

Workshop Biology: Demonstrating the Effectiveness of Active Learning in an Introductory Biology Course

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The University of Oregon's Workshop Biology curriculum is one of many experimental approaches to teaching introductory college-level science that emerged during the last decade (Lawson et al. 1990, Ebert-May et al. 1997, Laws 1997, McNeal and D'Avanzo 1997, Wyckoff 2001). Our motivation for developing Workshop Biology came partly from a concern that, despite generally favorable student course evaluations, our traditional approaches (for example, teacher-directed, "cookbook" activities and demonstrations) did not provide students with valuable skills or even with a body of knowledge that lasted much beyond the end of the term.

The Workshop Biology project aimed at improving science literacy among nonscience majors in the context of a major research university. The curriculum was developed, implemented, and evaluated during the period 1991–1994. The project included both the development of the Workshop Biology course (a three-term, lab-based introductory sequence for nonscience majors) and a thorough evaluation of its effectiveness as compared with a traditional lecture-based course.

The Workshop Biology curriculum incorporated three leading approaches in science education reform: (1) directly

confronting students' misconceptions through concrete experiences, or what we refer to as "conceptual change"; (2) integrating "science as inquiry" into the underlying philosophy of the course; and (3) introducing science in context.

The idea of "conceptual change" was drawn from the very successful Workshop Physics approach (Thornton and Sokoloff 1990, Laws 1997), which focuses on identifying common misconceptions and then confronting them through concrete experiences. We drew the name for our course, Workshop Biology, from this approach. Programs that teach "science as inquiry" focus on the need for students to experience the process of science in order to view science as a way of knowing, rather than as a body of knowledge. For example, the BioQUEST curriculum consortium's "3 P's" model, problem posing, problem solving, and peer persuasion (Peterson and Jungck 1988), helps students gain skills in the full range of scientific practice. Similarly, case studies can motivate students to search out information and develop analytical skills needed to solve a problem presented by a realistic, interesting case (Herreid 1994a, 1994b). Finally, programs addressing "science in context" focus on the personal and social

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meaning of scientific advances or on the role of science in society (Hobson 2000/2001). Helping students make connections between their science studies and their own lives is a major component of most recommendations for science education reform (AAAS 1989, NRC 1997). These three perspectives provided a good starting point for formulating goals for our course.

Course goals and structure

To establish goals for the course, we focused on what we could do that would have an impact on students' lives not only now but in 20 years. We decided that giving them skills to make informed, critical decisions consistent with their values would help them with everyday decisions such as what kind of car to drive or foods to eat, how many children to have, how to vote on environmental issues, and whether to remain ignorant or superstitious of major scientific advances.

Focusing on decisionmaking leads to more specific objectives. Students need to develop lifelong learning skills, including the ability to find, evaluate, and apply information to unfamiliar problems; understand the nature and importance of scientific inquiry as a human endeavor; and appreciate the role of science in society and in their personal lives.

Conceptual change. We started with the premise that students gain more from a deep understanding of a few significant concepts than from a superficial understanding of many. We designed activities that allow students to discover important biological concepts through their own questioning and hypothesis-testing activities, or that emphasize confronting misconceptions about fundamental concepts such as cell division (Smith 1991), natural selection (Greene 1990), or energy (Anderson et al. 1990).

As one example, we transformed a traditional heart exploration lab from one in which students dissected sheep hearts to identify and name structures into one in which the dissection was the basis for students making their own observations and inferences about the relationship between form and function. Both traditional and workshop versions involve hands-on activities—dissecting hearts—but the intellectual demands placed on students, their level of individual and collaborative responsibility for learning, and the resulting cognitive change that can occur are very different.

Another activity, developed for labs and later modified for use in large classes, challenges misconceptions about natural selection and evolution (Box 1). Student groups were given explanations about evolution of flight in bats and asked to critique them and to identify the explanation most acceptable to an evolutionary biologist. Group discussions and sometimes heated discussions between groups gave students deeper insights into challenging ideas and gave faculty a better appreciation of why students often find these ideas difficult to grasp (Udovic 1998).

Science as inquiry. We designed investigative activities to offer situations in which students can pose their own

problems, develop methods of attacking the problem, and then persuade their peers that their conclusions are supported by their findings (Peterson and Jungck 1988). Peer persuasion is particularly important in helping students realize that scientists do not simply discover the “right” answer through experimentation but must persuade peers that their interpretation should be accepted.

For example, in one investigative project, students designed a simple experiment on some aspect of homeostasis in the human body, such as the effects of different stimuli on heart rate and blood pressure. We also introduced a number of interactive computer simulations, some of which we designed as part of this project, to allow students to conduct investigations in areas such as Mendelian genetics (Jungck and Calley 1985, 1998) and population growth (Udovic et al. 1998). These computer models allow students to investigate important questions that would otherwise be too time- and labor-intensive to undertake.

Science in context. The science-in-context component of the course requires groups of students to research a particular area in depth, with the aim of making a personal decision about a socially important scientific issue (Does second-hand smoke cause cancer? Should dams be drawn down to preserve endangered salmon runs?). Our goal was not just to address interesting social and personal concerns but to help students apply their new scientific skills and understanding in their decisionmaking and to expand the range of issues and scientific ideas that they saw as relevant.

Our approach was designed to help students learn to identify and clarify issues, to locate appropriate information and resources concerning the issue, and to critically evaluate the evidence that they find (Udovic et al. 1996). Students received feedback on their work at several stages by turning in problem statements, abstracts, and rough drafts. These series of assignments allowed instructors to maintain a continuous dialogue with student groups on their progress, to emphasize the importance of revision in all types of writing, and to keep groups on task. The final product was usually a group poster, displayed in an end-of-term poster session in the atrium of our science building. Poster sessions were open not only to other students in their class but also to other science students and faculty.

Assemblies. We used large-class sessions (which we called assemblies rather than lectures) to help students construct an integrated overview of the discipline. Like lab activities, assemblies focused on active learning (for details on incorporating active learning into large classes, see Ebert-May et al. 1997, NRC 1997, MacGregor et al. 2000). They included small-group activities and discussion, as well as instructor presentations. Scientific and social issues were central to most assemblies, motivating our exploration of major ideas and helping students see what is interesting and important in areas of biology unfamiliar to them.

Box 1. An example of a concept activity: Confronting student misconceptions about evolution and natural selection. In this activity, students are asked to evaluate several explanations of the evolution of flight in bats. They work in groups to critique each explanation and to pick the one they feel would be most acceptable to an evolutionary biologist. After the class reaches a consensus on the best choice, they work in small groups again to construct better explanations (Udovic 1998).

Text given to students	Misconception confronted
Bats would be better adapted if they had wings, so gradually they developed them. Bats in each generation had better wings than their parents did.	Goal-directed—bats developed wings because they “wanted” or “needed” them.
Because the environment of their shrew-like ancestors favored gliding or flying, mutant individuals arose that were able to glide. Selection favored these individuals, and eventually all of them could glide. Repeating this process led ultimately to modern-day bats.	Changes are induced by the environment and arise out of need.
The existence of structures as complex as a bat wing cannot be explained by traditional evolutionary theory because structures like these are too complex to arise by chance.	Assumes that because there is no intelligent designer, the process is solely chance. Ignores the power of cumulative selection.
The shrew-like ancestors of bats kept stretching the skin and arms while jumping from tree branch to tree branch because that would help them glide better and jump farther. Gradually, through continued use of their arms in this way, they developed wings.	Requires inheritance of acquired traits and evolution through use and disuse of parts.

To emphasize the importance of the lab as a learning environment and to provide time and resources for our new activities, our original design reduced time spent in the lecture hall from 180 to 80 minutes per week and increased lab time from 50 minutes per week to two sessions of 110 minutes each. Later, we experimented with other formats to determine whether we could incorporate the workshop approach into a more traditional schedule that included more time in large classes.

Evaluation

Workshop Biology was introduced in the fall of 1991, but we continued to offer a comparison version of General Biology, which, during the first 3 years of the project, was composed of three 50-minute lectures and one 90-minute lab each week. During most of the project, the comparison course used more traditional lectures and lab activities, but we occasionally used the comparison course to test the workshop approach in different formats. The two courses met the same university requirements and attracted essentially the same student population.

We compared the outcomes of the two courses at each term, using a set of instruments administered to both classes; we also used qualitative methods such as student reflective writing and classroom observation. We administered the tests and instruments as pretests and posttests, so that we could determine actual gains (or losses) made by students over the course of the term. We also compared outcomes of the two courses for male and female students and for students in different class levels.

A project coordinator, hired specifically to design and conduct the project evaluation, facilitated frequent meetings of the project faculty to review and interpret results in the light

of other educational research and theory. The coordinator also conducted classroom observations and attended all workshop class sessions and most comparison class sessions for the first 3 years. During weekly meetings, the instructor, the coordinator, and other project participants compared notes and came to a consensus on the meaning of what we observed.

Our extensive comparisons convinced us that the workshop course represented a significant step forward in our ability to create effective learning opportunities for students, but often in ways we did not expect. Although we have gathered data on many aspects of the workshop’s effectiveness, in this paper we will focus on two hypotheses that we had about students’ learning and development:

- The more supportive environment of the workshop course and the focus on issues would improve students’ attitudes toward science and science courses more than the comparison versions of the course.
- However, for conceptual learning, workshop students would do as well as students in the comparison group, despite the coverage of more content in the traditional format course.

In fact, though, we now believe our results support the conclusion that inquiry-oriented activities are more effective at helping students construct better understanding of fundamental concepts and improving their ability to use concepts to solve unfamiliar problems. In terms of their attitudes and values, however, students’ reactions were complex. Workshop students tended to value their learning experiences more highly, but they were also more critical of them.

Conceptual learning and problem solving. Our primary tool for assessing students’ conceptual learning was a set

of essay-format or multiple-choice-with-explanation test items (Udovic and Morris 1995, Udovic et al. 1996) (Box 2). These items were designed to assess students' learning on all cognitive levels, from low-level recall and understanding to problem solving and analysis. Many were also designed to address fundamental misconceptions, which most faculty agree are important to address in any introductory biology course.

Concept tests were administered at the beginning and end of each term. Scorers could not identify whether they were scoring a pre- or posttest, or whether it came from the workshop or comparison group. We then performed our analyses on "change scores," the difference between each student's pre- and posttest, and compared mean change scores between workshop and comparison groups.

The first set of results comes from the spring term of the project's second year, because the first year resulted in little useable data (Udovic and Morris 1995). The comparison course in the spring term was a traditional, lecture-based course with cookbook-style labs.

A test covering basic concepts in natural selection, ecosystem interactions, and population growth was administered at the beginning and end of the term. Figure 1 shows mean change scores for each question for each of the two groups.

Not only did the workshop group improve more on most items, in some areas scores in the comparison group actually declined, and their answers reflected increased confusion over some concepts. Mean change scores are significantly higher in the workshop group than the comparison group for both males and females and for every class level.

Many of the overall differences between the two groups can be explained by the different experiences students had. For example, the greatest difference was in natural selection. This concept was addressed primarily in lecture in the comparison course, but in the workshop course it was the subject of an extended, computer-based laboratory that allowed students to test their predictions about changes in gene frequencies in a population and confront many of their misconceptions about natural selection.

We were not satisfied with these results, however, as we were essentially comparing apples and oranges. The two courses had very different goals and were taught by different instructors. Consequently, during the fall term of the project's third and fourth years, the same instructor taught both the comparison course and the workshop course, focusing on the same goals and using, whenever possible, the same kinds of activities. This also allowed us to explore integrating the workshop

Box 2. A sample question from one of the concept tests. Our primary tool for assessing students' conceptual learning was a set of essay-format or multiple-choice-with-explanation test items. These concept tests were administered at the start and end of each term for both the workshop and comparison groups. Here is a sample question from the spring term, 1993. Complete instruments are available at the Workshop Biology Web site, http://biology.uoregon.edu/Biology_WWW/Workshop_Biol/WB.html (Udovic and Morris 1995, Udovic et al. 1996).

Question: A disease somehow wipes out all primary producers (plants and other photosynthesizing organisms) on the earth. Could animals, including ourselves, continue to survive? If so, how? If not, why not?

Scoring: We scored answers to this question using a 7-point scale with the following criteria. A few sample student responses are included under the scores they received.

7: Answer focused on energy and specifically described how all animals depend on plants to convert light energy into a usable form.

No, primary producers are the first step of the food chain and are necessary to convert solar energy into consumable carb. and sugar in the primary producer's material. We also depend on their O₂ output.

No, we nor any animals could survive. As heterotrophs, we must rely on primary producers to create molecules that we need for energy (i.e., glucose).

6: Answer described all animals' dependence on plants for energy, or the nature of the food chain, with plants at the bottom and animals at the top.

5: Answer either (1) vaguely referred to a food chain or balance of nature but did not elaborate on its nature or on what kinds of organisms are involved or (2) mentioned only humans' dependence on plants for food.

No, we need the primary producers for the consumers to consume in order to survive.

No, we would have nothing to keep the food chain going.

4: Answer merely stated "no," or stated "no" and included irrelevant information or restated information included in the question.

3: Answer stated "no," or gave some other indication that animals would not be able to survive but included misconceptions.

Animals could not survive without producers because producers provide the food energy supply that consumers need. Many animals, all herbivores depend on plants for survival. However, carnivores eat other animals and could survive without plants and omnivores would have to only depend on meat.

2: Answer stated "yes," or gave some other indication that animals would be able to survive and included misconceptions (e.g., carnivores would still be all right because they eat other animals).

1: Answer stated "yes," or gave some other indication that animals would be able to survive but gave no support or restated information included in the question. Or, it missed the point of the question (e.g., addressed only animals' potential resistance to plant diseases).

Animals continue to survive or not depend on whether a disease is lethal. However, some genes in animals may have mutation to adapt to the unfavorable environment or fight for disease.

0: Answer left blank.

philosophy and methods into a more traditional, more efficient schedule without sacrificing too many of the workshop's advantages.

In the fall of 1993, the format for the comparison course (Workshop 2) was composed of three 50-minute, large-class sessions and one 90-minute lab, the same format used by our traditional course. The original course, Workshop 1, continued to be offered in two 2-hour labs and one 80-minute assembly. On the concepts test, Workshop 1 students still improved more than Workshop 2 students, but the differences were not as great as in previous terms, primarily because students in the comparison group did better than in the past (Figure 2).

We repeated this study the following fall (1994), when the same instructor again taught both courses. The major difference this term was that the format of the comparison course was changed from three 50-minute to two 90-minute, large-class sessions, given on Tuesdays and Thursdays, with the labs on Wednesdays (Workshop 2a). This format allowed the instructors to use the large-class setting for discussions of the lab, introducing it the day before, then wrapping up the lab on the following day. Perhaps because this gave the class greater continuity, allowing concept-oriented and investigative activities in the assembly to integrate smoothly with ac-

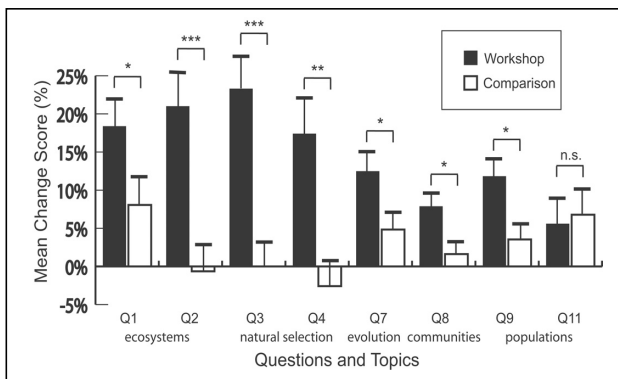


Figure 1. Mean change scores on spring 1993 concept test, by question. Change scores track the difference in individual student performance between a pretest administered at the beginning of the term and a posttest administered at the end. Change scores are presented as percentages of the total possible score for each question. Error bars represent one standard error. Change scores for the workshop group are significantly higher than the comparison group for all questions except question 11 (* $p < 0.05$; ** $p < 0.01$; *** $p < 0.001$; nonsignificant (n.s.): $p > 0.05$). Class size was about 70 for both courses. Sample sizes for the change scores are 61 for the workshop course and 62 for the comparison course. Questions 5, 6, and 10 turned out to be too difficult to score accurately and hence are not included (Box 2 has a sample question). Udovic and Morris (1995) give details on questions and analyses.

tivities in the labs, students' conceptual understanding in the Workshop 2a format improved as much as that in the Workshop 1 format (Figure 2). By the final term, it appears, enough of the workshop approach was incorporated into a more efficient schedule for Workshop 2a to create just as effective a learning experience, at least in terms of conceptual learning.

Views of science and scientific thinking. Our experiences in the workshop course have led us to believe that students' attitudes toward a course, its content and activities, are tightly interwoven with their ability and willingness to learn. To gather evidence of students' perspectives on their learning, we asked students in both courses to reflect on their experiences in writing, primarily on course evaluations but also on in-class and take-home assignments in the workshop class. As noted in the Limitations section, these activities served as learning experiences for students as well as sources of information for us.

We originally hypothesized that the workshop approach would be more effective in improving students' attitudes toward science. Because *attitudes* is an ambiguous term, we focused on whether students came to *value* scientific thinking

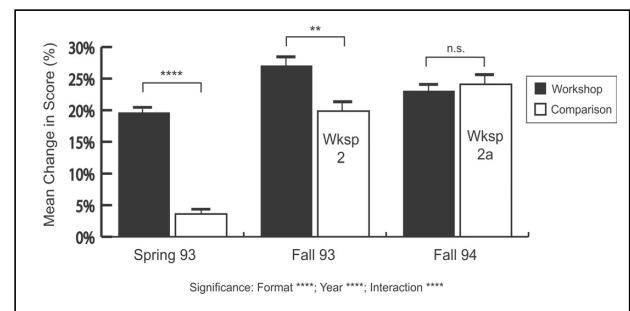


Figure 2. Concept test scores, by term and format. Differences between years and between formats are highly significant (* $p < 0.05$; ** $p < 0.01$; *** $p < 0.001$; **** $p < 0.0001$; nonsignificant (n.s.): $p > 0.05$). Change scores are presented as percentages of the total possible score. Error bars represent one standard error. Sample sizes for the change scores in fall 1993 were 115 for the workshop course and 59 for the comparison course (Workshop 2). Sample sizes in fall 1994 were 136 for the workshop course and 65 for the comparison course (Workshop 2a). The highly significant interaction between format and year indicates that the performance of students in the comparison group improved much more from spring 1993 to fall 1994 than did the performance of students in the workshop group. This appears to be a result of incorporating workshop approaches into the more traditional schedule of the comparison course. By fall 1994, there was no significant difference between the change scores for the workshop format (Workshop 1) and the comparison format (Workshop 2a).

and learning and whether they were able to critically reflect on their learning and values. Workshop students' reflective writing displayed significant changes in their views of science and scientific thinking. Their views of the course and their learning experiences, however, were far from unanimously positive and were often critical and highly complex.

To assess changes in students' views of science, we tried a number of quantitative surveys, none of which provided the information we needed. Because we wanted to know what students thought about science, we turned to reflective writing. At the end of the spring term of the project's second year, for example, we asked students in the workshop course to write a paragraph in response to the question, "How has this course changed your conceptions of biology?" Most students were able to articulate a substantial change (Box 3).

Since students in the comparison group did not complete this assignment, we have no direct evidence that they did not come to these same realizations. Comments on course evaluations, however, provide indirect evidence. Workshop students often connected specific learning experiences in the course to their new view of biology: "With [the issues project] assignment, I am using what I learn in class to discover how it is relevant to present-day society." No student in the comparison course referred to a specific learning experience as providing any new understanding.

Views of the course. Just as we became dissatisfied with traditional attitude surveys to assess students' views of science, we also became dissatisfied with traditional course evaluations to assess students' views of their learning experiences. Bubble-sheet forms and excellent–poor rating schemes cannot give a complete picture of whether students value and are able to critically reflect upon their learning. We discovered that many students had complex reactions to the course, to unfamiliar goals, and to new expectations. To argue that the course was a success because students liked it, or that it was a failure because they did not, would ignore the complexities of their reactions and even lead us to unfounded conclusions about our teaching effectiveness.

As evidence of workshop students' improved ability to reflect critically on their learning, comments on course evaluations were generally lengthy and well thought out, while comments made by students in the comparison class were brief and superficial. Workshop students' comments were more critical, often giving detailed suggestions for improving an activity and explaining in detail how their suggestions would be more effective. We saw these comments as additional evidence that students had improved their ability to think critically, not only about ideas and issues but about their own learning.

Most students' reactions to the workshop approach, then, could be classified as critically appreciative. A significant subset of students' criticisms indicated frustration with the approach. Many of these students appeared uncomfortable, at least initially, with the atypical demands of the workshop course. One interpretation is that these students are lazy or that they want to be spoon-fed. An alternative explanation is

that they see the world in black and white and don't understand that opinions must be substantiated, a view that arises in part from theories of intellectual development (Belenky et al. 1986, Perry 1970). It may also be that students don't value learning that goes beyond memorization and regurgitation. Perhaps it's not surprising if they have rarely encountered situations in which this kind of learning is valued.

Some students took different versions of the course throughout the year and could compare their experiences. Some preferred the traditional lecture-format course while others preferred the workshop approach. The most frequent response, however, was that the workshop provided a better learning experience but was more work. Those students who preferred the traditional approach were honest about their unwillingness to invest that extra effort when they could get the same credit for less work. This is an issue whenever "easier" options are available; even if we offered only Workshop Biology, most students can fulfill their science requirements with less demanding classes. We must consider whether it's the responsibility of faculty in general education courses to educate students about the value of general education—and persuade them that it's worth the effort.

Had we simply asked students to fill out a standard course evaluation, those unfamiliar with our teaching approach or unappreciative of its value probably would have given the course low ratings. We would not have had the information needed to interpret their reactions and might have sought higher course ratings by making the course less challenging. During terms in which we introduced some more drastic changes, such as eliminating exams in favor of portfolio evaluation, the frequency of negative comments was such that we could easily have concluded that the approach was a failure. Instead, we sought additional information from students to determine whether a particular strategy was effective but unpopular with students, whether it was essentially effective but in need of modification, or whether it really was ineffective and ought to be abandoned. Continued feedback from students, which improved with continued practice on their part, was invaluable in making decisions about how to modify our approach. Meeting students' needs often means helping them adjust to new expectations, without lowering those expectations.

Limitations. Well-designed, highly controlled experiments are extremely difficult to implement in an educational setting. We have instead concentrated on building up a persuasive body of evidence and triangulating on results by gathering a variety of data. Nevertheless, cause–effect relationships remain extremely difficult to establish, particularly when our efforts to assess outcomes influence those outcomes, as was very likely the case with reflective writing assignments and frequent written course evaluations.

We also found it difficult to control for confounding variables, such as class size. We planned that the workshop class would, over the project's 3 years, increase from a pilot class of 60 (two lab sections) to its final size of 180 (six lab sections),

Box 3. Analysis of students' written reflections. At the end of the second year of the project, we asked students in the Workshop Biology experimental course to respond in writing to the question, "How has this course changed your conceptions of biology?" As indicated by the excerpts below, most students were able to articulate a substantial change.

Its relevance to their lives

I used to think of biology as a "science" class. It was separate from my daily life—a subject. But after a full year I have learned that it pertains to my daily life very much. The issues that our classes have presented come up in my mind often when I pass by clear cut areas or abortion clinics. Every day I think of something that I have learned in my classes this year.

Its role in human social concerns

I see biology as an integrated part of our modern society. Many political issues: AIDS, the environment, forest management, etc. are biological in origin. I also see biology as a tool to be used in conjunction with other sciences: physics, geology, geography, etc. to understand natural systems and help manage human systems. This class in itself has not really changed how I see biology, but it has enhanced my view in some ways. In general, science is not a separate entity from anything, but rather a part of everything.

Its tentative nature

I originally felt biology was a "strict" science that was either right or wrong with no alternatives. But I have found that biology is something that concerns us all in every day life. I also found that many aspects of biology are subjective and open to many different views.

The importance of connections

Something I have learned from this class is the importance of connecting the seemingly small aspects of biological significance (fungus on roots) to big aspects of life that affect everyone (global warming).

The importance of questions

Biology is an attempt to explain life and its many amazing attributes. I've always enjoyed biology because of this and as I proceeded through the year as an adult many of my childhood questions are answered, but only to be replaced with adult questions. Biology is the only way to make sense of questions, which is why I'm glad to have taken this course.

End-of-term course evaluations provide another source of information about the development of students' critical thinking. The sample comments below are from year 2 of the project. Students in the comparison course, taught in a traditional manner, typically provided brief and superficial comments. Student comments from the traditional section included the following responses:

All material was valuable. Stick to the text more.

The labs were helpful, and the review sessions. I liked the video. I don't know [what could be improved].

The time in lab [was the best]. The lectures [need to be changed].

By contrast, students in the Workshop Biology experimental course generally gave longer, more thoughtful responses:

Issues projects and presentations [were the best thing about the class]. With this assignment, I am using what I learn in class to discover how it is relevant to present-day society. The biological aspect of the class comes out in researching my topic and discovering how pertinent material in class is to controversial biological issues. Suggestion: Change the format a little from term to term. Maybe replace the presentations with a field trip + paper one term or make paper revolve around in-class experiments one term.

The lab sections [were the best thing], they provided a hands-on approach to what concepts we were learning. The labs showed us how concepts in biology related to everyday life. Only the grading system [should be changed]. I liked first and second term grading better because it was very easy for us as students to figure out where we stood. But I understand this was difficult for you to do because of too many individual assignments. Most of the things that I felt were very useful involved a discussion or a type of group working together. I think this is important because it lets us bounce ideas off each other, and get a better idea of what we were doing.

The format of the tests is excellent. It allows us to explain our reasoning and understanding of the concepts. We also learn more when we get our tests back because we have to be critical of our reasoning in order to understand why we lost or gained points. We can't simply go, "oops, it was 'B.'" The soil fauna project had some problems: (1) having an experiment already set up does not help us to learn/experience how to construct a plausible hypothesis/prediction and then learn how to test it. (2) We had to make up a hypothesis to fit the experiment. (3) This also made it difficult to do an accurate write-up. Since we didn't construct the experiment it was easy to leave out crucial "methods" details. For example, how were the soil and litter samples separated?

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Box 3. Analysis of students' written reflections.

These comments from workshop students are representative of about half of the comments from that class in terms of length and level of critical thought displayed; another quarter were not as long but still gave a reasoned justification of their views. The comparison group students' comments cited above are representative of about 90 percent of the comments from that class. Only a few provided any evidence of reflective or critical ability, such as this one:

I really feel it would be more beneficial if we spent more time on each subject. At least enough time to where we could retain the information sufficiently. It is not as beneficial to cram huge amounts of info into us and just have us spit it back up on the exams, then turn around and forget it 2 days later. What then is the point of learning?

Although most students in the workshop group generally offered constructive criticism, a significant subset of student comments indicate frustration, as indicated in these comments from a midterm course assessment:

I didn't do too well [on the exam], and I'm really unsure why since so many of the questions were answerable with one's opinion.

I think it is unfair to grade questions that are like opinion questions, or are questions which cannot be answered from the assigned reading. If [the instructor] wants us to think about something that is related in some way to the chapter we are reading, he should request an educated opinion and not grade how correct our opinion is but just grade the fact that we wrote one down.

I think that this class is TERRIBLE! I have not learned but a few biological concepts and this is not because I am not trying because I have a 4.0 cumulative GPA.... I would rather have had weekly quizzes in class rather than a synthetic essay which is opinionated.... Too much individual thinking going on to be organized or to learn.

Note, however, that sometimes student opinions changed as they adjusted to the class and began to value the workshop approach. The same student who made the comment above made the following comment at the end of the term:

My view of biology and scientists has changed a lot since I have been in this class. I have learned that biology involves a lot of thought and analyzing. It's not just learning facts but it's applying those facts to almost everything around us. Learning how to think in a scientific way is very hard for me but I feel a lot more confident about it now that I have taken this class. One thing that has been so educational for me was learning how biology ties into all of the problems that are going on around me in the environment and the world.

allowing the traditional class to be gradually reduced from its original size of approximately 200 down to 75 in the final year. Most of the results discussed above came from the second year of the project, in which enrollments in the courses were about equal. By years 3 and 4, however, the comparison class was significantly smaller than the workshop class (~70 versus 140). The smaller size of Workshop 2 (fall 1993) and Workshop 2a (fall 1994) may have added to their comparative effectiveness. Additionally, some attitudinal and critical thinking gains diminished in the now-larger Workshop 1 course. Although students were still taking part in extended lab sections, the larger class size and the more impersonal environment may have adversely affected their level of engagement in their learning.

Other limitations arise from differences in instrument administration and the ways in which the culture of the two groups affected response patterns. In the workshop, for example, we attempted to increase student motivation for completing the concepts tests by giving it as an ungraded practice final, but we were, for the most part, unable to convince instructors of the traditional courses to do likewise. Thus, workshop students may have put more effort into completing the test than did traditional students. In the two fall term comparisons between the Workshop 1 and 2 formats, both groups took the concepts test as a practice final.

More generally, the workshop approach helped create a culture in which students knew their feedback was valued. Though we consistently gave midterm and end-of-term course evaluations in both classes, workshop students had additional opportunities to evaluate their learning experiences, as part of both in-class and out-of-class assignments. They also may have felt that instructors took their comments more seriously. It is likely that this had an effect on students' responses on the concepts tests and other instruments, as well as on course evaluations, including increasing workshop students' motivation to complete the instruments and write longer, more considered responses. Workshop students believed they were part of a larger effort to improve their learning. Even if they weren't always happy with the results, most became committed to the idea of working toward improvement. Although this can confound interpretations of our results, it is clearly evidence of the increased level of engagement of workshop students, which was one of our primary goals.

Major insights

Workshop Biology's central goal was to improve students' ability to make decisions about biologically based issues. This is difficult to assess directly and impossible to assess through comparisons with a course that does not have this as a goal. Instead, we focused on assessing students' progress in areas re-

lated to decisionmaking: their understanding of fundamental concepts, including their ability to apply their knowledge to new problems; their values and beliefs related to biology and scientific thinking; and their willingness and ability to critically reflect on their own learning in these areas. While these abilities may not be sufficient to ensure good decisionmaking skills, they are certainly necessary. Based on our results, we believe that the workshop approach prepares students for decisionmaking much more effectively than a traditional content-oriented, lecture-based course.

In our investigations of students' conceptual learning, in particular, one major conclusion we can draw is that inquiry-based learning activities can help students learn concepts better than traditional, transmission-oriented activities (namely lectures). Our initial expectations were that workshop students would gain more in the areas of critical thinking and reasoning skills and positive attitudes toward science but would not fall behind students in the comparison courses in terms of conceptual learning. In fact, the most dramatic gains are conceptual.

A common assumption evident in our discussions with other science educators, and in much of the literature, is that inquiry-based activities can motivate students and help them learn about the process of science, but that to learn content, students must sit and listen. Another common assumption is that students must learn some content before they can participate in inquiry. We believe our results provide evidence that neither of these assumptions is warranted. However, we have also found that students may not automatically recognize, and therefore may not immediately value, what they are learning, particularly when the learning goals and methods are unfamiliar. The structure and activities of an innovative course must support students as they not only learn new concepts and skills, but as they gain a new view of learning and how it can affect their lives. Most of our students did gain an increased appreciation of science and scientific learning. Rather than unquestioning acceptance or enthusiasm for their learning experiences, however, we saw a more critical view developing in most students, through which they were able to question constructively both the content and method of their learning in biology.

Whether the benefits achieved by the Workshop Biology approach, or other similar innovative approaches to teaching, are worth the extra time and effort is a value judgment that each instructor or department must make. We have come to realize that this kind of teaching offers benefits for instructors as well as for students; we come to know our students better and feel a greater sense of accomplishment when the outcomes of our efforts are so clearly evident.

Conclusions

Workshop Biology is one of many experimental approaches to teaching introductory college-level science that emerged during the 1990s. The goal of this nonmajors' course is to engage students in open-ended, interactive activities and projects designed to develop students' understanding of essen-

tial biological concepts, their understanding of the process of scientific discovery, and their critical thinking skills. Overall, our desire is to improve students' abilities to make good decisions about important personal and societal issues by fostering their ability to bring scientific knowledge and ways of thinking to bear on problems, whenever relevant.

Overall, workshop students displayed more improvement in conceptual learning and understanding of scientific reasoning, a greater appreciation of science and its role in their lives, and greater motivation and involvement in learning activities than did students in a comparison course taught in a more traditional, passive style. The teaching and evaluation strategies we have developed may serve as a model or starting point for others who wish to address problems of scientific literacy in their students.

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