University of Massachusetts
Biology 100 Course Redesign
Using Technology to Facilitate Active Learning in the Large Lecture Hall

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The Challenge:

Changing **large classes** to engage students as active participants in learning and not passive recipients of “Knowledge”.

*How do students learn critical thinking and problem solving in a lecture hall??*

Especially at the introductory level, students expect to be “told the answers” which they should memorize and reproduce for an exam. A basic challenge is to transforming students perspectives and make them active participants in “figuring things out” and not just learning the “facts” from the text or professor.
Learning depends upon the activity of the learner.

If we engage students in “active learning”, what do we have the students do?

This question is especially difficult in the large lecture hall setting of most introductory courses. Just keeping students awake long enough to take notes is a challenge. Engaging students in meaningful activities in the lecture hall is the goal of our redesign.
Historically, we frequently heard from upper level instructors that students come out of Intro not knowing much….., and were poorly prepared for advanced work. The reason for this poor preparation isn’t that mysterious if the instructor just looks out on the students mid-lecture.
By asking students to cooperate to solve interesting problems that challenge their ability to meaningfully use the material in the course, we have transformed the classroom into an active, energized environment for learning.
Reduction in faculty numbers and ballooning enrollment has created great pressure on faculty in the department.
In response, the faculty developed a set of Learning Goals that focus on skills students must possess to be successful biologists. This is quite different from the standard curriculum reform list of content topics students must “know”.

Biology 100 - before any redesign

• 700 Students per semester
• Diverse Student Population
  9 Different majors
  Biochemistry to Equine Studies
  “5” in AP Biology - 8th Grade Health
• “Core” (aka boring) concepts and topics
• 2 sections, 2 (or more) instructors in each
• “Short Straw” teaching assignment
• Straight lecture format

Teaching a quality Introductory Biology course is challenging at any research university, and these are common problems in presenting the course.
Biology 100
Redesign Step I  Active Learning

• Introduction of ClassTalk
  • Classroom communication system
  • Brief lecture segments
  • Problem solving
  • Small group discussion directed at answering questions
    • Responses for all students are compiled and displayed
  • Whole class discussion centered on strategy for problem solving

We began using a classroom communication system called ClassTalk in 1998. This system uses a network of connection nodes for TI-83 graphing calculators to allow students to enter responses to questions posed by the instructor. All student responses are compiled and can be displayed in a histogram for class discussion. Similar systems that are wireless, including PRS from EduCue (http://www.EduCue.com) can be used in very similar ways.

The essential feature of these systems is giving students opportunities to have small group discussions about problem solving events during class time that are followed by an instructor-guided discussion of problem solving strategy. This system was pioneered at UMass by a group in Physics and detailed discussions of the use of classroom communication systems to facilitate conceptual understanding is available at the UMass Physics Education Research Group web site (http://umperg.physics.umass.edu/projects/ASKIT/).
Which of the following is TRUE?

1. All cancers are genetic.
2. All cancers are inherited.
3. all of the above
4. none of the above

Using ClassTalk, we could generate discussions about concepts that frequently cause misunderstanding by students. We found that these discussions were more successful at clarifying concepts than presenting the issues in lecture format.
What would happen to the cell cycle if the G1 cyclin inhibitor genes were mutant and did not work?

1. Cell division would be normal.
2. DNA synthesis would be activated.
3. Mitosis would be blocked.
4. G1 cyclins would never be destroyed.
5. Growth of cells would slow down.

We could ask students to use causal models in biology to predict the result of some manipulation to a biological system. This ability to use causal models is central to the scientific research and is an important skill for students to develop early in their undergraduate careers. Because successful solutions to these problems require a wide array of cognitive skills, it is difficult to “teach” in a lecture, and requires repeated practice by students with feedback from peers or the instructor about problem solving strategy.
One of the most important events during problem solving is the small group discussions that occur between students. This is where students argue and puzzle over questions, present their own ideas, discuss their own misunderstandings and evaluate the arguments of classmates. As the semester proceeds, students become better at using the time effectively, and become more sophisticated in their argumentation skills.
After group discussions, students enter their answers through a handheld device.
ClassTalk Responses are compiled and displayed

The compiled responses of all students are presented in a histogram and used as a focus of discussion. Guiding these discussion to elicit the array of ideas and concepts students used is an important instructor skill. It is important that the instructor avoids using this as an opportunity to just give the “right” answer and move on. A good discussion from the whole class can help reveal key misunderstandings and allow all students see strategic approaches they may not have personally used during their small group problem solving discussions.
Benefits of in-class problem solving

- Students practice critical skills
- Group discussions increase range of approaches used by individual students
- Misconceptions are revealed
- Problem solving strategy is emphasized
- Provides a “reason for knowing all this stuff”

The final point here is especially important. Frequently introductory survey courses present long lists of facts and concepts without a clear, cohesive rationale for students to learn beyond “it will be on the test”. By focusing students on problem solving that requires the use of the facts and concepts and vocabulary they are expected to know, students develop a “reason for knowing all this stuff”.
Challenges after Initial Redesign

• Student Preparation for Problem Solving
• Time for content coverage and discussion
• Costs of the course
  4 + faculty
  support staff
  TA’s

After our initial introduction of ClassTalk in the lecture hall, we were trying to do too much, and some students struggled. We were still trying to lecture as well as present problem solving events. Students were coming to class without much outside preparation. They found lectures to be too brief and the problems solving was difficult.
Pew Redesign

- Offload basic content to a web site
  Class Preparation Page
    readings
    activities
    key concepts
    online quiz
- Build a database of questions and problems
- TA training through the web site
- Reduce faculty from 4 to 2

To solve these problems we asked students to do their homework to be properly prepared for the problem solving events in the classroom. To guide this preparation, we created a web site that we called the “Class Preparation Page” where students were given a list of specific readings, a list of key conceptual questions they should be able to answer, activities to reinforce the concepts and an online quiz. Students were required to complete these activities before class. Funding for this project was provided by the Pew Center for Academic Transformation.

http://www.center.rpi.edu/PewHome.html
The Class Preparation Page is a well designed, but fairly simple web site designed to be flexible and easy to use for both students and instructors.
The key concepts for the week’s material are presented as questions that students should be able to answer, and not as a list of facts students should memorize.
Reading assignments are quite specific and focus on just the text and figures that contain the key concepts, models and vocabulary students will need for problem solving.

Students are also sent to public web sites related to the weekly topic to do related activities or see the breadth of resources available for learning about any given topic.
Steve Brewer of the redesign team has created an open source on line quiz tool called Duck. Duck is free and available at http://bcrc.bio.umass.edu/projects/duck/.
Duck allows students to see either multiple choice or open ended questions (and possible answers). Students can select their favorite answer (or enter a written response).
After selecting an answer, students get feedback that is clearly marked from the instructor. The instructor can discuss key concepts or misconceptions that may have led to the answer, and can reinforce important ideas in this feedback. After reading the feedback, students can go back to the original question and select a different answer (where they will get additional feedback). Students are encouraged to go back and forth as much as they like to explore all of the answers and corresponding feedback from the instructor before they move on to the next question. In this way, students are encouraged to think about the reasons why an answer may be better (or worse) than another without experiencing any penalty for selecting the “wrong” answer.
3. Why are multiple mutations usually required before cells become cancerous?

1. There are multiple checkpoints in the cell cycle that need to be overcome.
2. There are many different cells that need to get the mutation before a cancer can develop.
3. There are many different types of cancer and each requires a different mutation.

Duck compiles responses from all students taking the quiz for instructor review before class. In this way, an instructor can use duck to tailor their lecture toward specific issues students struggled with on the class preparation page.
The specific activities of each student are also available for instructor review.
The web site also has a navigation tree for easy movement to many pages characteristic of many course web sites.
Most important and useful for students is a set of review materials that is generated from quizzes and ClassTalk questions. These allow students to make use of events in class to prepare for weekly paper quizzes and exams.
When added to the review materials pages, ClassTalk questions also get instructor comments which can reflect important concepts and include feedback about the class discussion that followed a particular problem event.
Redesign from a student perspective

Activities before class

• Visit web site to get assignments
• Read assigned text material
• Visit assigned web sites and do activities
• Take Duck quiz
• Come to class
Redesign from a student perspective

Activities **during** class

• Come to class
• Listen to rationale for problems/questions
• Discuss solutions with classmates
• Discuss *strategy* for problem solving with whole class/instructor
• Take weekly low-stakes quiz
Redesign from a student perspective
Activities after class

• Visit review page, reread text
• Read instructor feedback on ClassTalk questions/practice quiz
• Rework problems
• Take exam
Student Comments

“Classtalk forces me to think deeper and at a higher level”

“(I like) Classtalk - especially the explanations afterwards, since it lets me apply the knowledge I have already gained and it helps me understand the material more in depth.”

“The weekly quizzes I find beneficial because they are a good way of knowing how I am understanding the material....”

“The one bad thing about classtalk questions is that sometimes you are left still wondering which answer was right.”

Students very much like the system. On the mid-semester review in the Fall of 2001, there were 168 favorable comments about ClassTalk, and 2 negative comments. (On this review, students could discuss anything about the course, and 221 students responded.)

I rather like the idea that at least one student was “left wondering” about something when they left class.
Student Comments

“The course website is extremely helpful. I like having all review material like quizzes and classtalk questions available with the answers.”

“The Duck quizzes don’t help me very much since I am very unstable about the material in the beginning and I don’t get much help from them.”

“Thank god you don’t teach the class using Powerpoint.”

Again students were very favorable about the web site, and reflect on the fact that their understanding of the material develops as they perform the many activities around a topic. Because there are many chances for students to practice with the material, and early practice with the problems is presented without penalty for mistakes, students develop their skills over time.
“When my professor does PowerPoint, I have to copy it down so fast that…
…I don’t read what it says…
…comprehend it when I read it….
…or listen to the teacher when they try to explain it.”

**Linear vs Non-Linear class time….
Strategic thinking is often non-linear**

Powerpoint is a linear presentation tool with a predetermined sequence of slides. Problem solving is a non-linear task, and guiding students through problem solving events with a series of unpredictable connections between ideas brought up by students may be done best with class tools other than a linear sequence of slides.
Biol 100 attendance average 89.9% (n=244)

Attendance is outstanding. Averaged across the entire semester, including the day before Thanksgiving (perhaps you can guess which day that was) attendance was nearly 90% in the Fall 2001 semester.
Attendance is well correlated with success ($r=0.469$). Students who attended 90% of the time or more averaged much higher on exams than students who attended less than 90% of the time. ($p<<0.001$)
The web site was well used. Though there were strong peaks before each exam, there was strong and consistent use on a daily basis by the 234 students in this section of the course.
Web Site Use

> 62,000 hits over the semester
  ~ average 400 hits per day
  ~ 100 students/day
  ~ 3 visits / week / student

Peaks during review prior to exams

“I like the web site because it’s like a home for the course”

Students used the course on average 3 times a week. Ideally, once to get the reading assignment, once to take the online quiz and once to review for the weekly quiz.
### Engagement in problem solving

#### Formative Assessment

<table>
<thead>
<tr>
<th>Type</th>
<th># of ??</th>
</tr>
</thead>
<tbody>
<tr>
<td>On-line quiz</td>
<td>55</td>
</tr>
<tr>
<td>Classtalk</td>
<td>48</td>
</tr>
<tr>
<td>Weekly quiz</td>
<td>70</td>
</tr>
</tbody>
</table>

#### Summative Assessment

<table>
<thead>
<tr>
<th>Type</th>
<th># of ??</th>
</tr>
</thead>
<tbody>
<tr>
<td>Hour Exams</td>
<td>75</td>
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<tr>
<td>Final Exam</td>
<td>40</td>
</tr>
<tr>
<td>Total Questions</td>
<td>288</td>
</tr>
</tbody>
</table>

We asked many questions and problems of the students over the semester, more than half of which were no-stakes, or low stakes questions where students could get the problem wrong with little or no penalty. This kind of formative assessment is very important for students to move toward a clear understanding of the material with an ability to use the material to solve novel problems.
Learning Outcomes

Correlates with success in Biology 100
- High School GPA
- SAT score

Independent of success in Biology 100
- Gender
- Underrepresented minority status
- Honors status

As with most introductory university courses, high school GPA ($r=0.381$, $p<0.001$) and Math SAT ($r=0.282$, $p<0.001$) were correlated with success in the course. However, once variation from these factors is controlled, there is no significant effect of gender, minority status or honors status on success.
How do these questions differ?

1. Sister Chromatids...
   
   a. are formed from a single homolog during DNA replication.
   b. are visible during metaphase.
   c. separate during anaphase.
   d. have identical alleles.
   e. all of the above

This question is from an old exam from 1995 before we did any course redesign. Multiple choice answers a. through d. are all text surrounding the bold face word “sister chromatids” in the textbook. This kind of a definition question on exams was common on old exams.
2. What would occur if homologous chromosomes segregated during mitosis, instead of sister chromatids?

a. Cell division would be normal.
b. The daughter cells would have too many chromosomes.
c. The daughter cells would have too few chromosomes.
d. The daughter cells would be genetically identical.
e. The daughter cells would be genetically different.

This question asks students to use a model of chromosome segregation during mitosis to predict the outcome of an error in the process. This ability to use a causal model to predict an outcome of some change in conditions requires many cognitive skills, including knowing the definitions of the vocabulary words in the question.
Question analysis

0 - Recall of a definition or sequence of events

1 - Process manipulation
   Causes to effects
   (If a process is changed..what will result?)

   Effects from causes
   (If this results, what must have occurred?)

Questions can be divided into two simple categories.
<table>
<thead>
<tr>
<th>Reasoning Complexity of exam questions</th>
</tr>
</thead>
<tbody>
<tr>
<td><strong>Biol 100 1995 - R. Phillis</strong></td>
</tr>
<tr>
<td>RC = 0.26</td>
</tr>
<tr>
<td>Exam average = 62%</td>
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<tr>
<td><strong>Biol 100 1995 - S. Goodwin</strong></td>
</tr>
<tr>
<td>RC = 0.21</td>
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<tr>
<td>Exam Average = 58%</td>
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<tr>
<td><strong>Biol 100 2001 - R. Phillis/Goodwin</strong></td>
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<tr>
<td>RC = 0.68</td>
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<tr>
<td>Exam average = 72%</td>
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</table>

Our new exams engage students in much more problem solving and the course outcome is that students perform considerably better than on old exams centered primarily around recall of facts and definitions.
In collaboration with a cognitive science research group at Hampshire College headed by Neil Stillings, we designed and administered a pre / post test to assess student skill development during the course. This test presented causal models students had not seen before, and asked them to solve problems using those models. Students responded to both multiple choice and open ended questions on these tests. Students scores shifted significantly higher on the post test, suggesting that the ability to use causal models to solve novel problems was a generalized skill students developed in Biology 100.
Biology 100 Redesign

• Technology-mediated active learning in the classroom
• Basic content from web-directed independent learning
  Website home for course
  learning objectives
  assignments
  on-line quiz (Duck)
• Student engagement
  Attendance at 90%
  Students “buy in” and engage during class
  Web site use is high and consistent
• Challenging curriculum
  Biology Learning Goals
  Problem solving skills
  Manipulation of concepts and processes
Generalizable approaches

Keep student activities tightly in line with ultimate learning goals.

Constructive Discomfort

Expect/allow students to fail at first without penalty, and to learn from their mistakes.

Student-centered classroom

Design class time to focus on student attempts to solve problems, with instructor guidance in “real time”.
Use of the redesign in other courses

Web Site design / template
    All courses in Biology, Micro, Biochem

Full Redesign
    Biology 101 - Spring Intro Biology
    Biology 283 - Genetics

Davis Foundation Grant
    Intro courses in:
    Economics, Management, Communications
    Engineering, Statistics

The course redesign of Introductory Biology is being used as a model for redesign of many other courses at UMass. Recently, the Davis Foundation has provided funding to UMass for redesign of introductory courses in several other disciplines using Biology 100 as a model.
Instructor comments:

- New perspective on teaching; focus on “trouble spots” and problems.
- Can “plunge ahead” into “interesting” material without worrying that the basic material was covered.
- No more exam questions that are not problems…
- Difficult to write exams that are “hard enough!”

Instructors using the redesign have many positive comments.
Many people contributed to this work. Our apologies to any we may have overlooked.