# Teaching the Processes of Science:

# A Research Paper-Laboratory Technique

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OF THE CRITICISMS presently directed toward the quality and content of undergraduate biology courses, the most fundamental is that traditional courses fail to teach or develop the essential skills, intellectual abilities, and curiosity that are necessary characteristics of the biological scientist (Epstein 1970; Jeveli and Stevens 1975; Rasmussen 1970; Shell and Hawes-Davis 1965). As these and other authors have indicated, the traditional biology course with the lecture—"cookbook lab" format for transferring the maximum amount of factual material to the student has been inadequate for allowing the student to experience the processes by which biological information is generated. Few bachelor's or even master's degree biology students graduate with experience in scientific decision-making processes, in hypothesis formation, in experimental design, in the evaluation of meanings and strengths of data, in limitations and values of scientific processes, in the frustration of research, or in the excitement of discovery. In addition, university attempts to handle large numbers of undergraduates in giant lecture courses have generally forced students to postpone their curiosity and high motivation to do science until the beginning of thesis research. Moreover, nonbiology majors generally have no opportunity at all to experience the intellectual challenge and the excitement of the process of biological science. Instead, they have to devote virtually all of their time and efforts in a biology course to memorizing a body of knowledge.

The traditional lecture–lab emphasis is primarily on student data acquisition; thus, biology is presented to students as a static body of knowledge rather than a dynamic, growing field of discovery. Because the student does not necessarily see the interrelationships between the facts he learns and because he sees no immediate use for this knowledge, his motivation for learning becomes one of passing exams. Even if traditional biology courses are taught by faculty who organize their material well with continual updating and who are interested in their students, many students—often the brightest—are bored or dissatisfied with college education.

If this criticism is to be faced, educational objectives in undergraduate biology teaching must develop creative ability, foster scientific decision-making processes, and give students real experiences in the scientific process. Needless to say, the most effective way to do this would be to provide students with the opportunity to learn science by doing science.

## *New Strategies for Teaching Biology*

Early in the sixties Shell (1962) observed that some sort of real scientific investigation experience must be provided, especially for the brightest students, to provide a channel for curiosity and to develop innate skills of scientific inquiry. Shell substituted contemporary research projects instead of the traditional "cookbook" lab in a traditional lecture course for juniors and seniors. Some of his students actually published the results of their investigations. More recently Holt et al. (1969), Lee et al. (1970), and Taylor (1971) have used a similar approach for uncoupling the lecture from the lab portion of a course and having students conduct actual research projects in the lab. One of these research project courses effectively handled up to 1600 students; some were part of introductory courses for biology majors and one was even for nonmajors. Common findings for these programs were that students are more enthusiastic about the new "teach-

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ing" technique, that the students work exceptionally hard on their projects, and that faculty generally underestimate students' ability to conduct research.

Epstein (1970) conducted experiments in another new technique for teaching introductory biology, with the goal of training students in the processes of scientific investigation. He selected a series of 8–10 contemporary research papers to discuss with students in a one-semester introductory biology course for nonmajors. No lectures whatsoever were used in this teaching format. The papers were in Epstein's field (DNA basis of heredity) and were chosen so that each proceeded logically from the consequences of the previous paper in order to provide a connectedness to the learning experience.

In Epstein's format the instructor's role was to act as a resource person to answer students' questions as they attempted to understand each of the papers. The students were guided toward the sole explicit goal of understanding the thinking processes of the scientist sufficiently to be able to propose the next logical experiments in that field of investigation. No stress was placed on data acquisition or exams, since this was found to be counterproductive to this learning process. However, Epstein reported that in this new learning experience the students not only enjoyed the course more than the traditional lecture series and acquired a greater depth of appreciation and understanding of biological science but they also scored nearly as well on the traditional final exam as did students in the lecture series. He felt his experimental students had greater information retention, better ability to think scientifically, and more enthusiasm for biology. Although he conceded that his technique did not cover all the factual material in a well-planned lecture course, Epstein felt that the benefits of gaining insight into the thinking processes of science far outweighed this deficit, especially in light of the fact that his students showed no deficit in performance in upper-level courses; indeed, they appeared to be better than average students. Epstein suggested that his approach could be improved by linking the discussion of research papers technique with an experimental research project based on the papers.

## *Course Design and Execution*

At the University of Wisconsin-Green Bay, we devised a research paper–laboratory experience based on Epstein's teaching strategy. Our goals for the design were to investigate whether, indeed, the technique did increase student comprehension of scientific processes, whether students did find this approach a more rewarding learning experience, and also whether this approach could transfer nearly as much factual information as a well-designed lecture. In addition, we wished to determine course design parameters that would be appropriate to separate courses for upper level biology majors, lower level majors, and nonmajors. Our results were to be compared with the traditional lecture–lab course approach and also to be considered in the light of the innovative approaches of Epstein and of the techniques which coupled real research with a traditional lecture course.

An unusual aspect of the course design was that we included both biology majors and nonmajors—some with only high-school level biology course experience—in the same course. The goal of trying this admixture was to determine the effects on learning of what could be called the "one-room school house" effect, that is, whether inexperienced biology students could be aided by experienced biology students and whether experienced biology students might not learn more fruitfully when they have an explicit teacher role in the class. This admixture was also used in this pilot course in order to enable us in one semester's time to determine for what particular level of student a more permanent research paper–laboratory course would be appropriate.

Another unusual aspect of the course is that it was team taught (Jeveli and Stevens 1975). Two instructors representing two different fields of physiology were both present for all discussion sessions and for most laboratory sessions.

Students for the course were selected by their response to advertisements for an upper-level experimental course in contemporary biological problems based on the reading and discussion of research papers and on performing laboratory research. The course was advertised as being open to both biology and nonbiology majors who were interested in understanding the basic creative processes of biological scientists. At the first class meeting, students were introduced to the format of the course and its goals of understanding basic thinking processes of biological scientists and of designing logical next experiments suggested by the papers read. They were informed that acquisition of a specific body of information was not a required goal; that, instead, they were expected to acquire necessary background information from their own textbooks, the instructors, or other sources to understand the general area of biology in which the research was being conducted. They were also informed that the instructors would not lecture or dominate the discussions but rather were present solely to moderate the discussions and to answer student questions, "no matter how trivial," generated in attempts to understand the papers.

The class consisted of seven students—one senior, one junior, and one sophomore biology major and four nonmajors—one junior, two sophomores, and a freshman. (We had expected the course listing at the 400 level to eliminate sophomores and freshmen.) Each week involved a two-hour discussion period and, on a separate day, a four-hour laboratory related to the papers discussed. The semester was divided into two topics, each an area of research interest of one of the two faculty members. The first topic focused on physiological and psychological aspects of prepared childbirth techniques, and the second topic considered the biochemical mechanisms of actomyosin function in muscle contraction. The first topic was broad, with many divergent physiological and psychological aspects all united by the common popular theme of childbirth. The second topic was a quite specific, limited research area presented in historical perspective of the development of research papers in the field. A listing of the specific papers used in both topics is presented in the table.

**Research articles read by students on two current research topics.**

A. Physiological and psychological aspects of prepared childbirth techniques:

BROTANEK, V., C. H. HENDRICKS, and T. YOSHIDA. 1969. Changes in uterine blood flow during uterine contractions. *American Journal of Obstetrics and Gynecology* 103:1108.

COTTER, J. R., J. N. BLECHNER, and H. PRYSTOWSKY. 1969. Oxygen, carbon dioxide, and hydrogen ion concentration in arterial and uterine venous blood of pregnant goats. *American Journal of Obstetrics and Gynecology* 103:1102.

LEES, M. H., et al. 1971. Maternal placental and myometrial blood flow of the rhesus monkey during uterine contractions. *American Journal of Obstetrics and Gynecology* 110:68.

LUMLEY, J., et al. 1969. Hyperventilation in obstetrics. *American Journal of Obstetrics and Gynecology* 103:847.

PARER, J. T., and R. E. BEHRMAN. 1970. The influence of uterine blood flow on the acid-base status of the rhesus monkey. *American Journal of Obstetrics and Gynecology* 107:1241.

B. Biochemical mechanisms of actomyosin function in muscle contraction:

BOWEN, W. J. 1957. Adenosine triphosphate and the shortening of muscular models. *Journal of Cellular and Comparative Physiology* 49 (Supplement 1):267.

deVILLAFRANCA, G. W., and H. L. HOCHGRAF. 1962. Adenosine triphosphatase activity of frog myosin B. *Comparative Biochemistry and Physiology* 6:147.

HEFFRON, J. J. A., and P. F. DUGGAN. 1971. Adenosine triphosphatase activity and superprecipitation of actomyosin from the frog, *Rana temporaria. International Journal of Biochemistry* 2(9):324.

HUXLEY, H. E. 1969. The mechanism of muscular contraction. *Science* 164:1356.

———. 1958. The contraction of muscle. *Scientific American* 199:3.

MOMMAERTS, W. F., and K. SERAIDARIAN. 1947. A study of the adenosine triphosphatase activity of myosin and actomyosin. *Journal of General Physiology* 30:401.

One faculty member took the role of a resource person for his area of interest while the second faculty member quite naturally took the role of interested student (Jeveli and Stevens 1975). Most information presented to the students by the resource person was in specific response to student questions generated from reading or discussing the research papers. Emphasis in discussion sessions and in lab was placed specifically on understanding the goals, approaches, and limitations of the project described in each paper. Students were urged to propose and design the next logical experiment to follow the paper read.

The first half of the course focused on the physiological and psychological creditability of the relaxing and breathing techniques used during labor and delivery in "prepared childbirth." Students were first presented a paper written by an advanced student on his research in pain endurance related to childbirth relaxation techniques. During the next few sessions this paper served as a background for discussions based mostly on terminology and simple physiological concepts. The students were then asked to give oral presentations on more advanced topics obtained from recent journal articles on physiological and psychological aspects of childbirth. Topics presented included physiological and anatomical aspects of the blood supply to the placenta; oxygen–carbon dioxide transport in the blood stream and across the placental barrier; pH homeostasis; and buffering systems in the blood. Experiments were devised to study human pain endurance to ice-water and the effects of prepared childbirth techniques such as varying breathing patterns. Spirometry measurements were performed to study oxygen consumption under varying environmental conditions. The students and the instructors worked together in developing, criticizing, and modifying experiments as the work progressed.

About halfway through the course the topic was changed to muscle biochemistry, the research interest of the other faculty member. A series of papers were studied on ATPase activity of muscle proteins; isolation of actin and myosin; enzyme kinetics; excitation-contraction coupling; and histological structure of skeletal muscle. Again, the initial encounter consisted of terminology sessions and explanations of simple concepts. Eventually it took a much shorter time for students to read the papers, analyze the experimental approach, and predict next logical experiments. Laboratory work was based on the ATPase activity of myosin using procedures reported in a paper (deVillafranca and Hockgraf 1962) read by the students. This group of papers and experiments was definitely more conceptually difficult, particularly for the nonmajors. However, after two or three slow sessions, papers were being read at a rate of one or two per session.

The last few sessions of the course involved open discussion of the learning experience and the students' evaluation of what specifically they had learned. Students were asked to write a report in the form of a scientific research paper (analogous to the research reports they had read) analyzing the experimental learning process they had experienced.

## *Results and Conclusions*

The open discussions and student research papers indicated that the students gained insights into (i) the selection and design of a research problem; (ii) the limitations placed by available equipment on types of research to be performed; (iii) the narrow scope of a given research area; (iv) the role of errors in the developing of a body of knowledge; (v) the limited understandings achieved by a research effort; and (vi) the entrenchment of ideas that occurs when old concepts are challenged. Most nonmajors and majors alike stated that they felt the mysticism which had previously surrounded the practices of scientists had been eliminated in this course, and they expressed confidence in their new ability to understand even difficult research papers with the aid of some background reading and of some definitions of terms. One junior nonmajor, who had a great reluctance to take traditional biology courses, went on from this course to receive an "A" in a marine biology course at a major marine research station. She said that she would never have had the courage to enter the course if she had not developed her interests and confidence in coping with scientific material in the experimental course. With the aid of the instructors and upper-level students, even the sophomore nonmajors were able to propose reasonable experiments to proceed from the papers discussed.

The students considered the labs as basically routine procedures, but they felt it was absolutely necessary to their understanding of the difficulty of interpreting data as found in the research papers. The nonbiology students generally had difficulty in performing lab procedures, in grasping the significance of some procedures, and in appreciating the value of serious, controlled laboratory conditions. It was difficult at times to establish a professional attitude toward lab procedures. Nonmajors found it especially difficult to follow the biochemical analyses. Two biology majors performed most of the laboratory work in biochemistry and explained their procedures to the other students. In the pain endurance and respiratory experiments the meaning of the procedures was more self-evident. Some nonbiology students stated that they would like to have had a separate discussion period devoted to understanding laboratory procedures to aid their comprehension. However, they, too, felt that the lab work was indispensable to their in-depth comprehension of the research papers.

Student overall analyses of this course were generally favorable and all students felt it was a valuable experience, necessary for understanding biological science. Some student comments which give an insight into their impressions of their experience follow.

> This course was one of the most worthwhile I have ever taken. I wasn't exposed to the usual semester's worth of facts, but my understanding of what I've learned is such that it will remain with me beyond the end of the class. I also discovered a great deal about how to learn, and some of the fun of learning that 13 years of school has effectively destroyed was brought back. (R. Holthouser, sophomore biology major.)

> If a student decides to continue in biological sciences, I would assert it to be in spite of and not because of the biology courses he has taken. . . . Probably the most exciting understanding I came to [in this course] was about the nature of scientific research itself. No longer is science and scientific research a mysterious region of unapproachable complexity. No longer will I have to stand completely removed and in awe of any scientific problem or discussion. I have really begun to understand the thought processes at work and am really relieved to know that these are things that I can understand. (J. Kinoy, junior, former biology major.)

> Should we have special labs for the techniques themselves? No, I don't think so. We made many mistakes but through these came to understand the value of precision and concentration in carrying them out effectively. The lab also served to make the research papers more real, a simulation of the experience the scientist goes through. Also, it exploded the myth that only superhumans can perform and understand these procedures. (R. Humphrey, junior nonbiology major.)

> This type of format, although valuable for the nonbiology and biology student alike, can't transfer data as efficiently as a typical lecture course. For that reason, those who are planning a career in biology must not consider the course as a substitute for other biology courses. It should be looked at as though it were a "vitamin." The biology student won't have a complete "diet" without it, but he can't survive only on it alone. I believe this course should be made available to all students. (M. Brauer, senior biology major.)

Student criticism of the course focused upon faculty attempts to stress data transfer rather than process of biology, faculty answers which diverged too long and too far from the immediate paper, the rate of reading of the biochemistry papers (some people thought it was too fast, one biology major thought it too slow), the need to more emphatically communicate at the beginning of the course that any questions no matter how simple are welcome in discussion, and the suggestion that the semester include only one set of research papers, that is, one topic and, hence, one set of biological vocabulary. Two students felt it would be a good idea to have a two-semester course—one semester to "catch on" to the learning technique and the second to participate more effectively.

Our own observations on the value of this technique are subjective; this was a preliminary project and time limitations prevented adequate design of both pre- and posttesting for student information acquisition, scientific thinking ability (critical evaluation of data, experimental design, and so on), and attitude toward biological science.

We feel that this technique cannot do as adequate a job of data transfer for upper-level students as Epstein reported for lower-level students. We believe that the main reason for this is the mixing of the student population; as might be expected. However, the unfavorable mixing did not necessarily appear to be between biology majors and nonmajors but rather between those students with motivation and maturity and those without. The students who understood the papers best, who consistently had significant questions related to the papers and to background material, who seemed to develop a greater body of background information, and who, in general, seemed to progress the furthest were generally the juniors and seniors and particularly a highly motivated sophomore. Experience in independent study techniques and desire to work at a subject matter on their own seemed to us to be the primary ingredients of the successful students.

Two nonmajors, one junior and one sophomore, felt lost halfway through the actomyosin papers and said they definitely needed more help. Even so, both students seemed to be highly motivated. In discussing the problem at the end of the semester, both the students and the faculty agreed that the problem could have been circumvented if the students had taken greater advantage of the faculty members' offer to be available to the students and if the faculty had realized the need to stress more frequently and emphatically that they were indeed available for consultation. The students both felt that their reluctance to make better use of the faculty was mostly due to their previous university conditioning which, they felt, communicated that faculty are most likely not available to students and to their fear of asking "dumb" questions in the discussions.

It seems that a possible model to handle the dichotomy between either nonmajors and majors or between mature students and less experienced, less motivated students would be to consider only one topic and, therefore, one set of biological vocabulary, for the less mature student.

**(Concluded on p. 170)**

tell the students what the liquids are, or that the liquids are different.

2. Ask the students what would happen if you were to put ice cubes in each liquid. Then place an ice cube in each beaker and ask the students to explain the results. The most typical comment is that the ice is strange or "funny." Interchange the ice cubes. Then the comment will probably be that you must have "funny" water.

Discussion:

1. In what way is the water "funny?" The discussion should lead the students to realize that one liquid supports the ice the way water does and the other does not. The first liquid then probably is water and the second liquid, which does not support ice, must in some way be different from water.

2. The fact that ice floats in the water and not in the alcohol is the basis for establishing a relative density scale. Ask the students to list the three materials in order of increasing density.

# *Teaching Processes . . .*

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Another alternative might be to use a two-semester design to allow for the slower pace of these students.

One student, a freshman, appeared to be generally less motivated toward learning and less able to carry out independent study. In discussions this student tended to avoid rigor, was ill-prepared, and frequently detracted from the subject matter. Therefore, we feel that a more successful experience can be achieved when admission to the course is limited to either upper or to lower classmen and also when screening is done to select for motivated mature students. It is clear that separation into majors and nonmajors as well as into upper- and lower-level students would simplify the course design and the time commitment of the faculty. However, our experience has shown that, with the highly specialized research material studied (which biology majors have most likely not had in lectures), highly motivated nonmajors can achieve an understanding of the processes of biological science equal to the understanding of a biology major. As Laetsch (1967) has observed,

> Biology does not consist of a hierarchy of increasingly sophisticated concepts in the manner of physics and mathematics. This means that a student can come to grips with the foundations of biological concepts soon after his initial exposure to the subject. If students are reasonably diligent, they can even criticize the very basis for such concepts. It is through biology that society has its best chance of understanding science. Biologists have not begun to take advantage of this opportunity, and there is no guarantee that the opportunity will exist indefinitely.

In addition, we observed that both the biology and the nonbiology majors benefited from working together, and we hope to clarify the parameters of this interaction and to improve its quality in a later project in which the parameter of class level is eliminated.

We recognize that the small student–faculty ratio in this class, no doubt, has helped to increase student enjoyment of the pilot course. However, our observations in this course as well as in our individual readings and research courses indicate that this course design in itself has significant value for improving the undergraduate's learning experience. In fact, one of our best students reluctantly suggested that the learning experience would have been improved if the class contained a larger number of students in order to improve the student-directed discussion and to minimize faculty tendencies to talk too much. Parameters which we hope to clarify in later projects include (i) differences in design for a lower level class versus an upper level class; (ii) optimal number of research topics to cover per semester; (iii) whether a one- or a two-semester course is optimal; and (iv) whether the proportion of time spent in discussion versus in laboratory is optimal.

Our experience has convinced us that this teaching technique is of benefit to both biology students and nonmajors as well as to both upper and lower classmen in increasing excitement for and understanding of biological science. We are particularly convinced that, while this learning experience is not a substitute for traditional courses, it does add an important dimension to a biology major's undergraduate education. We would urge that a research paper–laboratory experience be included in the curriculum for all biological science majors. This technique has the added advantage of allowing a researcher to devise an exciting learning experience for his undergraduates with minimal preparation because the "course" can involve his own research projects.

We have also concluded from our study that the research paper–laboratory experience is of value for nonmajors, in that it exposes them to the beauty and excitement of scientific discovery and removes the feeling of mysticism and enormous complexity which they frequently associate with the workings of scientists.

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