# Teaching freshmen to think—does active learning work?

by Leonard Goodwin, Judith E. Miller, and Ronald D. Cheetham

Students entering science careers in the next century are likely to rely little on the factual information conveyed by their teachers. They will rely heavily on problem-solving skills, collaborative work skills, and an enthusiasm for the rapidly changing challenges in their fields. A key recommendation of the report by the National Institute of Education (1984) on improving higher education was that faculty should design courses that enable students to be actively involved in the learning process. Likewise, the Carnegie Foundation report on higher education (1986) stated that "The undergraduate experience, at its best, involves active learning and disciplined inquiry that leads to the intellectual empowerment of students." In her Research Corporation report, Tobias (1990) emphasizes that able students who transferred out of science could have been encouraged to stay if close working relationships with professors had been available and if more learning had occurred through collaboration and discussion.

This article reports on data gathered to determine the impact of a new introductory biology course sequence, Biology I and Biology II, taught by J. E. Miller and R. D. Cheetham at Worchester Polytechnic Institute. In a previous article (*BioScience* 40: 388–391), we described the philosophy, mechanics, and subjective results of these courses, which make up the only introductory biology sequence for majors. The new sequence, redesigned to incorporate experience-based group learning, involved almost no lectures and placed heavy emphasis on students learning biology through completing group projects.

Rather than listening to lectures and regurgitating the material on tests, students worked in project groups and gathered their own information around topics such as design of a closed life-support system for long-term space flight. Four weekly class meetings—two large group meetings and two smaller discussion sessions—examined, evaluated, and integrated the material gathered for the projects. The laboratory focused on techniques and on independent experimentation and did not directly bear on the project topics.

An independent investigator (Goodwin) traced during 15 months the attitudes and class performance of 46 students who began the first offering of the new Biology I in January 1989. He also examined the attitudes of 40 students who started a revised version of the new Biology I in January 1990 and the attitudes of a comparison group of 69 students who completed Biology I in the traditional lecture format in 1987 and 1988. Questionnaires, group interviews with the 1989 students, grades in advanced biology courses, and comments by instructors of advanced courses provided data for the study. The aim was to determine how the project-oriented approach is perceived by students and how it affects their subsequent performance in more advanced courses.

## The 1989 experience

The students entering Biology I in 1989 had initial expectations about the course (and also attitudes toward education and science) similar to those of students in the 1987 and 1988 comparison group, even though more of the 1989 group expected to graduate as biology majors. However, by the end of the term, when a second questionnaire was administered, the 1989 group members believed that they had learned much less biology than did students in the comparison group. The 1989 group was also very worried about not being prepared for higher-level courses and felt that the class assignments had been too vague. Biology I students who were biology majors tended to be more favorable toward the course than those who were nonmajors.

These questionnaire results support findings from the group interviews Goodwin carried out with the 1989 group halfway through the Biology I course. Many students were upset by the lack of guidance they received while trying to carry out project assignments related to devising life-support systems on a spaceship. They believed they did not have the necessary basic biological knowledge.

The instructors (Miller and Cheetham) had assumed that all entrants into Biology I would have a high school background in biology, because the course was designed for biology majors. In fact, more than a third of the 1989 class were nonmajors; and even among majors, basic biological knowledge was not always there.

Many students would have preferred traditional lectures about traditional biological topics, according to the final questionnaire responses of the 1989 Biology I group. At the same time, these students expressed positive feelings about working in project groups and about the instructors. In addition, they said that the new approach had made them interested in learning more biology. Another positive effect of the new Biology I was that students considered a wider array of problems interesting. In particular, students showed a much greater preference for problems that had more than one solution.

## Attitude changes

The Biology II course in 1989, in which students were to design a unicellular organism to colonize the fictitious plant Xenon, was designed on

the basis of the early feedback from Biology I. Changes from Biology I included the introduction of some overview lecturing (no more than once a week, often for only half a 50-minute period) and the incorporation of interim assignments and feedback to guide students through each problem.

The questionnaire responses of Biology II students were dramatically different from their responses at the end of Biology I. Students believed they learned much more biology in Biology II than in Biology I. Their rating was similar to that given by the comparison group of students in the traditional course.

During Biology II, students were much less concerned about the vagueness of the course than they were in Biology I. Similarly, they said the course stimulated their interest in biology even more than did Biology I. They also felt significantly less worried about being unprepared for higher-level courses at the end of Biology II, although the worry level was still higher than in earlier years. These results suggested that Biology I could be improved further over a traditional biology course once its content was geared more to the level of beginning students' knowledge.

## Subsequent attitudes of 1989 students

Student attitudes toward the new Biology I course were gathered again more than a year after the course ended. Questionnaire responses were solicited from the 1989 students: 23 had taken advanced biology courses beyond Biology II, 10 students did not go beyond Biology II, and 13 students did not take Biology II. Eighty percent of the students responded.

All these students continued to believe that they learned little biology in Biology I. There was, however, a dramatic drop in preference for a traditional introductory biology course among the students who had gone on to advanced biology courses. Students who stopped after Biology II would still have preferred a traditional introductory biology class.

A similar situation was observed with respect to the belief that Biology I created interest in studying more biology. That is, the advanced students, looking back at Biology I more than a year later, regarded that course as having significantly stimulated them to a further interest in biology. Students who stopped after Biology II did not share that view. These findings suggest that as biology majors proceeded with their education, the value of the project-oriented approach became more evident.

## Subsequent performance of 1989 students

Although student attitudes toward a course are important, another test of the new project-oriented sequence is student performance in more advanced work. Were worries about lack of preparation justified?

The grades were pooled for three advanced courses—cell biology, microbiology, and genetics—with the distributions made for the 23 students who had taken the new Biology I course in 1989 and 8 students who had not, a group we refer to as "other." This "other" group consisted of students who had transferred into the college as sophomores and those who had taken the introductory courses before 1989.

The grade point average of the 1989 group is virtually identical to that of the others—a B average. Also, the distributions of grades show that the 1989 group had 16% more As and 19% more Cs than the others (not statistically different). There is a hint here that the project experience may enhance the academic performance of some students and lessen the performance of others. The number of students in this analysis is so small that such conclusions can be used only as the basis for further research.

It seems clear that the 1989 group held its own in the advanced courses. Furthermore, the requested written comments of two instructors of the advanced courses suggest that the 1989 group had gained important learning skills. One instructor said, "This year's group was more receptive of the 'open lab' format. They were less likely than the previous year's group to expect the TAs or myself to tell them exactly what to do. . . There seemed to be some sort of group esprit going. The students relied on themselves and each other much more than on the instructor. . . I got few complaints about the difficulty of the homework."

According to the other instructor, "This year's sophomore class is less afraid to ask questions. They seem more aggressive, and less likely to remain silent if dissatisfied. They also seem to have provided more highly creative answers on their essay exams . . . more alternative explanation than any preceding class I have taught."

After completion of the advanced courses, the 1989 group members stated that their own hard work, rather than their Biology I experience, was responsible for their achievement in advanced courses. The students may be correct in their judgment, but it also may be that their project experience taught them how to go about learning biology in a more productive fashion and encouraged them to believe that original thinking is acceptable. The instructors' comments and our speculations are not strong proof of the efficacy of the new project-oriented approach, but they suggest a potentially important payoff from further exploration of that approach. To advance such exploration, we surveyed the next Biology I class in 1990.

## The 1990 experience

The second offering of Biology I and II in the spring of 1990 was similar to the 1989 version, with the following changes. In response to student requests for more concretely defined problems, especially at first, we reversed the topic order in Biology I and Biology II. Biology I in 1990 covered molecular and cell biology; in Biology II, we moved into organismal and environmental biology.

Because student organizations maintain files of previous years' assignments, we needed to change the problems for the second offering. In the limited time available, we were unable to develop a unifying theme for the course that was plausible, for which library resources were available, and that was compatible with the students' limited knowledge of chemistry and physics. Therefore, we developed problems one at a time, without student input. For example, we asked the students to design a membrane without lipids, artificial organs for insects and

fishes, and a synthetic immune system.

We believe that a unifying theme and student-generated topics are both worthwhile, and we plan to pursue this approach in the future. The advantage of having a unifying theme is that each problem would logically lead to the next set of questions. For example, in a future course, we may ask students to address the question "Should Vietnam veterans exposed to Agent Orange be compensated?" This question could provoke questions related to molecular and cell biology, epidemiology, and plant biology.

To accommodate students' need to feel that they were learning biological facts, and to provide data on individual performance for another evaluation project, we included quizzes (as 10% of the course grade). Quiz questions were taken verbatim from a previously published study guide. To provide incentive for group members to help each other learn, groups in which the average score was 90% or above, all received 100%.

One of our major unsolved problems from the 1989 course offerings was the lack of substantial incentives for all students within a group to contribute to group work. This problem was especially great in Biology I, which consisted of about one-third nonmajors. The 15% of the course grade, which was assigned by fellow project group members, did not have sufficient effect on the grades of nonparticipants to induce a change in their behavior. Therefore, we changed the grading such that group members' evaluations of one another were used as a multiplier (a decimal fraction between 0 and 1.00) for the group-written report grade (40% of the student's grade) awarded to each individual. This system improved evaluation of individual effort, and it made intragroup conflicts more evident. Students realized that their grade depended heavily on group dynamics and were more likely to complain about or confront problems, although not always successfully.

## Attitudes of the 1990 group

The 1990 group consisted of 46 students, almost all freshmen who planned to major in biology, a big difference from the previous year. This group's responses to the initial questionnaire revealed that they had unusually high expections of learning a lot of biology, strong rejection of learning by the lecture method, and strong interest in the project mode.

At the end of Biology I, the 1990 group showed a much more positive attitude toward what they had learned about biology and significantly less worry about being prepared for advanced courses than their 1989 counterparts. The 1990 group also had much lower preference for a traditional biology course. The changes made by the instructors in Biology I after the initial 1989 class are clearly evident in the more positive ratings given the 1990 group at the end of its class. Students' evaluation of the instructors' concern for them was much higher in the 1990 class than in the 1989 class.

There are, however, certain issues raised by the data that call for further exploration. Liking to work in groups and liking to work on projects were given high ratings by the 1990 class, but not as high as the 1989 students' ratings. It appears that more attention should be given to the formation and functioning of the project groups. Certain combinations of personalities, learning styles, or familiarity with biology may make group functioning more or less difficult. Awareness of such matters could help the instructors and students devise ways of countering potentially dysfunctional situations.

Even though the project experience might have been imperfect for some students, it seemed to engender a difference in preference for kinds of problems to be solved. From the beginning to the end of the course, both the 1989 and 1990 groups showed a dramatic lowering of preference for problems that have only one definite solution.

## Conclusions

Moving from the traditional lecture to the project-oriented mode of instruction involved radical changes for both instructors and students. The instructors spent large amounts of time and energy revising their traditional approach, developing project topics, locating information resources, and working with students individually and in small groups. Students were involved in a process of exploration, learning how to go about gathering information rather than being fed information and asked to memorize it. The 1989 Biology I course went perhaps too far in that direction, leaving students who had little factual knowledge of biology too much on their own. The situation was corrected in the 1989 Biology II course and the 1990 Biology I course, with students in those courses feeling more secure about their preparation for advanced courses.

Because the 1989 students did as well in advanced biology courses as students who did not take the new sequence of Biology I and II, it appears that the 1989 students were not disadvantaged by the new approach. Indeed, the comments made by instructors of the advanced courses indicate that, compared with traditional students, the 1989 students had a superior grasp of how to work in groups, utilize the open lab, and come up with novel solutions to problems. The new project-oriented course sequence seems to have encouraged students to learn how to learn.

Followup of the 1990 students is needed to test more accurately the short- and long-term effectiveness of the new biology sequence. It would be particularly useful to carry out a longer-term evaluation, examining the creative performance of students from the new Biology I and II courses in their junior and senior years. However, the more pressing problem is determining the factors such as conflict and group dynamics that affect project-group functioning in the new course sequence. It also would be advisable to make certain changes in the questionnaires used. Rather than just asking students how much biology they learned, the question should be divided into two parts: How much factual information did you learn? How much problem-solving skill did you develop? The latter skill seems to have been appropriately valued by the 1989 students only after they have taken advanced courses.

It is important to determine the attitudes of students toward an innovative course, so instructors can make the course more effective, as was the case in Biology I and II. At the same time, it is unwise to use those initial evaluations as a basis for canceling

the innovation; student views may change later in their academic careers. The worries of the 1989 group about not being prepared for advanced courses were not well founded; but this observation could only have been made after they had successfully completed advanced biology courses.

Group work is probably more useful for biology majors than nonmajors. Students who take only one or two biology courses are often looking for an overview of facts and concepts, which is best presented in lecture format. Biology majors, however, benefit greatly from the project approach. It allows them to move quickly beyond the simple memorization of facts to the process of creative problem-solving, which will stand them in good stead in their advanced coursework and eventually in their careers.

The project-oriented approach described here should be applicable in different educational settings, from the large university to the small college. However, the approach requires a substantial commitment of time and effort to change educational practice. We believe the reformulations suggested in this article are beneficial in terms of educational outcome, but making so drastic a change requires a major investment from both administrators and faculty.

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