Tutorials* at their own pace in class, reviewing concepts and reworking problems as many times as they like. When they feel they have a grasp on the material, they move on to the *Give a Try* section. At the end of each week, they turn in problems from this section to their instructor for grading and comments.

The homework is submitted electronically, through a website known as “Course Space.” Tim Braun, the C&M lab technician, explained that students log in to Course Space to submit and retrieve their homework and view announcements and assignments.

*Course Space has announcements from the instructors and the TAs. It has a syllabus with all the assignments and when they’re due and when the tests are going to be. Students also use Course Space to turn in their assignments—they upload them to that server. Then, their class assistant downloads them from the server, grades them and then uploads the graded files again. There are no disks being passed back and forth; it’s all done through networks now.*
In addition to the *Basics*, *Tutorials* and *Give it a Try* homework sections, each lesson includes a “literacy sheet”—a set of printed problems (not graded) that students complete by hand. Literacy sheets signpost the concepts a student should know and be able to discuss after completing each lesson. They also indicate to the students the level of pencil-and-paper calculations they should be able to perform. Twice during the semester, students take one-hour “literacy tests.” These are pencil-and-paper tests (calculators are allowed) and, Jerry explained, are often based on the literacy sheets.

**A Bricoleur Moment:**

How one graduate teaching assistant uses “Course Space”

Dan* (graduate teaching assistant): We have something we call Course Space. It’s a website for C&M students. There’s a place, for instance, where students can ask questions on problems and other students answer. What I do—I think I’m the only one doing it—I post Jeopardy problems.

Tony (interviewer): Jeopardy problems?

Dan: That’s right. For instance, “The function whose expansion is such that when you take a derivative time-wise, you get the same expansion.” People start pouring in answers.

Tony: Your students participate in this?

Dan: They do. And it works well because, using this format, I can ask very conceptual questions. They like it. They can have fun with it, but also learn from it at the same time.

**The Role of Technology**

Technology, when employed in ways consistent with the Seven Principles, can have powerful and lasting effects on student learning (Chickering & Ehrmann 1996).

For an in-depth discussion of the BioCalc learning environment and Chickering and Gamson’s Seven Principles, see [Discussion 1](#).

In BioCalc and the other C&M courses, the learning technology (e.g., the computer, the *Mathematica* program, and the C&M courseware) is critical to student learning. It is not used to complement the learning process but rather to initiate it. Remember the math kitties? The technology allows students to see and interact with ideas and concepts previously deemed “too hard” to introduce at the start.

Bruce: [The C&M courseware] really does rethink the approach to mathematics from the ground level. When you first start to study a topic, you start at a very elementary level traditionally. Then you introduce concepts, etc., etc., and then basically the semester runs out before you really hit the broader stuff, the stuff that’s really applicable. With the addition of technology, what you can essentially do is take those traditionally hard to
reach subjects and put them at the very beginning. Get students feet wet at the very beginning with the really major stuff because they’re not disenfranchised by the inability to do the hard calculations.

Students in BioCalc, for example, can sometimes be heard complaining about having to do differential equations. Their counterparts in standard Math 120 courses, however, have minimal exposure to differential equations. In this case, the use of technology gives students exposure to key concepts and topics they might not otherwise see. It also allows them to begin using those concepts in meaningful, interactive ways.
OUTCOMES AND ASSESSMENT: MEASURING SUCCESS

The BioCalc and C&M faculty strive to make learning meaningful by emphasizing visualization and self-paced problem solving in order to develop conceptual understanding. Briefly, let’s review the goals they have set for student learning. Then, in the following sections, we will look at how their success is being measured. (A definition of assessment, as used in the LT² case studies, is provided in the Glossary.)

<table>
<thead>
<tr>
<th>Problems</th>
<th>Goals</th>
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<tbody>
<tr>
<td>1. Students failing or performing poorly in required math courses for life science majors—can’t continue in chosen field of study</td>
<td>1. Improve student learning by motivating students to learn and dispel the myth that some students “can’t do math”</td>
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<tr>
<td>2. Faculty don’t expect students to be able to connect what they learn in math with what they study in life sciences</td>
<td>2. Help students bridge the gap between what they do in a math class and what they study in life sciences by emphasizing relationships between ideas, concepts and processes</td>
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Formal Assessment of C&M Courses

Do C&M students learn as well as their cohorts in traditional courses? Can they perform on par, both conceptually and computationally (hand calculations)? Two independent studies have been done comparing students in traditional, lecture-based courses with their C&M counterparts, and in each study, the results were positive: C&M students have been shown to perform slightly better on conceptual problems and as well as their traditional counterparts on hand calculations.

At the U.S. Air Force Academy, for example, an anchored final exam was administered to students in a C&M course and a traditional, lecture-based course. The study found “that students in Calculus & Mathematica scored significantly higher on conceptual questions and slightly higher on computational questions” (Holdner 1997).
Another study of C&M courses, conducted at UIUC by researchers in the College of Education, concluded that C&M students not only performed as well as or better than traditional calculus students, but also developed a more positive outlook on mathematics in general (Park & Travers 1996):

*Generally, the findings from an achievement test, attitude survey, concept maps, and interviews were all favorable to the C&M students. The C&M group obtained a higher level of conceptual understanding than did the standard group without loss of computational proficiency. Furthermore, the C&M group’s disposition toward mathematics and computers was far more positive than that of the standard group.*

**Formal Assessment of BioCalc at UIUC**

An assessment of BioCalc is being conducted as part of two on-going projects at UIUC. One project, funded through the Howard Hughes Medical Institute, will involve a direct assessment of BioCalc. As Susan Fahrbach, director of the Howard Hughes Program at UIUC, told us, the assessment is important because it will provide “hard data to share with the rest of the faculty.”

*Susan Fahrbach:* Under our current four-year award from the Howard Hughes Medical Institute, we’re charged with assessing the success of the program in the hopes that we can recommend to those who make decisions about the curriculum, whether or not this should be a required or recommended course for our undergraduate life sciences majors.

For that reason, Susan explained, the assessment will focus primarily on getting that “hard data:”
Susan: Jerry and I and the people involved with BioCalc are very interested in mastery, concept development, intellectual growth. And actually the audience for our assessment is primarily interested in outcomes. So, we’re probably going to use most of our resources on doing statistical comparisons of matched-pair students in BioCalc and non-BioCalc sections and looking at many aspects of their performance.

Tony (interviewer): I’m not an educational researcher, but it sounds like a tough task because the courses really have such different emphasis.

Susan Fahrbach: Right, but one can look at how BioCalc has impacted our students’ subsequent careers in life sciences. We can look at course grades, courses taken, retention rates—did they actually graduate as a life sciences major? We’ve been told by the current directors of the School of Life Sciences and other colleagues who are on the curricula committee that that’s the type of information that will sway their recommendation for inclusion of BioCalc in the curriculum.

...And we’ll be looking not only at outcomes but also attitudes. For that, we are going to take data that is being collected by an NSF-funded Indicators project, which is looking at all the students in the Math 120 sections and doing pre-evaluation: what is your attitude, are you scared, are you happy, do you think this will be relevant to your life, to your course, to your major? Then doing a similar post-evaluation. We will have access to the data for both BioCalc and non-BioCalc sections.

At the time of our interviews, the Department of Mathematics was in the midst of this NSF-funded project, which will include an assessment of the first two years of the engineering calculus program at UIUC (all sections of Math 120, 130, 135, 242 and 245). It was not known at that time when the project might be completed, because, due to the complexity of the department’s instructional program, data were still being compiled and methodologies had yet to be established.

The BioCalc assessment for the Howard Hughes Program was completed in April, 2001. For a summary of the results, please see Discussion 2.

Measuring Success in Other Ways

When it comes to C&M courses, however, Jerry Uhl believes strongly that the Indicators project will show the same results as other formal studies: C&M students perform as well conceptually and no worse with hand calculations than their counterparts in typical lecture-based calculus courses. These studies focus, perhaps too narrowly, on the statistical outcomes. As the UIUC faculty and administrators pointed out to us, there are other ways to measure success.

Charles Miller, director of the School of Molecular and Cellular Biology, for example, remarked that BioCalc students’ attitudes about math seemed to change as a result of the course:

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a The Department’s calculus courses are taught in three distinct styles: traditional lecture-discussion, computer-based instruction (C&M), and small group learning. Within each of these styles, moreover, there are variations, and because there are no common final exams for courses, instructional style and content vary considerably within sections. Assessment in this case can be expected to labor-intensive and time consuming. Descriptions of the instructional approaches used at UIUC (along with syllabi) can be found at the math department’s Website: www.math.uiuc.edu.
Right from the start, it seemed that—for whatever reasons—BioCalc went better. The kids liked it. They didn’t have so many negative attitudes. They stopped viewing [calculus] as a terrible hoop they had to jump through.

In fact, as Jerry, Bruce and Brad noted, many BioCalc students go on to take math classes beyond the prerequisites of their major. Some even take a minor in mathematics.

**Jerry:** A number of students have actually come out of BioCalc and become math minors.

**Bruce:** Students have taken BioCalc and then gone on to take, what is for them, unnecessary math courses.

**Brad:** In fact, one of the BioCalc students with whom you just spoke stopped me in the hall when he left and said, “I also want to talk to you about becoming a [C&M] class assistant because I think that would be a good thing to do.” Students who have gone into the life sciences are finding that mathematics is something they enjoy well enough to come work in our math program [as classroom and lab assistants]. They don’t give up their interest in life sciences—we don’t convert them and we’re not trying to by any stretch of the imagination—but they do find out that mathematics is not as separate from what they’re doing as they thought it was.

Susan Fahrbach echoed their observations and added that students’ growing interest in math was an indication of BioCalc’s success, which she believes the assessments will show:

**One interesting phenomenon has emerged which Jerry is quite convinced is true, and I think we’ll have the data to support it:** We now have life science majors who are going on and taking other math courses—for fun. That is really a new thing for us. It’s really interesting. It’s a small number, but it certainly suggests that BioCalc is preparing the students well for any math they want to do in the future.
IMPLEMENTATION

Before we turn to the issue of how to go about integrating new technologies and innovations into an existing institutional framework, we’d like to say a word or two about proper implementation. By proper implementation, we mean implementing new technologies in a way that is consistent with Chickering and Gamson’s *Seven Principles* (1987). As noted in *Discussion 1 (A Discussion of BioCalc and the Seven Principles)*, BioCalc exemplifies a learning environment in strong accord with these principles. But as our *bricoleurs* were quick to point out to us, a learning environment like BioCalc doesn’t just happen with the addition of a computer or any other learning technology. What matters most is how that technology is used, and that, our *bricoleurs* suggest, requires a new way of thinking about teaching and learning.

*Bruce:* What happens when a new type of technology becomes available? Take, for example, the CD-ROM. When the CD-ROM first came out, the very first thing that happened was to take a book and just slap it on CD-ROM. Now that’s just transplanting the old onto the new. The same thing happens with these computer labs: just slap on a computer, which means just duplicating the classroom in a computer lab. There’s no new thinking. It’s very natural, but it’s very bad in the long term. For one thing, when you go to a new medium, you often leave behind lots of things that were easily done before and that requires more work. And sometimes you don’t make full use of the new medium’s full capabilities. So what you end up with is the worst of both possible worlds (more work and less efficiency), and that has a tendency to turn people off. They blame the medium and not the way it’s being utilized.

In the following sections, we tell the story of how BioCalc got off the ground, presenting as we go the advice and suggestions that UIUC faculty and administrators had for others who are about to embark on the path of implementation. We begin with an examination of the necessary resources—personal as well as institutional—then follow with a discussion of potential problems and how to address them.

**Necessary Resources**

*Personal Resources: “It takes commitment.”*

When we asked Jerry Uhl how it was possible to get a course like BioCalc going, his first comment was, “In the beginning of this, we had someone very committed from life sciences and someone very committed from math.” And, without a doubt, most of the people with whom we spoke attributed BioCalc’s development and implementation to the strong commitment made by Jerry Uhl (math) and Sondra Lazarowitz (life sciences). They were what we would call "champions”—people who embrace a cause and creatively and vigorously support it.

Jerry’s and Sandy’s championing of BioCalc got it off the ground, but as Susan Fahrbach pointed out, keeping the program going has meant tapping into and relying on the abilities of others. She particularly stressed the point that while BioCalc’s initial success had a great deal to do with its champions, since that time BioCalc seems to work regardless of who is teaching it.

*Susan Fahrbach:* My initial impression was that Jerry Uhl and Sandy Lazarowitz were
true believers and just through their energy alone they were able to carry the program. They also had help from incredibly able and committed people like Bruce Carpenter. That’s how things got started. But since then, there have been lots of sections of BioCalc that have been taught by TAs who don’t need to be such true believers.

The “true believers” were able to get the program up and running, but its success now lies with those who are teaching it and interacting with the students on a daily basis.

Institutional Resources

The UIUC faculty and administrators commented on a number of institutional resources that were necessary to secure in order to establish the BioCalc program.

Funding

It’s no secret that technology-based courses generally cost more, at least initially, than traditional lecture-based courses. Therefore, finding both initial and sustained funding is vitally important. In the case of BioCalc, the first four years of the program were funded primarily through a Howard Hughes Medical Institute (HHMI) grant. That money, Susan Fahrbach (faculty director of the Howard Hughes Program at UIUC) pointed out, “was then used to leverage funds from the math department.”

But, as Charles Miller noted, that was just the initial phase of funding:

Originally the Hughes program put money into BioCalc. But, as is common, the outside funding organizations see such projects as seedlings which will eventually become “institutionalized” (the word we all know and love). The major support now is through the College of Liberal Arts and Sciences and the math department. Life Sciences also helps by providing space, computers, and network support.

Sustainable funding of BioCalc has been somewhat problematic in light of financial constraints facing the math department. But because the program has garnered strong support both within the department and in the College of Liberal Arts and Sciences, funding has continued.

Jerry: Right now the College of Liberal Arts and Sciences is underwriting the extra expenses in BioCalc. The decision was made that we didn’t want to stop [offering sections of BioCalc]. We wanted to make it available to the students who needed it, and everyone agreed—with a little teeth pulling.

Space

With technology-based courses, finding the appropriate class space is as important as finding funding. BioCalc, for instance, meets four days a week in a computer lab. At UIUC, there are numerous computer labs on campus where students have access to Mathematica and the C&M courseware. In addition, C&M classes are taught in two dedicated labs, which are also open to students at most times during the day and evening.
With BioCalc, however, it was decided early on that there should be a computer lab available in one of the life sciences buildings rather than the math building. The funding for the BioCalc lab was included in the original grant from the Howard Hughes Medical Institute.

*Susan Fahrbach:* The funding for the first computers and the first computer lab came from the HHMI. It was in our proposal, the money to make a computer lab to be used specifically for BioCalc students.

Jerry noted the value of providing a lab specifically for BioCalc students: “The kids in BioCalc feel more comfortable taking this course because it’s in a life science building.”

**Technical Resources: Computers, Servers, and Software**

Unless you’re a tekkie, the array of necessary technical resources for a course like BioCalc can be mind-boggling. We asked Tim Braun, a C&M lab technician, and Barbara Meyer, a computer-assisted instructional specialist in the School of Life Sciences, for specific advice on what’s necessary to get a course of this technological caliber up and running smoothly.

**Computers.** First things first. BioCalc (as well as the other C&M courses) require, as Tim put it, “reasonably fast computers with reasonable amounts of memory and hard drive space.” This doesn’t necessarily mean that the computers have be the newest on the market, but neither should you expect to get very far with, say, an IBM 286 or Apple Ile…

*Tim:* The oldest computers in our lab right now are six years old, and they’re scheduled to be replaced soon. These older computers will run the programs; they’re just a little slow at it. Students know they’re slower and generally avoid them.

Keep in mind, too, that in technology-based courses like BioCalc, enrollment numbers are circumscribed in part by the number of available computers.

*Bruce:* BioCalc is well-suited to 30 students, but that cap is driven primarily by the computing facilities available. There are roughly 15 computers in the lab, and therefore, having two students work at each computer, you get 30.

*Brad:* That’s a good point. The design of the course doesn’t restrict the number of students; it’s basically the physical facilities that dictate the enrollment caps.

**Networks.** In order for a class like BioCalc to run smoothly, Tim told us, a good network is critical.

*Tim:* [If you’re going to implement a class like this], look at implementing a network solution like we’ve got. You can’t run this class on individual computers. Without a network, it gets to be a monstrous stack of floppy disks; and the lessons are usually too big for floppy disks. They did try for a couple years doing it without the network and everyone I talked to said it got really bad—just disks everywhere.
Software. BioCalc and other C&M courses use Mathematica software in conjunction with Calculus&Mathematica courseware. The University has a site license with Wolfram, the producer of Mathematica, so students do not need to purchase individual copies of the program if they are going to be using campus computers. If they want to use Mathematica on their home computer, however, they do need to purchase a copy. (Wolfram offers a relatively inexpensive student edition of the program.) All students are required to purchase the C&M courseware package (akin to a textbook in a traditional course), which includes a lesson CD.

Tim: They have to buy the lesson CD whether they’re going to use it in the lab or at home. If they want to use a public computer, that CD is all they have to buy. If they want to use their own computer, they also have to buy a copy of the Mathematica program. But there are plenty of students who have never owned a computer, who always use the public computers, and they get through the classes just fine. There are thousands of copies of Mathematica available on the campus computers. Some of these computers are available 24-7 and some are available during the day only.

What about support staff?
Both Barbara and Tim agreed that technical support staff are vital to maintain the resources necessary for the BioCalc and C&M courses. “You have to have someone,” Barbara told us, “who knows how to troubleshoot.”

Barbara: The network has to be good. The computers have to be up and running. The operating systems have to be perfect. The last thing you want is hardware problems. Students will get frustrated, for example, if they can’t reach the server. You want to make the computer interface as transparent as possible. ...My feeling is that you have to have fast computers. You have to have memory. And you have to have someone who knows how to troubleshoot.

Tim reiterated that point:

Tim: You need someone to take care of the labs. Every academic computer lab has to have someone watching over it, taking care of it, some way to prevent the few students who decide they’d like to hack around with the system from causing any damage.

By way of example, we asked Tim to explain just what his job as lab technician entailed.

Tim: With the BioCalc course, I advise the instructors on their lab set-up. I take care of the servers that hold onto the lessons and the homework. I also take care of the main Calculus&Mathematica lab, from choosing which machines to buy to setting them up and maintaining them and deciding when to retire them.

Support staff, the BioCalc folks agreed, are truly instrumental in keeping the labs and courses running smoothly.
Getting Started

Personal and institutional resources are an important part of the story, but it’s also important to know what others in similar situations have done. We know that every faculty member develops his or her own style and will only rarely simply adopt a new approach without modifications of their own. (This characteristic of faculty is one of the greatest strengths of higher education.) At the same time, we suspect that, with respect to knowledge about how to create and implement new approaches to learning, the vast majority of faculty innovators and early adapters end up “reinventing the wheel,” and that, quite frankly, is an inefficient use of faculty time and effort.

With this point in mind, we asked the people involved with BioCalc what they would tell those who are interested in implementing a similar type of reform on their own campuses. By far the most common answer was, “Seek out the folks who have or are doing it.” Such people, the bricoleurs agreed, are a valuable resource in themselves.

**Brad:** My predecessor was a graduate student in the mathematics program doing the same sort of work I’m doing now. I would go to him and say, “Such-and-such seems to be going on. What would you do about it? What do other people do about it? Who’s a good person to talk to about this?” And then I’d hang around a lab when Bruce or Jerry was teaching and see the way that they dealt with things. Ultimately, there are a lot of ways you can learn about what has succeeded for other people, but the best way is by being someplace where they’re doing it. The modeling I saw was in the classrooms, and it was a result of my wanting to go find people who were doing things and doing things well. One of my jobs now is to advise instructors who come to me and say, “Hey, what can I do about this or where can I talk to someone about this?”

Tim told us that, in addition, it’s important for someone interested in this type of course to get a first-hand feel for the program and courseware.

**Tim:** I think the very first thing someone should do is get one computer set up with Mathematica and the courseware that they’re planning to use and just play with it and get a little bit of a feel for it. [It’s important to know how it works] because there’s a different teaching style involved, as well as a different learning style. Then after they do that, they can talk to people like me, who’ve taken the class, and other instructors who’ve taught the class to see what they think. It’s especially useful to talk with other instructors and see what they thought, where they saw potential problems and where they thought it was stronger, etc.
Potential Problems and Ways to Address Them

In an effort to provide (as closely as possible) a conversation like the one recommended above, the BioCalc people with whom we spoke very generously shared with us the problems and issues that they had to address (and still do address, from time to time), as well as recommendations for improving the likelihood of successful implementation for others.

**Individuals: Champions and Otherwise**

One of the first things the BioCalc folks talked about was the role of individuals in the implementation process. Specifically, they mentioned the need for course “champions” like Jerry Uhl and Sondra Lazarowitz. Champions have the energy and commitment to get the ball rolling.

*Ruth Wene:* From life sciences, it was the passionate true believer, Sandy Lazarowitz, who got things going. She surveyed other faculty to find out what they thought students needed. She worked very hard, out of her passion to improve the lot of our students.

Champions are able to attract the attention needed to secure funding—from both internal and external sources—and garner high-level support in their own departments.

*Susan Fahrbach:* [In addition], Sandy had the support of the director of the School of Life Sciences. She had the high level administrative support that was necessary. That was due in part to generally good feelings about the Howard Hughes Program [of which Lazarowitz was faculty director]: any program that attracts more than a million dollars in funding every time it gets a grant must be doing something right. She took the positive image of the Hughes program and her own intense commitment—which just goes above and beyond what most faculty would do—and leveraged that into good relationships with our School of Life Sciences director, who I must say happened to be from her home department. So she was in a very favorable situation.

Developing this kind of support and respect is crucial to reform efforts. As one person whom we interviewed noted, “Jerry Uhl was very savvy in securing top level support in the math department, which was crucial to getting BioCalc going because UIUC, like most universities, is a very hierarchical place.” Having the support of the department head and others in the administration can get reform efforts on the path to implementation, whether or not others in the department are on board.

Taking on the role of champion, however, is not for everyone, the BioCalc *bricoleurs* warned. Only tenured faculty should take on the challenge of *developing* this type of program from the ground up (including development of the instructional materials). As Jerry noted, “Untenured assistant professors [need to be cautious] because showing too much interest in something like this can be taken negatively.”

Which is not to say, Bruce was quick to add, that assistant professors can’t *teach* reform courses.

*Bruce:* When I was referring to how it’s not advisable for an untenured person to get
involved in reform, I wasn’t talking about teaching courses. I was talking about
developing similar types of materials, or developing a similar type of program.
Developing materials is extremely difficult and very labor intensive. It’s very difficult to
get non-tenured faculty interested in developing an entire program to improve the
education of a group of students. But if the materials already exist and just need to be
adapted to the course, then that’s much easier.

Cultural and Historical Factors
It’s also important to consider how cultural and historical factors will affect change—in some
cases impeding it; in others, accelerating it. Being aware of these factors can help reformers
anticipate difficulties and recognize and make use of opportunities that present themselves.

Consider your department culture
At UIUC, BioCalc’s implementation was facilitated by the culture of the math department,
which was generally supportive of experimental instruction and valued an array of instructional
approaches. In fact, the department currently offers three different sections of Math 120
(Calculus I): traditional lecture/discussion using a standard text; computer-based instruction
using Mathematica (C&M courses); and small group, collaborative learning sections that use
graphing calculators (the Harvard section).a

Jerry: One thing about the math department here: they didn’t try to stop us, even if not
everyone agreed with us. The result is that we have standard lecture calculus, we have
calculator calculus, and we have computer-based calculus.

Paul Weichsel, associate chair of the Department of Mathematics, explained further, noting that
even in the midst of financial crisis, the math department as whole maintains its commitment to
diverse instructional approaches.

Paul: About three years ago, we ran into a very serious financial pinch. The math
department was really constrained to make some rather draconian cuts, so people were
looking at all kinds of ways to do this. The small group structure, for example, is
obviously very labor intensive, and the cost per student is substantially above that of a
traditional course. So the question was, do we need this type of course? It was under
severe attack, and the people who came to its defense most vigorously were the graduate
students who had been teaching it. Then the question of C&M courses came up. The
[financial] support from the Hughes Institute and the NSF was long since gone, and the
cost per student is relatively high. But a member of the department, who is very
influential, got up and said, “Look, Mathematica is our reform project. One of our
colleagues has put his professional life on the line and has devoted himself to this. That
deserves our support.”

Now [this kind of support for C&M in the face of financial constraints] was a
kind of a cultural statement. It wasn’t based on statistics and studies that said, “Hey, this
stuff really works!” And that’s generally the way we do things: try different approaches.

a Descriptions of the instructional approaches used at UIUC (along with syllabi) can be found at the math
department’s Website: www.math.uiuc.edu.
Then we look back and ask, “Is there a principle that governed the way this operated?”
And, in this case, the retrospective principle is simply this: One size does not fit all. The fact is, different students learn different ways. And offering people an array of possibilities in choosing their instructional style is a very sound thing to do, educationally.

Consider your timing (Ride the wave…)
BioCalc was initiated in 1994 at a time when calculus reform efforts were being mainstreamed into math curricula across the country. Five years earlier, when reform efforts were getting under way, Jerry Uhl and colleagues at UIUC and Ohio State University began developing the C&M courses (with funding from the National Science Foundation). By the time BioCalc came on line, several sections of C&M courses were up and running.

Susan Fahrbach: It really was a time when the math department was beginning to diversify. So this was sort of part of the zeitgeist of “Let’s serve our undergraduates better.”
Ruth Wene: They started teaching sections of Harvard calculus at about the same time. So calculus reform was in the air, and this was part of it.
Susan Fahrbach: The math department had started offering other courses with Mathematica, some special sections for engineering undergraduates. BioCalc was definitely separate and life science oriented, but we sort of caught that wave.

Use reform efforts to strengthen service to client departments
Faculty in departments that require mathematics courses for their majors ("client" departments) often are not satisfied with the way these courses are taught. They frequently view the mathematics faculty as concerned primarily with the mathematics majors and not with the needs of other majors. In these cases, they fault the courses with being too abstract and the mathematics too divorced from the subject matter and research themes of their own disciplines.

Reform efforts like BioCalc, however, can help bridge this gap in expectations and offer math departments the opportunity to position themselves as a resource, rather than hindrance, to client departments and students. At UIUC, for example, BioCalc has become a resource that life science faculty can draw on to help achieve their own goals for student learning, especially at a time when study in the life science fields is demanding higher-level quantitative skills.

As Jerry pointed out, the ability—and willingness—of math departments to respond and meet the needs of not only their own students but those of students from other disciplines, as well, is vital to insure their survival. Other departments can (and, in many cases, do) teach the math their students need, if math departments don’t.

Jerry: One idea is for a life science department to try this out and teach it themselves.
Susan (interviewer): What about all those math TAs who would be out of business?
Jerry: If Ford Motor Company still marketed 1950 Fords, they would have been out of business a long time ago.
Be Aware of the Need to Convince Others

New courses like BioCalc have to be actively “sold”—first, to faculty and administrators; then to students and advisors.

Niche marketing is important

The BioCalc *bricoleurs* put it simply enough: students won’t enroll in a course if they don’t know about it. To ensure that students who can benefit (the “niche”) will choose the course, they must effectively receive information about the course.

As one life science faculty member told us, an easy way to generate student interest in a class is through its name.

Susan Fahrbach: If a student has a strong identification with his or her major, having “bio” in the course name, for example, almost sells it for you. They don’t even look and see what’s different about it: “If that’s the calculus for biologists, that must be the calculus for me.”

But the BioCalc folks warn, targeting a course to particular students is not enough to ensure enrollment. Students have to be aware of not just the options available but which option might be best for them.

Brad: No one ought to feel like they’re being forced to take this course. If they feel forced, it undercuts what we’re trying to accomplish. We very much want to present the material so that the students take it, rather than having us feed it to them.

Bruce: Ideally, if they have sufficient instructional options, they can select for themselves the style of course that’s for them.

Brad: Exactly. We’ve seen here that sufficient options aren’t enough. We have to somehow reach the students so that they really understand what those options are.

At the time of our interviews (February 2000), BioCalc did in fact have a rather low enrollment. Describing the situation, the associate chair of the math department implied that this was due to a “marketing” problem.

Paul Weichsel: BioCalc consists of one course, Math 120. It’s generally the only calculus course that most of the life science students take [and it’s usually offered in the fall]. Then someone suggested that we offer a section in the spring, as well. We went to the life science advisors and said, “Let’s open this up. Let’s spread the net a little wider.” But that hasn’t worked so far. Right now we have one section with eight students in it. That’s absurd to run a class like that.

The *bricoleurs* explicitly attributed this to a lack of proper marketing; that is, the students were not enrolling because they weren’t aware of their option to do so, either through direct advertising or through advisors.

Brad: My opinion—and I don’t have anything solid to base it on—is that students are faced with a very large number of choices when they hit college and one of those choices,
which is relatively unimportant to them, is what kind of mathematics class to take. Unless they really understand that this course was designed to help people who don’t do well in a traditional environment, then they don’t have any particular reason to look our direction. We inform them about the different approaches to calculus that we offer, but they tell us in focus groups when they are about to graduate, “We had four thousand different pieces of information in two days during orientation.” It just goes right out of their minds. My opinion is, we’re losing enrollments because we are not successfully getting information to students either by advertising or by going through the advisors.

Advising, as one interviewee told us, is crucial; it can make or break a course: “I think it would be fair to say that advising in the School of Life Sciences had changed somewhat over the last several years, and as a result there is a smaller fraction of students enrolling in BioCalc.”

**Don’t expect to convince all your colleagues**

Another point that the BioCalc folks stressed is that some faculty will not support reform efforts, despite evidence of success.

**Paul Weichsel:** Now, Jerry will say that advisors are telling the students that Mathematica is worthless, et cetera. [But we’ve talked with some of the faculty], and the thing that I have found very interesting was not that these people were saying, “Our students need to know W, X, Y, Z, and they are not getting X, Y, Z.” What they really were telling us was, “I learned calculus in this way, and my students now are not being taught calculus in that way. They are not going through the ordeal of fire that I did. This is new, this is different. There are certain specific topics that they don’t seem to be very conversant with.” Now, they never make the argument that those topics are very central to the lives of their students; rather, it’s this terrible discomfort with the fact that they are not cloning.

We’ve had cases, actually, where a professor will give an exam and a bunch of kids in the class will display a clear lack of understanding of a some mathematical technique, and the professor with say, “Aha! It’s the Mathematica!” So in one of these cases, we looked into it. We looked at all the grades, and it was simply not true. The kids who had not performed well were not the kids who had taken Mathematica. But those impressions die hard. You know, otherwise intelligent people are saying, “Don’t bother me with the facts, I’ve already made up my mind.” You see that all the time.

Such resistance is common because, as Jerry put it, “math faculties have very mixed opinions about computer-based teaching”—for many of the reasons mentioned above: it’s not the way they learned calculus; it’s new and different and hasn’t been “proven.” And as Susan Fahrbach noted, reform can have a polarizing effect.

**Susan Fahrbach:** A small number [of the life sciences faculty] are enthusiastic about BioCalc, but the vast majority [don’t know much about it]. Then, there’s a small number who seem to feel that if this course is different from the traditional calculus, it must be worthless. So we have three groups: a small group with a positive view, a small group with a negative view, and a large group with no view. But it’s the small groups that are often more vocal when course requirements are set.
Respect the skeptics’ need for evidence
While it’s not likely that those with negative views of reform efforts will change their minds, it is important to provide evidence of reform successes for those who have a healthy skepticism. These are the folks who are concerned that efforts to help students could in fact end up hurting them and believe that unless there is evidence that a new approach is better, caution is called for. Charles Miller, for example, was initially concerned about the quality of math education the School’s major were receiving.

Biochemistry has [been added to our school], so we now have a segment of students who are more quantitatively inclined. We also have programs in bio-physics and computational biology, which will be in our school. Some of these students probably ought to take a math course every semester. So I was concerned that we not give students a second rate, watered down experience that wouldn’t provide them with the skills and knowledge they needed to go ahead, because if we’re giving a kind of elementary math appreciation kind of thing, we’re really not doing right by them. Jerry Uhl feels very strongly that this is not the case and claims that they have data to show that some of the BioCalc students have gone on to further study in math, sometimes extensive study, and do just as well or better than those who have take the standard sequence. I haven’t really seen that, but if that’s the case, I think that’s another endorsement of BioCalc.

This need for evidence is one reason why assessment is critical to reform efforts. (See Outcomes and Assessment as well as Discussion 2 for information on BioCalc assessment at UIUC.)

Expect Student Resistance to the C&M Approach
Students, like faculty, have expectations of what a course should entail. When they find that a course differs from what they expected, they may begin to question what they are learning.

Susan Fahrbach: We have a high percentage of students who know somebody who went here, and from that they get their own idea about what their courses are going to be like. If a course is very different from the picture they have in their head, they require some reassurance that they are still going to learn as much as everybody else.

For instance, a common expectation among calculus students is that, unless you suffer, you haven’t learned “real” calculus.

Brad: One of the problems we face in our courses is that people come out of them thinking they didn’t have the character-building experience that a calculus class is supposed to be. All through high school, calculus is spoken of as if it is the ultimate mathematics class on steroids and, boy, you better be brilliant to get through that. In my experience, calculus is easy to teach: there are four or five main ideas and if you can get those through, people will follow what’s going on. But because students have been given to believe that it’s not calculus unless they’ve hurt themselves over it, they conclude that they must not have done it right.

Jerry: As one C&M student put it, “If you take the standard calculus, you’re regular army, and if you take C&M, you’re National Guard.”
Moreover, some students view the computer as a crutch: “The computer is doing the work and therefore I’m not learning what I should.”

**Bruce:** The BioCalc students typically are not as comfortable with the computer technology as engineering students. They’re very interested in what you do with computers, but they’re not focused on the computers themselves, and so they frequently have a concern that because they’re doing the mathematics on computer, that somehow they’re not going to be able to carry that into other courses; they’re not going to be able to do the kinds of calculations that the engineering students do. The BioCalc students are concerned about using the computer as a crutch.

**Jerry:** Now, what they don’t know is that the people coming out of the standard calculus courses also can’t do those calculations very well, either.

For some students, just the fact that they’re not doing paper and pencil calculations is cause for alarm.

**Ruth Wene:** There is resistance in the incoming students to using the computer. Some students start BioCalc, and they’re in my office two weeks later saying, “I want to get into the regular sections because I’m not learning anything.” They really don’t know what they’re learning, but what they do know is that they’re not doing paper and pencil problems, which is the only method that they have ever used to learn math. They’re very anxious that they are somehow being denied access to mathematical information because they’re not using paper and pencil.

In a course like BioCalc, faculty need to be prepared to address students’ concerns about learning.

**Expect a Learning Curve for Instructors and Students**

BioCalc is a learning environment that requires both students and instructors to adjust to new approaches to learning and teaching. Most faculty and students—including those featured in this case study—bring to their courses complex assumptions about teacher and student roles that can present formidable barriers to implementing such approaches. We examine some of these barriers below.

**For Instructors**

**Need to orient instructors and CAs.** Each BioCalc class has an instructor as well as a class assistant (CA). The CA is an undergraduate student who has taken C&M courses. Because of their prior experience, CAs are often the ones who have the best advice for how to run the class.

**Jerry:** We depend on the class assistant to break in the new instructor because the class assistant has been through this. The instructor is the lieutenant and the class assistant is the sergeant.

As Brad noted, this situation is a bit of a turn-around for instructors—it is not often that they find themselves receiving instruction from and relying upon their undergraduates. Instructors, who
find it difficult to make this adjustment, often end up doing more work in the course than they otherwise need to.

**Brad:** We make a very big deal during the [instructor] orientation of pointing out to the instructors, especially the new ones, that the class assistants have experience with the program, they have experience with the lessons, and they know a lot about what might or might not work in a C&M class—principally because they’ve taken it as a student themselves. We make a big point of the fact that we don’t utilize our CAs as well as we could. We tell them, “Ask your class assistant what they can do for you, because they know better than we do.” I’ve never worked as a class assistant; the class assistants themselves know better than I do what they can offer. But we still have trouble with underutilization, partly because of what people think of working with an undergraduate and partly because Calculus&Mathematica is a very different teaching model. A teaching assistant or faculty member going into that environment, I think, tries to maintain more control until they become comfortable with the situation, and as a result they don’t have someone else doing as much as they could.

**Need to adopt “guide-on-the-side” role and come to terms with the “Atlas complex.”**

As Brad noted above, new instructors often find it difficult to relinquish control, even to a class assistant. But the philosophy upon which BioCalc is based—actively engaging students in their own learning—requires just that: instructors must adopt a “guide-on-the-side” role, rather than the traditional “sage-on-the-stage” role, in order to help students self-discover concepts and connections.

Finkel and Monk (1983) use the term “Atlas complex” to refer to the very common difficulty faculty experience in relinquishing this kind of control. As they put it, instructors need to abandon the notion that they, like Atlas, must bear the weight of the entire classroom world on their shoulders.

**Jerry:** Some people who have taught in our program say, “I want to contribute more to my students than your program allows.” What they’re really saying is, “I want to think for my students.”

Breaking out of the Atlas complex involves a willingness to step aside from the authority and power of center-stage and a desire to empower students. It requires asking questions instead of providing answers, listening instead of talking, and feeling comfortable with student confusion instead of rushing to fix things. This is an on-going process, Bruce pointed out, of which faculty must be aware and actively pursue.

**Bruce:** You could say I’m in touch with my Atlas complex: I still have it, but I actively push it to the side. I actually like giving lectures, and I still occasionally teach a lecture course. But the reasons I enjoy it are not the reasons why the students learn. It’s just nice, as a mathematician, to have a captive audience. And I like organizing the ideas. So, yes, there are a lot of things about the lecture system that I really enjoy, but almost none of them contribute effectively to teaching. Or learning. When I’m lecturing, the focus of the class is upon me. But that’s not where the focus should be, because I’m the one who
already knows the material. In BioCalc, we place the focus on the student.

**Need to expect students will be very “answer-oriented.”** When instructors do assume more of a guide-on-the-side approach, they should expect that students will need time to adjust. Students are used to the idea that the instructor has all the answers and that proper teaching involves giving them those answers.

**Bruce:** There’s also a tendency with a lot of students to be very answer oriented. They ask a question, and they want an instant answer. Typically what that means is that they don’t want to think about the problem—they don’t really want to flesh out their conceptual understanding of how things fit together. They just want to get the answer to this one problem and move on.

We really try to resist that. We don’t refuse to answer a question, but we do resist just giving answers straight out. Instead, I start asking them questions in return, find out places where they really need to go back and review the material or they need to go back and think about a point that’s covered in a prior homework problem. The students really need to flesh out that understanding on their own. Once they’ve done that, then they can see for themselves how to proceed in solving the problem. By answering someone’s question right away, you prevent them from knowing the material, and you strip of them of the joy of discovery.

**For Students**
Students, like instructors, have their own set of unique issues in a course like BioCalc. Aside from adjusting to the different roles of instructors and learners (the Atlas complex), students also often experience start-up difficulties in learning to use—and learn from—a computer.

In particular, the first two to four weeks of the course are generally the most difficult for students, the BioCalc folks told us, because it can take some time to learn the *Mathematica* code.

**Tim:** Sometimes the students will get bogged down with the Mathematica code. They don’t realize that it’s a basic programming language and once you understand a few commands, you can pretty much understand what it’s doing. Generally, most of them get over the frustration. A few drop the class and go for a tradition calculus course, but most stick with it. They realize it’s just a new method of learning, like the first time they picked up a scientific calculator: “Hey, what are all these buttons? How does this work?”

One student with whom we spoke confirmed Tim’s point.

**Mark:** At first, I thought the class was going to be hard because of the computer. But the program is actually pretty easy to use, once you figure out how to cut and paste commands and stuff. You definitely don’t have to be a genius at computer script in order to get it.

Ruth Wene, an advisor in life sciences, told us that when students express concern over learning the code, it’s important to remind them of the greater payoff down the road.

**Ruth:** I think the first couple weeks are rough because the [Mathematica] program is complicated. It takes a fair amount of input at the beginning to get comfortable with the
program, and then you begin to see the payoff. If they stick it out for a month, they’re usually fine. I just report to them what other students tell me, which is that you’re not going to have to solve calculus problems per se in your biology classes. But, it’s going to be enormously helpful for you to be able to look at graphs and charts and be able to use the calculus you know to understand the meaning of these depictions. That’s mostly what calculus is going to be used for. This method of presentation in math is going to be much more helpful to you than paper and pencil problems will be.

The BioCalc folks noted that this start-up period can be more difficult for students who are computer illiterate or computer phobic, but the payoff is relatively greater.

**Ruth:** I see many students for whom computers have been part of their high school education, or they have them at home; they’re not nervous about using them. I still see some who are kind of computer phobic and don’t see them as learning instruments. For these students, a course like BioCalc is wonderful because they begin to see that the computer can do some of the work and allows you to learn in a different way. Do you really want to get a problem wrong because you added or multiplied wrong? Or would you like the computer to do all of that correctly for you and you work on the concepts?
SUMMING UP

“This is action calculus.”

It is clear that the BioCalc folks at UIUC have given a great deal of thought to how students learn. In designing a calculus course for life science students, they have adhered to a principle that has informed their efforts from the start: Students learn best when they are actively and contextually engaged with their subject matter. Using a computer-based approach to teaching calculus allows BioCalc instructors to utilize learning activities that require students to interact with ideas and concepts, with instructors, and with other students. And the assessment data on BioCalc indicates success. BioCalc students are more likely than other life science calculus students to perform better in Math 120; to take additional non-required math courses; and to remain in a biological major.

BioCalc instructors don’t use lectures as a learning activity. Instead, students work (often together) with electronic notebooks that allow them to see, interact and manipulate the very ideas and concepts they are trying to learn. This learning process is not abstract; it’s not spectatorial. In Jerry’s words, “This is action calculus.” Students clearly respond to this type of approach. The BioCalc students we interviewed talked about the increased confidence and sense of productivity they gained in an active learning environment; the way they were able to connect concepts learned in BioCalc to their life science courses; and the value of collaborative learning. They clearly conveyed a sense of empowerment over their own learning.

BioCalc instructors reap rewards of their own. With the higher degree of student-instructor communication, instructors get to know their students better and can more readily gauge their progress. They play a more direct role in the learning process and consequently gain a greater sense of satisfaction in both their own performance and that of their students.

In sum, the BioCalc course at UIUC has provided meaningful and motivating learning experiences—for students and faculty alike—in addition to impressive student outcomes. Through the use of life science models and examples, students see firsthand how calculus is relevant to their field of study. Moreover, using the computer-based approach prepares future graduates and scientists for the world they face after graduation.
DISCUSSIONS

1. A Discussion of the Seven Principles and BioCalc
   “Lighting the Fire”

As noted in *The Learning Process*, BioCalc and other C&M courses focus on learning as a process rather than a product. The *bricoleurs* believe that such a shift in focus creates an environment where learning, rather than teaching, takes precedence. Bruce explained the impact that such an environment can have on students: it empowers them, or (as he put it) “lights a fire under them.”

**Bruce:** In BioCalc, particularly, I’ve noticed the following pattern emerge. Typically a female student, after several weeks in the program, will walk up to me and express concern about the fact that she and her boyfriend—who’s in engineering and is in the standard calculus course—were working on their homework together and it seems that he’s learning and doing things that she’s not learning. Therefore, she thinks she’s not getting what she needs from the course. I look at her and I say, “Why do you automatically assume that you’re not getting what you need? Why aren’t you questioning whether he’s getting what he needs?” I don’t do anything but say, “Look at it from the other standpoint. You’re learning all kinds of things.” Sometimes I’ll talk about the things that she’s learning that she may not even realize are part of the learning process: learning to think about a problem, learning to set up a problem—all these things that are not answer oriented but are process oriented. Then, typically after a month or so, that student never fails to come back to me and say, “You know, my boyfriend was working on his homework, and I was able to help him because I understood what the point of the problem was. I understood the process that needed to go on, but he was too mired in the details. He was too focused on pushing symbols around.” And at that point, it’s like a fire gets lit under them.

The activities and tools chosen by the *bricoleurs* (described in *The Learning Environment*) help set in motion the processes that *light a fire under their students*. Their students are not just learning math, Jerry told us; they’re learning how to learn.

Of note, the BioCalc learning environment is in strong accord with the seven principles for good practice in undergraduate education that Gamson and Chickering synthesized from their research on undergraduate education (1991). Below, we present each principle, followed by examples and testimony of how that principle is enacted in the BioCalc learning environment.

**Good practice encourages contact between students and faculty.**

“Frequent student-faculty contact in and out of class is a most important factor in student motivation and involvement. Faculty concern helps students get through rough times and keep on working. Knowing a few faculty members well enhances students’ intellectual commitment and encourages them to think about their own values and plans.”

The UIUC faculty place a high emphasis on contact with students. The result is an environment that is less formal and much more communicative than a typical, lecture-based course.
Brad: One of the things that’s really wonderful about the course, in my opinion, is that it is not in the formal voice of traditional textbooks, and that encourages the students to respond. I’ve had students go so far as to turn in homework assignments that had their names at the top and then my name as the instructor appended with the words “Rock Star” because they thought something about the way I was acting needed to be lampooned in this manner. You do not see that on your homework in traditional class. Here, the students interact with you in their homework in a way that is much more like the way their own mind works.

One of the factors in establishing a more communicative environment is class size. BioCalc and C&M courses have typical enrollments of 15-30 students. As one student noted, “I like the smaller atmosphere, because I can get help whenever I need it. We can always get our questions answered, and no one has to wait.” Being able to approach the instructor in class, this student also commented, is easier and less intimidating “than in the traditional course, where you’d have to make an appointment or find out the instructor’s office hours.” In BioCalc, another student told us, “you just raise your hand and [the instructor] comes over.”

Communication is further facilitated by the lab environment, where students and instructors spend eighty percent of their class time.

Luca* (graduate teaching assistant): You’re talking to them personally most of the time. They’re sitting in groups of two or maybe three in front of the computer. They ask a few questions, you come to them; you talk to them a lot during lab. In the traditional, lecture-based section, you might not talk to your students at all during the whole semester. You don’t have even a chance to meet your students. In BioCalc, that’s impossible. Even if a student does not ask a question, you can ask them if everything’s okay, you can ask how it’s going, you can ask some questions to make sure they understand what they’re doing.

Moreover, student-faculty contact is made easier and more effective by the availability of a course website (“Course Space”). Here, students can post messages to their instructors, email them, or even chat with them online.

Good practice develops reciprocity and cooperation among students.
“Learning is enhanced when it is more like a team effort than a solo race. Good learning, like good work, is collaborative and social, not competitive and isolated. Working with others often increases involvement in learning. Sharing one’s ideas and responding to others’ improves thinking and deepens understanding.”

Collaborative learning is another key feature of BioCalc and C&M courses. Students are strongly encouraged to work together, both in class and out, because the bricoleurs believe students learn better in a social and collaborative environment. And, Jerry noted, “most of the time you do see students working together—to get an idea of what a derivative is, for example.”

Many instructors allow students to choose their own partners, but Bruce prefers a “mix-and-match” approach, in order to amplify results.
**Bruce:** There are two reasons why I mix and match groups. One reason is so people don’t get stuck [with an unsuitable partner]. The other is that, for the first lesson they’re partnered with someone and then the next lesson they’re partnered with someone else, and then the next lesson they’re partnered with someone else... Then this interesting multiple group thing starts to happen where a group is working on a problem and they get stuck. One of them says, “Oh, I’ll go ask so-and-so, who I worked with last time.” So the groups start grouping themselves together, and I can tell it’s clicking when somebody jumps up from their computer and runs over to another group. That’s a clicking indicator: when they actually start talking—not just among their group—but with other groups.

The students, too, are quick to pick up on the benefits of a more cooperative environment. Ann and Michelle, two students whom we interviewed, explained:

**Ann:** Michelle explains it to me when I don’t understand.
**Michelle:** I think it’s good because if there’s something that I kind of get, by explaining it back to her and making sure I understand it—because she questions me on anything—if I didn’t understand it entirely myself, between the two of us, it makes us go back and have to check and make sure that we understand everything that’s going on. We can’t just look at the computer and be, like, “Oh, okay, I got that,” and go on. We have to explain it to each other.

They also feel free to consult others in the class.

**Michelle:** If we don’t understand something, we’ll ask around and find somebody else who’s either on the same problem or has just worked it.

Creating a less formal environment encourages not only more faculty-student interaction, but more student-student interaction, as well.

**Dan* (graduate teaching assistant):** Bio-calc meets five days a week, so the students see each other every day, and they know each other very well. I actually have a student who brings a box of drinks every week, every Thursday. And when one of the students had a birthday, we actually celebrated in class. We benefit from stuff like that, actually, because the students won’t hesitate when they are trying to help the other. They’ll just go ahead and say, “Oh, I know that,” and just start talking to each other instead of being shy.

Being in a calculus class with other life science students is an appealing feature of BioCalc, another student told us.

**Steve:** Well, I knew Mathematica was a new program that they were trying out here. I heard it was a math class geared more towards life science majors. So I thought maybe that would better suit me, rather than the normal calculus class. Plus, there was the advantage of meeting other people that were going into the same major as I was. It was neat because I actually got to be good friends with some of the people in that class and
they were later in my lab classes. So, it was kind of a nice starting block.

BioCalc was formulated in part to offer a more supportive environment to students. As Susan Fahrbach, director the Howard Hughes Program in Life Sciences, noted, the power of learning in a social context is often overlooked.

Susan: I think this is a key point—that those students who like BioCalc enjoy being in a class with other life science majors. They’re meeting people that they’re going to be in classes with for the rest of their time at Illinois. I think we tend to underestimate that social aspect.

But students don’t just talk and work together in class. They also use the Course Space website to email, chat and post messages to one another.

**Good practice uses active learning techniques.**

“Learning is not a spectator sport. Students do not learn much just sitting in classes listening to teachers, memorizing prepackaged assignments, and spitting out answers. They must talk about what they are learning, write reflectively about it, relate it to past experiences, and apply it to their daily lives. They must make what they learn part of themselves.”

Active learning is the backbone of BioCalc and other C&M courses. As Jerry put it, “Math is not a spectator sport. You don’t learn math by watching someone else do it.”

We’ve already presented the *bricoleurs* ideas on how the graphics-based, interactive C&M notebooks more actively engage students in their own learning (*The Learning Process*). But the students, too, recognize how the BioCalc learning environment induces them to learn in a more active way.

In the notebooks, for examples, students are able to rework and restyle problems to suit their own needs, as many times as they need. This allows them to stay engaged with a problem for as long as they want and then move on, rather than having to work a preset number of problems.

Michelle: I prefer working with the Mathematica. I found the other way was just regurgitation-style. Here, you have to actually figure things out. The computer gives you the answer [in the Basics and Tutorial sections], but you have to figure out what it did—on your own. I find this a lot more interesting than doing the same type of problems twenty or thirty times just to get the steps down.

Another feature of the notebooks that the *bricoleurs* believe promotes active learning is the word processing: asking students to give written explanations of their answers gives them the opportunity to organize their thoughts and reinforces learning.

Bruce: The problems in the standard [lecture-based calculus] are algorithmic and fact-oriented. In this class, we’re more process-oriented, very communication-oriented. We want to develop conceptual understanding. The text feature of Mathematica makes it easier to do that because the questions aren’t: “Find the answer to this,” or “Do this algorithm to get this answer.” It’s: “Why does that work? Look at this picture and
Moreover, the students themselves told us that the interaction required by the C&M courseware makes them feel more productive.

**Elizabeth:** This is more interactive. I was more passive in the last class—I just sat there and didn’t really participate that much, because there wasn’t really much participation to do obviously in the lectures. We’d sit there for an hour. And then the discussion, you can ask questions if you want to, otherwise you sit there and take more notes. But here, I just feel like I’m doing more. I’m being more productive than I was last semester, and I feel like I’m learning more.

**Good practice gives prompt feedback.**

“Knowing what you know and don’t know focuses your learning. In getting started, students need help in assessing their existing knowledge and competence. Then, in classes, students need frequent opportunities to perform and receive feedback on their performance. At various points during college, and at its end, students need chances to reflect on what they have learned, what they still need to know, and how they might assess themselves.”

Learning is further facilitated by the immediate feedback students get while working through problems and examples. By changing input factors, students are able to manipulate and change output data, changes that they see immediately with the press of a button. As Dan*, a graduate teaching assistant, explained, immediate feedback enables students to better understand ideas and gives them a sense of satisfaction, as well.

**Dan:** One reason [students learn better] is because of the way the Mathematica lessons are structured. They get a sense of satisfaction when they do the problems because they can see the results. For instance, they start with a real world problem, they work through it, and at the end they see the results: perhaps a graph or something. And from that, it clicks. They’re getting fairly immediate feedback, and that’s very important.

Students do not just get feedback from the notebooks, however. If a student is having problems with any part of the lessons, he or she has a number of opportunities to get immediate help. During class, the instructor, class assistant and other students are available. When not in class, students have available three C&M labs on campus, each of which is staffed during the day with lab assistants. Students can also get help when they log in to Course Space; here they can enter an online chat room and discuss problems with other students or get help, at specified times, from C&M staff.

**Good practice emphasizes time on task.**

“Time plus energy equals learning. Learning to use one’s time well is critical for students and professionals alike. Allocating realistic amounts of time means effective learning for students and effective teaching for faculty.”

Time on task is almost a built-in feature of BioCalc because it’s what Jerry calls a “unified learning environment.” Students are able to spend most of their time in lab, working with a single, unified medium: the electronic notebooks. This, Jerry stressed, allows them to avoid the
distractions of switching mediums (from book to pencil to paper to calculator, for instance) and instead maintain focus on the task at hand.

Because students are able to spend most of their class time on assignments, they can more easily get help when needed and the instructor can more accurately gauge student progress and adjust assignments accordingly.

**Good practice communicates high expectations.**

"Expect more and you will get it. High expectations are important for everyone — for the poorly prepared, for those unwilling to exert themselves, and for the bright and well motivated. Expecting students to perform well becomes a self-fulfilling prophecy."

The *bricoleurs* told us that one of their goals for student learning was to convince students that math is something they *can* do. They expect their students to learn and to succeed, and the students pick up on that. The impetus to interact and engage with the ideas presented come from the students themselves, who understand the implicit assumption that they are responsible for their own learning.

**Jeremy* (student & class assistant):** Homework is very important. You can sit and listen to however many lectures, but if you don’t do it yourself, you’re probably not going to learn it. And when you get to Mathematica, it’s based primarily on you doing it yourself.

**Good practice respects diverse talents and ways of learning.**

"Many roads lead to learning. Different students bring different talents and styles to college. Brilliant students in a seminar might be all thumbs in a lab or studio; students rich in hands-on experience may not do so well with theory. Students need opportunities to show their talents and learn in ways that work for them. Then they can be pushed to learn in new ways that do not come so easily."

BioCalc and other C&M courses invoke different methods of learning by using the strong visualization capacities of *Mathematica*; by asking students to not just solve problems, but to set up, solve, and explain problems; and by providing students with a context in which concepts and applications appear connected and applicable to real world pursuits. Several students told us that they learn better in this type of learning environment.

**Tim (student & lab tech):** It’s easier to see how [concepts] directly apply, rather than getting lost in the theories. That sometimes happened to me when I took book calc in high school. I’m a very visual learner, and there are so many graphics [with Mathematica]—it helps me a lot to just be able to see what’s happening, to be able to throw out tons and tons of graphs without a whole lot of work, and I can look and see every step of the way what it’s doing. I learn the basic concepts through seeing it in action. That’s what the Calculus&Mathematica courses are all about.

Jeremy, a C&M student and classroom assistant, expressed similar thoughts:

*One of the advantages of Mathematica is that it’s a lot more visual. If I took [a course without Mathematica], I’d be looking at equations all the time. I mean, how are you going to graph a 3-D vector field in a handwritten course? In the book, you get a nice*
picture of one equation. But [using Mathematica] I can come up with a 3-D vector field, a picture of it, for every single equation that I have.

Moreover, BioCalc relies heavily on using life science examples and applications to show students what calculus “is good for.”

Luca* (graduate teaching assistant): Some students, when the math is getting complicated—when it’s difficult, when it’s a lot of material, it’s hard and it’s getting boring—they think that it’s not for them. They don’t understand why they need to solve all these problems. Why do they need to remember all these rules if they are not going to apply them in their real life? So that’s why in the Mathematica courses we’re going from the other position. We are showing them problems that they may meet in real life, and we’re showing them how to solve these problems—how to apply mathematics to solve these problems.

Such an approach allows students of all levels to more easily make the important connections that both the math and life science faculty at UIUC say are needed.
2. A Summary of the Results of a BioCalc Assessment

As stated in Outcomes and Assessment: Measuring Success, at the time of our interviews, an assessment of BioCalc and it’s impact on life sciences majors was underway. The assessment was completed and a summary report issued in April 2001. The report, entitled “The Impact of BioCalc on Life Sciences Undergraduates at UIUC” was prepared for the Howard Hughes Medical Institute, from which a grant was received for the development of BioCalc. With the permission of Susan Fahrbach, director of the Howard Hughes Program at UIUC, we quote from the report’s findings below.

This assessment was based on the records of “1273 life sciences majors who completed MATH 120 on the UIUC campus during the period from Fall Semester 1995 through Spring Semester 1999” (p.7).

Summary of the Initial Analysis of BioCalc Students

The impact of BioCalc on life sciences majors can be simply stated: students who take BioCalc receive better grades in MATH 120 than non-BioCalc students and are roughly twice as likely to take an additional math course. That the improved performance of BioCalc students in MATH 120 is unlikely to result solely from “easier grading” in BioCalc is indicated by the success of these students in the next course in the sequence, MATH 130. Also, BioCalc students do not differ from non-BioCalc students on other measures of academic success. There is also no evidence that the higher MATH 120 grades of the BioCalc students represent superior initial preparation or overall better academic performance on the part of the BioCalc students. In fact, the opposite is likely true given the inclusion of the CalcPrime students in the BioCalc totals. Note again that the population analyzed excludes students transferring credit for this course and students who entered with AP credit in Mathematics, so that the information presented only described life science students taking MATH 120. (p.9)

The following major conclusions are reported (p.11):

- The BioCalc option is equally attractive to all life science students required to take MATH 120. No life sciences options is over- or underrepresented.
- BioCalc students receive higher grades in MATH 120 than non-BioCalc students.
- BioCalc students are as well-prepared for MATH 130 as non-BioCalc students, as judged by grades obtained in MATH 130.
- BioCalc students are significantly more likely to take an additional math course than non-BioCalc students.
- BioCalc students are slightly more likely to remain in a biological science than non-BioCalc students.

CalcPrime is a program offered through the Howard Hughes Program at UIUC for students who do not perform well enough on the math placement exam to enroll directly in MATH 120. It offers students an alternative to enrolling in a pre-calculus course. For more information on this innovative program, see http://www.life.uiuc.edu/hughes/prime/prime.dir.html.
Table 3 gives average grades received by BioCalc and non-BioCalc students in MATH 120, MATH 130, and the first-year introductory biology sequence (BIOL 120, 121, 122).

Table 3. Median Final Course Grades of Life Sciences Students Enrolled in MATH 120, 1995 – 1999

<table>
<thead>
<tr>
<th>Course</th>
<th>BioCalc</th>
<th>Non-BioCalc</th>
</tr>
</thead>
<tbody>
<tr>
<td>MATH 120</td>
<td>3.67 (499)</td>
<td>3.0 (774)</td>
</tr>
<tr>
<td>MATH 130</td>
<td>3.0 (121)</td>
<td>3.0 (242)</td>
</tr>
<tr>
<td>BIOLOGY 120</td>
<td>2.67 (348)</td>
<td>3.0 (526)</td>
</tr>
<tr>
<td>BIOLOGY 121</td>
<td>3.0 (308)</td>
<td>3.0 (424)</td>
</tr>
<tr>
<td>BIOLOGY 122</td>
<td>2.67 (263)</td>
<td>3.0 (368)</td>
</tr>
</tbody>
</table>

Number of students is given in parentheses.

For more information about the BioCalc assessment or to obtain a copy of the report, please contact the Hughes Program Office at UIUC, 429 Natural History Building, Urbana IL 61801. (217) 244-1984.
RESOURCES

A. Institutional Description
The University of Illinois, Urbana-Champaign

Located 140 miles southeast of Chicago, the University of Illinois at Urbana-Champaign is the state’s flagship public university. It is continually ranked as one of the best universities in the world. Originally chartered as a land-grant institution in 1867, the University currently provides graduate and undergraduate education in over 150 fields of study, conducts both theoretical and applied research, and provides public service to the state and the nation.

Faculty. The University employs nearly 2000 tenured faculty. Ten scientists have received the National Medal of Science, and more than sixty have received the National Science Foundation Young Investigator Award.

Students. The undergraduate population at UIUC hovers near 28,000 students. (In addition, there are nearly 9,000 graduate and professional students enrolled in more than 100 disciplines.) Admission is highly selective. In the 1999 freshman class, for example, students in the middle fifty percent had ACT scores between 25 and 29 and ranked between the 81st and 95th percentiles of their high school graduating classes. Over 4000 courses are offered in more than 150 undergraduate fields.

Alumni. The University has had many distinguished alumni, among which ten have received Nobel Prizes for the United States and another sixteen, Pulitzer Prizes.

Budget and Facilities. The campus includes some 200 buildings on nearly 1,500 acres of land in the twin cities of Champaign and Urbana (combined population: 100,000). It has an annual budget of about $1 billion, of which about 27 percent comes from state appropriations and the rest from tuition, gifts, grants, contracts and other revenues.

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*a Information presented here was obtained from the online Visitors Guide at [http://www.uiuc.edu/visitors/vguide.html](http://www.uiuc.edu/visitors/vguide.html), and the University of Illinois Facts 2001, available at [http://www.uiuc.edu/admin2/facts.html](http://www.uiuc.edu/admin2/facts.html). These sites were accessed on July 20, 2001.
B. Methods Used to Produce this Case Study

Susan Millar and Anthony Jacob, researchers for the Institute on Learning Technology, conducted interviews and observed labs and classrooms during February 2000 at the University of Illinois at Urbana-Champaign. They interviewed four members of the Department of Mathematics: Professor Jerry Uhl; Bruce Carpenter, Teaching Associate; Brad Edge, graduate teaching assistant; and Paul Weichsel, Associate Chair. They interviewed three other graduate teaching assistants with experience teaching BioCalc, and Tim Braun, a C&M student and lab technician in one of the three C&M computer labs. Four members of the School of Life Sciences were interviewed: Susan Fahrbach, Associate Professor of Entomology and Faculty Director of the Howard Hughes Program; Ruth Wene, Academic Advisor in the School’s Advising Office; Barbara Meyer, Computer-Assisted Instruction Specialist; and Charles Miller, director of the School of Molecular and Cellular Biology.

They interviewed a group of four students currently enrolled in the BioCalc course and two students who had previously completed a BioCalc course, as well as an undergraduate classroom assistant.

The interviews were guided by the protocols used in all the Learning Through Technology case studies and were taped and transcribed. Sharon Schlegel analyzed the interview material to produce this case study, with substantial input and editing from Susan Millar. Andy Beversdorf, Sue Daffinrud, and Mark Connolly offered valuable editing and organizational suggestions in addition too much needed comedic relief.

Acknowledgements:
The authors thank the wonderful faculty, staff, and students at the University of Illinois at Urbana-Champaign who participated in this study. These individuals very graciously responded to our request for their time and attention not only during the interview process, but during the writing of this case study as well.

This case study is based on a collaborative analysis and planning process undertaken by the NISE’s Learning Through Technology “Fellows” group: Jean-Pierre Bayard, Stephen Erhmann, John Jungck, Flora McMartin, Susan Millar, and Marco Molinaro. The Fellows, in turn, benefited substantially from members of the College Level One Team: Susan Daffinrud, Art Ellis, Kate Loftus-Fahl, Anthony Jacob, and Robert Mathieu.

A brief word on the purpose of the BioCalc case study:
The purpose of presenting this case study (as well as the others on the LT² Website) is not to promote particular learning technologies like C&M but rather to promote the appropriate use of such technologies. We present our case studies with the hope that a narrative of others’ efforts to achieve better student learning will be beneficial to those considering a similar pursuit.
Assessment – What do faculty who are experimenting with interactive learning strategies (see constructivism) mean by “assessment”? In the simplest terms, assessment is a process for gathering and using data about student learning and performance. The LT² web site distinguishes the following two types of assessment:

- **Formative assessments** – activities that simultaneously (1) provide instructors with feedback about how and what students are learning, which the instructors can then immediately use to adjust and improve their teaching efforts; and (2) foster student learning directly because the students in the process of performing such activities. (For more information, see the FLAG website, which features classroom assessment techniques that have been show to improve learning.)

I. **Summative assessments** – formal examinations or tests, the results of which faculty use to demonstrate in a way that is definitive and visible to people outside the course the degree to which students have accomplished the course’s learning goals.

Tom Angelo (1995) defines assessment as an ongoing process aimed at understanding and improving student learning. It involves:

- making our expectations explicit and public;
- setting appropriate criteria and high standards for learning quality;
- systematically gathering, analyzing, and interpreting evidence to determine how well performance matches these expectations and standards; and
- using the resulting information to document, explain, and improve performance.

When it is embedded effectively within larger institutional systems, assessment can help us focus our collective attention, examine our assumptions, and create a shared academic culture dedicated to assuring and improving the quality of higher education.

**Bricoleur** – a French term for a person who is adept at finding, or simply recognizing in their environment, resources that can be used to build something she or he believes is important and then putting resources together in a combination to achieve her or his goals.

**Constructivism** – According to Schwandt, constructivism is a “philosophical perspective interested in the ways in which human beings individually and collectively interpret or construct the social and psychological world in specific linguistic, social, and historical contexts” (1997, p.19). During the last 20 or so years, cognitive psychologists (James Wertsch, Barbara Rogoff, and Jean Lave, among many others) have found that constructivist theories of how people construct meaning are closely aligned with their observations of how people learn: knowledge is mediated by social interactions and many other features of cultural environments.

**Learning activity** – As used in the LT² case studies, learning activity refers to specific pursuits that faculty expect students to undertake in order to learn. Thus, “Computer-enabled hands-on experimentation is a useful way to get students to take responsibility for their own learning” is a statement of belief that a particular learning activity (experimentation) helps realize a particular teaching principle.
Learning environment – According to Wilson, a learning environment is a place where learners may work together and support each other as they use a variety of tools and information resources in their pursuit of learning goals and problem-solving activities (1995). This definition of learning environments is informed by constructivist theories of learning.

Seven Principles for Good Practice in Undergraduate Education – These principles, published in “Seven Principles for Good Practice in Undergraduate Education” by Zelda Gamson and Arthur Chickering, were synthesized from their research on undergraduate education (1991). According to their findings, good practice entails:

1. Encouraging student-faculty contact.
2. Encouraging cooperation among students.
3. Encouraging active learning.
5. Emphasizing time on task.
6. Communicating high expectations.
7. Respecting diverse talents and ways of learning.

Teaching principles – Teaching principles refer to a faculty member’s more general beliefs about, or philosophy of, learning. For example, the idea that “students should take responsibility for their own learning” is a teaching principle. It is general and informed by a theory of learning. It does not refer to something specific that one might actually do in a course.
REFERENCES


Fahrbach, S., C. Washburn, et al. (2001). The Impact of BioCalc on Life Sciences Undergraduates at UIUC. Urbana-Champaign, IL: Howard Hughes Program for Undergraduate Science Education at the University of Illinois at Urbana-Champaign.


ENDNOTES

1 These results are from an assessment of BioCalc Math 120 conducted in 2001 by the staff of the Howard Hughes Program at UIUC. For a copy of the report or for additional information, contact the Hughes Program Office at 217-244-1984, 429 Natural History Building, Urbana IL 61801.

2 Seymour and Hewitt (1997) point out that

‘Weed-out’ is a long-established tradition in a number of academic disciplines, but it is dominant in all S.M.E. majors. It has a semi-legitimate, legendary status…. ‘Weed-out’ strategies are perceived as a test for both ability and character and are the main mechanism by which S.M.E. disciplines seek to find those students presumed to be the most able and interested. There are no references to weed-out systems in official literature…. Switchers [students who leave their first choice major] who reported that they were ‘weeded out’ typically went on to explain which aspects of the ‘weed-out’ process had been critical in their decision to leave… problems with curricular pace and load, the effects of assessment and grading practices, and the competitive atmosphere to which these practices contribute. (pp. 122-23)

3 At the time of our interviews (February 2000), the School of Life Sciences was in the process of reorganizing into two separate schools: the School of Molecular and Cellular Biology and the School of Integrative Biology. The split became official in July 2000. For the purpose of clarity and to reflect reality at the time of our interviews, we will refer to the unified School of Life Sciences (SOLS).

4 Source: University of Illinois at Urbana-Champaign 2000-2001 Campus Profile. Enrollment information is available online at http://www.dmi.uiuc.edu/cp/.

5 Professor Lazarowitz left UIUC in 1998 and is currently Professor of Plant Pathology at Cornell University.

6 Deborah Hughes-Hallet (1998) notes that typically “courses taken in other departments have to be approved by the major field, but the content is seldom closely supervised by the major field.”

7 A report by the National Research Council (1986) characterized calculus education as “out of date in content, unimaginative, poorly organized for students with different interests, and not reflecting recent advances in the understanding of teaching and learning” (cited in Alexander, Burda, & Millar, 1997).

8 At the core of the problem is a lack of communication and cooperation between the departments that use math in applied situations, like life sciences, and the math departments that often teach a more “pure” form of mathematics. As Deborah Hughes-Hallet (1998) has pointed out, this apparent disjunction has a deleterious effect on the way non-math majors perceive the function and usefulness of math to their particular fields: “From the point of view of the students, they will not see their subjects as interrelated unless the faculty does and unless the faculty takes the trouble to present them that way.”

9 This assessment was completed shortly before the publication of this case study. In keeping with the accuracy of the information presented to us during the time of our interviews (February 2000), we have opted not to present the results in the main body of the case study. Instead, we summarize the results of the BioCalc assessment in an appendix, Resource E.

10 More information on the Indicators project can be found at www.mste.uiuc.edu/indicators/index.htm.