Freshmen "Discover" Principles of Biology

By J. F. DAVIDSON

The following comments by students who completed the course I shall describe may serve to indicate some of its desirable features:

"When I came into Biology 1, I was scared to death because from my past experience with biology it was hell. But now I am interested in it and have found it very enjoyable. With this type of class I'll be willing to go further into biology, whereas before I wanted to get biology and get it over for good."

"I also learned to question authorities, such as science books, and not to believe everything just because it is published."

"To think for myself—using the part of my brain that hasn't been used for awhile. It used to be 'read and remember,' but now it is 'read and question and conclude.' Words have no set definitions; they are arbitrary, man-made—especially the definition of life."

"I learned that after I've failed once, to look for another answer—quickly, so as not to waste time."

"Working with other people to achieve a common goal (such as developing a good demonstration)."

"To keep an open mind whenever having a discussion on a scientific subject (or any other subject) and not to accept anything as an absolute truth but as an answer until something better is found."

"I will retain an impression of what scientific investigations must entail; that is, a habit of research, the synthesis of many large ideas into one intent, the development of active laboratory procedures, the feeling of cooperation and curiosity that must be present."

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"There is usually more than one acceptable answer to a problem."

"I have found that in some cases searching for answers on my own, instead of having them presented to me, offers a better learning situation."

"Conciseness was one of the basic things that I learned. I can now see that I can't leave things just dangling in the air. I have to break things apart and be very careful of what I say."

"I'll remember that our group induced two acorns to germinate in two weeks with the use of infrared light, because it was so amazing."

"After all the discussions of 'controlled experiments' and 'identical conditions,' there is no possible way that I can forget that."

"The principle, 'life entails change,' impressed me quite a lot, for it is so simple yet so universal. I find myself thinking of specific examples and trying to find an exception, but as yet I haven't. I know I will remember this principle, because I think it is quite profound."

"I have learned the self-satisfaction of making up and successfully demonstrating our own labs. The knowledge acquired from doing labs this way exceeds the knowledge gained from structured labs by far."

"I have learned not to accept proof without first examining the work behind it. I took too many things for granted. I have learned to evaluate, criticize, and question statements before accepting them."

"Questioned Rather than Told"

These students were among the 50 college freshmen enrolled in my introductory-biology class. All but one of the students had had biology in high school. The class was scheduled for three lecture sessions and one three-hour laboratory a week, and the lab assistants were able to attend only one of the lecture sessions.

The idea of lecturing, either by presenting abstracts from various texts or by attempting to embellish a text, with the prospect of testing the students' ability to regurgitate information so presented, was distasteful to me: I have long been an advocate of inductive teaching. The problem seemed to be, "How can we really involve the students in biologic thinking?" Could a program be set up so that the students would be *questioned* rather than *told?* Could freshmen be expected to develop their own statements of biologic principles? The idea seemed to be worth trying.

The class was divided into two laboratory sections. In the lecture room the members of the two labs were seated on opposite sides, so that each student knew that the people across the aisle were in the other lab.

During the first meeting we discussed the meanings of three terms: *principle* (a biologic principle being something that holds for all living organisms); *generality* (a statement using the words "in general" or "generally," which implies the existence of exceptions); and *truism* (a self-evident statement of truth —usually so self-evident as to be meaningless). Following the discussion, members of each section were challenged to state as many biologic principles as they could, wording each principle so that it was acceptable—not to the professor but to the other section of the class. After a number of principles had been accepted, I asked each section to select one and attempt to prove it to the other section by devising laboratory demonstrations.

As an innovation, I required each student to use a hard-cover sewn notebook (so that pages could not be readily removed or inserted) as a record of his work. The student was to write on the right-hand pages only those things that he was confident were right—the mnemonic was intentional—and the left-hand pages were to be used for jotting down ideas, notes on references, and tentative conclusions.

For the first two or three weeks, all the time was spent in trying to state principles. A student would propose a statement; then members of (usually) the other lab section would cite an exception. The statement would be altered, dissected, and edited by elimination of nonessential words. Eventually it would be tentatively accepted or else discarded because of exceptions. The students asked for more lab time, which was unavailable; but each lab did meet separately during one of the scheduled lecture sessions for lab-planning sessions.

After a few principles had been accepted, members of one section would decide which principle they wished to prove, and the other section would then tell them what organisms to use. For example, when one lab wanted to prove the proposition, "For any living organism there is at least one stimulus to which it will react," the second lab suggested the use of *Planaria* as a lower animal, yeast as a lower plant, a rat as a higher animal, and an acorn as a higher plant.

Testing and Accepting Principles

It was soon apparent to most of the students that principles could not be "proved"; they could only be demonstrated. As an outcome of the discussion just mentioned, it was decided that demonstrations should sample the plant and animal kingdoms at least to the extent of working with a lower and a higher plant and a lower and a higher animal. The demonstrations were planned by the students, with the teaching assistants helping to locate apparatus or occasionally helping with techniques, such as sectioning, staining, or maintaining the organisms. I told the assistants to refrain from contributing ideas but encouraged them to question the students until student ideas were crystallized and clearly expressed.

One of the biggest problems of the professor and of the teaching assistants was to simply keep quiet long enough to allow the students time to think before expressing themselves. It was not unusual, at the beginning of a class period, for the students to converse in small groups for 5 or 10 minutes before someone presented ideas to the class as a whole. The longest such period was 35 minutes, and at the end of that time the presentation was one of the best of the whole semester. This was a good example of the axiom that one cannot reasonably say to a student, "Hurry up and think!"

The students were fascinated to discover that, in spite of all that has been said about biologic principles—even in books entitled *Principles of Biology*— they could not go to the literature and find a list of such principles. In fact, they could not find *any* principle in the literature that could be accepted by the class as stated. Hence they developed a proprietary feeling for those principles they helped formulate, and they showed obvious self-satisfaction when their principle was accepted by the rest of the class.

As teacher I did not evaluate the principles that were accepted by the class; nor do I do so now, as I present them to indicate the results of the method used. (It should be mentioned that the students agreed to eliminate viruses from consideration, since they did not have the equipment to study them adequately.)

Principles developed by the freshman class

All living organisms are composed of one or more cells.

All living organisms react to some kind of stimulus.

All living organisms transfer energy to and from their environment.

Water in some state is necessary for life.

All living organisms are capable of initiating internal or external movement.

The expression of traits is a result of hereditary and/or environmental factors.

All living organisms transfer matter to and from their environment.

All living organisms must inevitably cease to function as single living organisms.

Reproduction is necessary for the continuation of life.

All living organisms are unique in structure and/or function.

Life entails change.

All living organisms structure nonliving substances into living protoplasm.

All living organisms are composed of matter.

The physical and chemical laws or principles governing the environment of an organism must also apply to the organism. Some of these laws are (i) the amount of matter and energy remains constant; (ii) matter is in continuous motion; (iii) matter occupies space; and (iv) all matter is affected by gravitational interaction.

Statements rejected by the class

Here are four examples of statements rejected by the class, for the reasons given in parentheses:

All living cells are nucleate. (Bacteria and blue-green algae lack organized nuclei, and nuclei are absent in plant sieve tubes.)

All living organisms are adapted to their environment. (Death comes about by lack of such adaptation.)

The sun is the ultimate source of biologic energy. (Some plants kept aboard nuclear submarines carry out photosynthesis, using light from the release of nuclear energy. This reminds us that the sun's own energy source is nuclear, and therefore the statement would have to be modified as follows: "Nuclear energy is the ultimate source of biologic energy.")

All life comes from life. (This does not allow for the origin of life in the primordial past or for present attempts to synthesize living material.)

To revert to the "principles": they may not be accurate, nor is the list complete for the science of biology. But I believe the experiences of the class in formulating and trying to demonstrate them were at least commensurate with the experiences offered by a traditional approach. "Thinking and demonstrating" is a method that seems to merit further trials.

FUNDAMENTALS OF WATER POLLUTION

Q. What is biodegradability?

A. A biodegradable material—for example, the organic surfactant portion of a detergent—is one which the useful bacteria commonly found in sewage, surface waters, and soils can attack, break down, and utilize as food. After biodegradation, the surfactant loses its wetting and sudsing action and ultimately reverts to carbon dioxide and water.

The complex inorganic phosphate in detergents is converted into a simpler form by hydrolysis, a chemical reaction in which water acts upon the phosphate molecule. This process occurs in sewers, sewage-treatment plants, and receiving streams.

Q. What is eutrophication?

A. The process of enrichment of waters with nutrients is known as eutrophication (Greek *eu,* "well," and *trophein,* "to nourish"). Some people mistakenly refer to eutrophication as a form of water pollution, but a pollutant is usually a toxic substance rather than a nutrient. The terms are not synonymous, although it is true that the discharge of waste materials can add both pollutants and nutrients to a receiving lake or stream.

Eutrophication is a complex biologic process that occurs in all lakes over thousands of years of their normal life. In the beginning a lake is oligotrophic—poor in nutrient supply, clean but unable to support much aquatic life. Next, it becomes mesotrophic—well-balanced in plant and animal life. Finally, it is eutrophic—having an overabundance of nutrients, which causes the development of objectionable plants, changes in types of fish life, and large-scale algal growths, known as algal "blooms." The algae die and, in their decomposition process, use up available oxygen in the water. This tends to affect fish life; the lake begins to fill up with decaying matter, weeds, and the like; and the lake eventually becomes a marsh and then a meadow.

Q. What nutrients cause eutrophication?

A. There are some 15 or 20 nutrients that, when combined in proper proportions, cause biologic enrichment of a lake's waters. These include carbon, nitrogen, phosphorus, potassium, silica, trace metals, and vitamins. Carbon is essential. Next in order, by quantity, are nitrogen and phosphorus, which have been given the greatest attention. If one of these nutrients is completely absent, algae cannot grow. The prevailing opinion has been that phosphorus is usually, although not always, the most controllable nutrient in the eutrophication picture.

Q. What is cultural eutrophication?

A. A cause for concern today is cultural eutrophication; that is, the man-caused accelerated eutrophication of some lakes. The by-products of "people activity"—municipal sewage containing human wastes and detergents, industrial wastes, and agricultural run-off—have stepped up this natural aging process and have interfered with esthetic and recreational uses of lakes.