A major concern of biology educators who want to replace lectures with active learning pedagogy is how to cover the same content they would teach in a lecture. A second concern is how to find methods they can immediately employ in their classrooms without the aid of teaching assistants, without the guidance of a university “center for teaching and learning,” without grant money, or even without the support and approbation of department colleagues.

Several journals as well as a variety of books about science teaching (see Resources and References sections) are a rich source of ideas, but inserting active learning exercises into an otherwise traditionally-taught course can produce a disjointed experience for students. Over several years of reading hundreds of sources, I have incorporated diverse low technology, low cost ideas and integrated them into a constantly evolving, but coherent, repertoire. I have refined my lecture-free design as I taught 11 sections of five different introductory and upper level science courses at the University of Maine at Presque Isle. In the Resources section, I provide sources of ideas for cooperative learning, peer instruction, problem-based learning, service learning, critical thinking, scavenger hunts, book reviews, and each of the case studies and hands-on activities listed in the General Biology I Topic Schedule (Figure 1). I also explain how I modify these ideas to

BONNIE S. WOOD, Ph.D., is Professor of Biology at the University of Maine at Presque Isle, Presque Isle, Maine 04769; e-mail: wood@umpi.maine.edu.
<table>
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<th>WEEK</th>
<th>TUESDAY</th>
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<th>ASSIGNMENTS</th>
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| 1    | 9/3: Introductions  
• Word Root Worksheet  
• Grouping Geometric Figures  
• Case Study: Nanobacteria: Are They or Aren’t They Alive?  
• Word Root Worksheet (Outline 1) and Scientific Method (Outline 2)  
9/5: Characteristics of Living Organisms  
Ch. 1, 12  
9/12: Chemistry of Living Things (Outline 3)  
“Ask the Experts” Student Presentations about Chemistry (Red Group)  
DNA Replication Outside the (Cereal) Box | Ch. 1, 12 |
| 2    | 9/10: Chemistry of Living Things (Outline 3)  
• Atoms Represented by Bolts, Screws, Nuts, and Washers  
9/12: Chemistry of Living Things (Outline 3)  
“Ask the Experts” Student Presentations about Chemistry (Red Group)  
DNA Replication Outside the (Cereal) Box | Ch. 3 |
| 3    | 9/17: Cells (Outline 4)  
• Size and Shape of Cells  
Surface Area:Volume Ratios  
9/19: Cells (Outline 4)  
• A Problem About Osmosis  
CELL STRUCTURE CROSSWORD DUE  
TEST REVIEW QUESTIONS DUE  
www.cellsalive.com (Cell Biology: How Big is a?; Plant and Animal Cell Models; Cell CAMS) | Ch. 4  
Cell Structure Crossword www.cellsalive.com (Cell Biology: How Big is a?; Plant and Animal Cell Models; Cell CAMS) |
| 4    | 9/24: Test Review Activity  
9/26: TEST (Outlines 1-4) | TEST (Outlines 1-4) |
| 5    | 10/1: Cell Reproduction (Outline 5)  
Mitosis models:  
• Sweat Sock Chromosomes  
• Paper Chromosomes  
CUT OUT PINK & BLUE PAPER CHROMOSOMES & BRING TO CLASS WITH 6 PAPERCLIPS  
10/3: Cell Reproduction (Outline 5)  
Meiosis models:  
• Sweat Sock Chromosomes  
• Paper Chromosomes  
Ch. 6  
Prepare paper chromosomes before class www.cellsalive.com (Cell Biology: Mitosis; The Cell Cycle) | Ch. 6  
Prepare paper chromosomes before class www.cellsalive.com (Cell Biology: Mitosis; The Cell Cycle) |
| 6    | 10/8: Genetics (Outline 6)  
• Taste Test  
• Coin Toss Pedigrees  
10/10: Genetics (Outline 6)  
• DNA Fingerprinting  
10/17: Genetics (Outline 6)  
“Ask the Experts” Student Presentations about Genetics (Yellow Group)  
• Restriction Enzyme/DNA Fingerprinting Simulation  
TEST REVIEW QUESTIONS DUE | Ch. 7, 8 |
| 7    | 10/15: Holiday—No Class  
10/17: Genetics (Outline 6)  
“Ask the Experts” Student Presentations about Genetics (Yellow Group)  
• Restriction Enzyme/DNA Fingerprinting Simulation | Ch. 9 |
| 8    | 10/22: Test Review Activity  
10/24: TEST (Outlines 5-6) | TEST (Outlines 5-6) (Midterm grades submitted on 10/25/02) |

**Key to Fonts:**  
Outline Titles  
Chapters and other assignments  
• In-class activities  
Student presentations, OTHER ASSIGNMENTS, TESTS
Ask your students:

“What do you want to be when you grow up?”

Medical Technology is experiencing a severe shortage of workers entering the field. Students interested in science should be strongly encouraged to look into a career as a Medical Laboratory professional.

The medical laboratory offers exciting career opportunities for students with an interest in science and an analytical mind. The professionals who work in the medical laboratory are problem solvers, people who like challenge and responsibility, set high standards, and are fascinated by science.

The popularity of the critically acclaimed television program *CSI: Crime Scene Investigation*, starring William Petersen, has sparked a new interest in the laboratory professions. While the stories are fiction, the *CSI* show is based on actual forensic and laboratory sciences. In the modern hospital, laboratory professionals use science to analyze blood and tissue samples in ways that save lives and care for patients.

As a teacher, you can guide science students who may be interested in saving lives through a future career in the medical laboratory. For information on how your students can become pathologists, medical technologists or medical laboratory technicians, call the American Society for Clinical Pathology at 800.621.4142 or visit our Website at www.ascp.org/bor/medlab/careers.

“As *CSI: Crime Scene Investigation*, I play Gil Grissom and work with a great cast who portray a dedicated team of laboratory professionals. But I salute the thousands of real pathologists and laboratory professionals who use their skills and knowledge to save lives, as well as solve crimes, through their work in the laboratory.”

— William Petersen
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| 9    | 10/29: Cellular Energy and Enzymes (Outline 7)  
  • Atoms Represented by Bolts, Screws, Nuts, and Washers  
  • Relating Enzyme Function to Concepts of Dominance and Recessiveness | 10/31: Photosynthesis (Outline 8)  
  • Photosynthesis: A Dynamic Demonstration in Two Acts | Ch. 5  
  www.cellsalive.com  
  (Cell Biology: Plant Cell Models) |
|      | 10/31: Photosynthesis (Outline 8)  
  • Photosynthesis: A Dynamic Demonstration in Two Acts | 11/7: Plant Structure, Nutrition, and Transport (Outline 10)  
  “Ask the Experts” Student Presentations about Plants (Blue Group) | Chs. 5, 17 |
| 10   | 11/5: Cellular Respiration (Outline 9)  
  • Cellular Respiration and Photosynthesis Jigsaw Exercise | 11/14:  
  • Test Review Activity  
  SUBMIT PEER-GRADED BOOK REVIEW DRAFTS | Ch. 18 |
|      | 11/12: Plant Growth and Development (Outline 11)  
  BOOK REVIEW DRAFT DUE  
  (Exchange with another student)  
  TEST REVIEW QUESTIONS DUE | 11/21: Animal Circulation and Respiration (Outline 12)  
  • Circulation Challenge Questions  
  • Case Study: Lost in the Desert | Ch. 23  
  www.cellsalive.com  
  (Cell Biology: Pumping Myocytes) |
| 11   | 11/19: TEST (OUTLINES 7-11) | 11/26: Animal Immunity (Outline 13)  
  • Acting Out the Immune System:  
  the Third Line of Defense  
  • Jigsaw Activity  
  • Case Study: A Bad Reaction:  
  A Case Study in Immunology | Thanksgiving Holiday  
  www.cellsalive.com  
  (Immunology) |
|      | 11/26: Animal Immunity (Outline 13)  
  • Acting Out the Immune System:  
  the Third Line of Defense  
  • Jigsaw Activity  
  • Case Study: A Bad Reaction:  
  A Case Study in Immunology | 12/5: Animal Reproduction (Outline 15)  
  • Case Study-Gender: In the Genes or in the Jeans? | Chs. 26, 28 |
|      | 12/5: Animal Reproduction (Outline 15)  
  • Case Study-Gender: In the Genes or in the Jeans? | 12/10: Evolution (Outline 16)  
  • Natural Selection Using Jelly Beans  
  • A Gambler’s Model of Natural Selection | Chs. 2, 11 |
| 15   | 12/10: Evolution (Outline 16)  
  • Natural Selection Using Jelly Beans  
  • A Gambler’s Model of Natural Selection | 12/12:  
  • Final Exam Review | |
| 16   | COMPREHENSIVE FINAL EXAM (OUTLINES 1 - 16)  
  Tuesday, December 17, 2002, 8:00 am - 10:00 am | | |

Key to Fonts:  
Outline Titles  
Chapters and other assignments  
• In-class activities  
Student presentations, OTHER ASSIGNMENTS, TESTS
meet my own course objectives and financial constraints.

Described below are seven steps for transforming a previously-taught lecture course into an active learning format. I have easily adapted this procedure to plan a course I have not taught before. By applying these steps to course objectives, I have achieved lecture-free teaching.

1. Use the course textbook and lecture notes to produce outlines of important terms and topics for which students are responsible.

As indicated in the General Biology I Topic Schedule (Figure 1), the topic for Week 3 (consisting of two 75-minute class meetings) is cells. Using the textbook and my previously-used lecture notes, I produced an outline (Figure 2) of content topics on cells for which the students are responsible. Their homework assignment, to be completed before the first class meeting of Week 3, is to take notes on Outline 4 while reading the textbook chapter on cells. In other words, students use the outlines to determine which topics in textbook chapters they should study and to prepare for each class meeting. The outlines ensure that the course content is identical to what would be covered in lectures. Generous spacing (not shown in Figure 2) between outline headings permits students to write notes about each term directly on the outline as they are reading the chapter.

2. Distribute among the outlines (created in Step 1) worksheets for in-class activities as well as homework assignments that incorporate current, relevant biological issues.

In the example of Outline 4, Cells (Figure 2), I knew from previous experience that even after a lecture and reading the chapter, many students retained misconceptions about surface area-to-volume ratio and its relationship not only to cell structure and function but also to many biological systems to be covered in upcoming weeks of the course. After reading a journal article describing a hands-on method for teaching this concept (Cohen, Moreh & Chayoth, 1999), I purchased sets of inexpensive plastic interlocking centimeter cubes (Teaching Resource Center, San Diego, California) and converted the ideas in the article to an in-class activity. During class, students work in learning groups to complete the Size and Shapes of Cells, Surface Area:Volume Ratios worksheet (Figure 3) as I lead a discussion of the results of each worksheet step. The References section lists articles I have similarly adapted for each of the in-class activities listed in Figure 1.

To link course topics to contemporary biological issues, I assign learning group presentations from Scientific American’s “Ask the Experts” column (Ask the Experts). On the topic schedule (Figure 1), I assign each cooperative learning group of four to six students a date corresponding to an outline. Each student in the group chooses a different “Ask the Experts” question that relates to that outline. Students select a question they find particularly intriguing. On the scheduled date, each member of the learning group gives a one- to two-minute presentation answering the question in his or her own words and explaining how it relates to the week’s topic. This assignment is engaging for both presenters and audience and encourages curiosity about science.

3. Construct a detailed syllabus that emphasizes students’ responsibility for their own learning.

Figure 3. Example of in-class activity worksheet

This worksheet would immediately follow Outline 4 in the coursepack. Two spaces are given between each question to allow students to write answers as they complete the activity with their learning group.

Size and Shapes of Cells
Surface Area:Volume Ratios

1. Count out 27 plastic cubes. The dimensions of each cube are 1 centimeter (cm) x 1 cm x 1 cm.
2. Examine a single cube. (KEEP THIS CUBE SEPARATE)
   A. What is its surface area?
   B. What is its volume?
   C. What is its surface area:volume ratio?
3. Make a cube that is 2 cm x 2 cm x 2 cm. (KEEP THIS CUBE SEPARATE)
   A. What is its surface area?
   B. What is its volume?
   C. What is its surface area:volume ratio?
4. Make a cube that is 3 cm x 3 cm x 3 cm. (KEEP THIS CUBE SEPARATE)
   A. What is its surface area?
   B. What is its volume?
   C. What is its surface area:volume ratio?
5. Compare the ratios you obtained in the progressively larger cubes.
6. Look at the three cubes you have constructed. If these represented the sizes of three different living cells, how would the size of the cells affect their functioning?
7. Using just 24 of your smallest cubes, produce a larger structure that is 4 cm long, 3 cm wide, and 2 cm high.
   A. What is its surface area?
   B. What is its volume?
   C. What is its surface area:volume ratio?
   D. What type of cell might this shape represent?
8. Using the same 24 cubes, produce a structure that is 8 cm long, 3 cm wide, and 1 cm high.
   A. What is its surface area?
   B. What is its volume?
   C. What is its surface area:volume ratio?
   D. What type of cell might this shape represent?
9. Using the same 24 cubes, produce a structure with the surface area of 98 cm².
   A. What is its volume?
   B. What is its surface area:volume ratio?
   C. What type of cell might this shape represent?
10. Which of the shapes you produced in 7, 8, and 9 would be the most efficient for an especially active (metabolically) cell?
11. Using the 4 x 3 x 2 cube you made in #7 above, rearrange the blocks in a way that increases the surface area while keeping the volume constant.
   A. Draw the shape of the model you produced.
   B. What is its surface area?
   C. What is its volume?
   D. What is its surface area:volume ratio?
   E. What type of cell might this shape represent?
12. Imagine that you have recently eaten a cheeseburger. Large globules of fat have left your stomach and entered your small intestine. The pancreas then releases an enzyme (pancreatic lipase) into the small intestine which can break down the lipids into molecules small enough to be absorbed into the intestinal cells. Bile is a substance produced by the liver and also released into the small intestine in response to the presence of the fat. The function of the bile is to increase the surface area of the fat globule so that the pancreatic enzymes can work on it more effectively.
   A. Once again make a cube that is 4 cm long, 3 cm wide, and 2 cm high (#11 above) and this time imagine that it is a fat globule.
      i. What is its surface area? (See your calculations from #7 above.)
      ii. What is its volume?
      iii. What is its surface area:volume ratio?
   B. What could the bile do to the fat globule to greatly increase its surface area?
      i. Rearrange the blocks to show this and draw what you have done to the fat globule.
      ii. Now what is the surface area?
      iii. Now what is the volume?
      iv. Now what is the surface area to volume ratio?
      v. How would these changes affect the digestion of lipids?
Approach as a guide, I designed a syllabus that explains my teaching methods and gives detailed instructions for successfully completing each part of the course. The syllabus is a resource for the entire semester.

My eight-page syllabus is divided into the sections listed below. Figure 4 is an excerpt from What’s Different about This Course? Syllabi for General Biology I and my other courses can be viewed on my homepage (http://www.umpi.maine.edu/~wood).

How To Find Me
• office location, office hours
• voice mail number
• e-mail address, Web page URL

What’s Different about This Course?
Rules And Regulations
• General Biology I CoursePack
• e-mail communications
• academic honesty
• attendance

Resources
• textbook
• coursepack
• laboratory manual
• my Web site
• computer labs
• tutoring and other assistance

Assignments
• learning groups
• a meal with the professor
• first day assignments
• readings and other homework
• book review
• “Ask the Experts” student presentations

Tests & Exams
• test review activities
• types of test questions
• make-up
• grading procedures

Figure 4. Excerpt from General Biology I Syllabus

WHAT’S DIFFERENT ABOUT THIS COURSE?
Take a look at the Topic Schedule to see what will be covered this semester.

Biology 112 is the first course of a two-semester sequence. Although some of you are science majors, many more of you are not. Some consider the science course graduation requirement a major obstacle.

My goal is to ACTIVELY engage you in the learning of biology so this course becomes a positive component of your undergraduate experience—a part that is not only a stepping stone to a degree but also enriches your life. This class will emphasize using facts about biology rather than simply acquiring those facts. Sometimes you will do this alone; sometimes you will do it in collaboration with fellow students.

I teach Biology 112 using methods that I hope will significantly change the way you view the world. I want to foster an interest in biology that will continue beyond the date of the final exam; to prepare you to make effective choices in the voting booth, and to be a citizen of the world; to help you acquire thinking skills that you can use in other life endeavors.

To accomplish my goals, I use “lecture-free” teaching methods. Active learning will NOT make the course easier and will NOT take less of your time. However, if you follow my guidelines you will not only enjoy the course more but also will increase your likelihood of success in the class.

To be successful you must accept responsibility for your own learning. This syllabus describes how you will do this.

4. Organize the topic schedule, syllabus, outlines, and worksheets in a loose-leaf binder coursepack.

Both the coursepack and the textbook are required materials. The coursepack can either be given to students or sold in the bookstore for the cost of copying. Outlines and worksheets are the core of the coursepack. A worksheet for an in-class activity immediately follows the relevant outline so that the outline notetaking assignments and the in-class activities are in chronological order in the coursepack. If journal articles are included, each student’s share of copyright clearance fees is added to the price. I believe that having students purchase the coursepack not only saves the school money, but also encourages commitment of students to the course and the teaching methods.

5. Include on the topic schedule weekly homework assignments for reading chapters and taking notes on outlines as well as in-class activities for particular dates (Figure 1). Instruct students to e-mail any specific questions about the textbook reading or outline notetaking before each class meeting so you can answer them during class.

Taking notes on an outline before the class meeting for which it is assigned is the most important responsibility of the students and the most difficult to get them to do successfully. I explain that although it takes self-discipline to prepare before each class, this effort eventually saves them time because they are able to understand and learn material during class meetings. I collect the outlines periodically, without advance notice, to grade and to give the students feedback.

6. Use class time to answer questions submitted by students and to engage students in
in peer instruction and active learning exercises.

Students have three different ways to communicate their need to spend class time on a specific topic: they can e-mail me before class about any confusion they had while taking notes on an outline topic; they can raise their hands during class; and they can describe their confusion in “The Murkiest Point.” At the conclusion of each class, students submit a brief description of one point that was confusing. If nothing was “murky,” they instead write “The Most Interesting Point.” With this method I get immediate feedback as well as an attendance record. I clarify “murkies” at the beginning of the next class.

7. Don’t be afraid to get off schedule a bit and to experiment with innovative teaching methods.

Maintaining flexibility is challenging if you like to stay on schedule or if you tend to pack too much into one class period. I’ve learned that even if I have three wonderful active learning exercises that relate to a topic, I may have time to include just one of them. The goal is for students to truly understand a concept before they leave the classroom. Some active learning exercises work well and I continue to use them. Others are not as effective and are eliminated or replaced in future semesters. Some exercises go off on a tangent that leaves students feeling confused about the purpose of the exercise. Do not use an exercise for the sake of having an exercise during a particular class meeting. A useful substitution in a class meeting that lacks a formal in-class activity is to present a series of multiple choice questions for use with peer instruction (Mazur, 1997).

Summary

Because I changed my testing methods to complement my new pedagogy, comparing test scores, course grades, and other quantitative data before and after instituting lecture-free teaching was not useful. Similarly, comparing students in a traditionally taught section of a course to students in my lecture-free section has limited value because there are so many uncontrolled variables. I do, however, carefully read student evaluations at the end of each semester to continue to refine and improve my teaching methods. Below are quotes from student evaluations about my lecture-free teaching:

I've never had a science class that I have been able to feel like I knew what was going on. This teaching style has helped me to understanding the concepts being studied. I wish that I could have had this kind of exposure to science at an earlier age. It might have made a difference in my chosen career.

... teaching methods are an effective and refreshing approach to teaching science.

Overall I learned a lot this semester. I stress learned over memorized. I learn better through hands-on work.

... I was worried about the different teaching style, but I have found that I have a better understanding of the material and can apply it to different situations. This has been my most challenging class, but also my most rewarding.

I enjoy the unique style of teaching. Having a variety of ways to learn keeps me interested . . .

I am completely impressed with how you applied the new teaching method to this class. It is inspiring as a future teacher.

Her approach is excellent and the interactive exercises should be used as a model for all other instructors.

For several years, I have successfully applied these chronological steps for transforming previously-taught lecture courses into an active learning format. The steps were equally applicable when I taught a new course. If, however, an educator prefers not to convert to a totally lecture-free format, my methods can be incorporated on a limited basis by alternating ten- or fifteen-minute lectures with a variety of active learning and peer instruction exercises.

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Explore the Educational Opportunities:

BOTANY 2005

Learning from Plants

Botany 2005: the annual meeting of four societies:
Botanical Society of America (BSA),
American Fern Society (AFS),
American Society of Plant Taxonomists (ASPT)
American Bryological and Lichenological Society (ABLS)

Learn new ways to bring the fun of Science Inquiry through plants to your classroom

Join us in Austin for:

- FREE Hands on Workshops
- Scientific Field Trips
- Teaching Resources and Ideas
- Inspiring Keynote speaker: Barbara Schulz,
  Educator Leader, The National Academies Teacher Advisory Council

"Is it cool to know and do science? Can we create a Scientific Temper?" 

Increase interest in plant science in your students with the BSA’s new and innovative SCI11 program

Become involved with teaching science at the National level

Texas Educators earn up to 15 CPE Credits

Complete Meeting Information at www.2005.botanyconference.org
My lecture-free science courses do not sacrifice content and incur little or no additional cost. The more I use lecture-free teaching, the more comfortable I have become with these methods and the more creatively and effectively I teach biology.

Resources

Cooperative Learning: Lord, 2001
Peer Instruction: Mazur, 1997
Problem-Based Learning: Allen, Duch & Groh, 1996
Case Studies: Smith & Murphy, 1998; The National Center for Case Study Teaching in Science Case Collection
Critical Thinking: Allen & Stroup, 1993; Stroup & Allen, 1992
Scavenger Hunts: Griffin, Dew & Kronberg, 2000
Book Reviews: Brandriss, 1999

References

The National Center for Case Study Teaching in Science Case Collection, Case Studies in Science, State University of New York at Buffalo, available online at: http://ublib.buffalo.edu/libraries/projects/cases/ubcase.htm.