A Research Approach to Inquiry In High-School Biology

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FOR SEVERAL YEARS I had felt a growing dissatisfaction with my teaching method. I had taught a traditional course and then moved through all three BSCS versions. After reading what Brandwein (1969), Hurd (1970), Lee (1971), and others interested in science education have had to say about the need for change in science instruction, I felt compelled to make a break from a commercial program. It was my intention to develop a course that would not rely on a textbook, would cover the basic concepts of biology, would allow for individualized study in what I call "student interest areas," and would stress inquiry methods. The intention was to put into practice what I feel should be the goals of a biology course (table 1).

Some General Considerations

In order to focus on an aspect of biology, it is my feeling that a grouped classroom situation is desirable. The group provides a means of learning from others through interaction and discussion. Learning through group interaction involves a sharing of opinion and thought and therefore, I believe, occurs best in a classroom of students of mixed background and abilities. This grouping does not mean loss of individualization of instruction. In the method described in this paper it is subject matter rather than rate that is individualized.

I am dismayed by the sole use of specific behavioral objectives, directed primarily toward content, in biology instruction. The objectives often are made from or for a test. What usually results is a bunch of spoon-fed, test-oriented addicts who depend on the teacher to crank out more of his objectives. This kind of instruction too often has the teacher involved with an objective bureaucracy rather than with students. How can a teacher write a behavioral objective for a student to initiate creative thinking? I am not saying that the use of specific-content behavioral objectives is all bad, but it often has been overdone. One good place for their use is in the development of skills.

The experimental method of instruction described here was developed from that used by Epstein (1970) for teaching introductory biology for non-majors at Brandeis University. Epstein designed an analytic course to teach what a biologist does when he is doing biology. The system was developed to interest researchers in teaching. Each instructor selected eight to 10 research papers over his interest area, with the idea that one paper would lead into the others. The results as reported by Epstein were favorable.

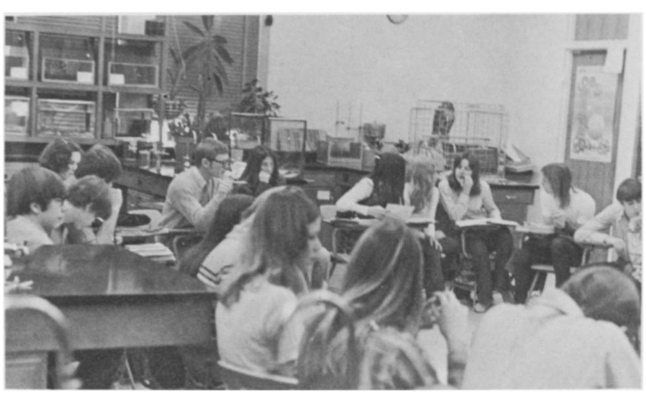

Fig. 1. Class discussion of topics works well in circle formation: everyone has a front-row seat and there is no posturing of authority. Note that the teacher (left center) is situationally at one with the students.

It was my intention to modify Epstein's methods and develop a biology course that would use carefully chosen scientific or science-related papers to cover major aspects of biology (table 2).

Questions, Labs Arise from Readings

Each new paper is assigned without explanation. Students are asked to compose a list of questions covering all words, concepts, and techniques that they do not understand. Student report teams are formed, and each is arbitrarily assigned a section of the paper to read critically. The teams subdivide their assigned sections among the members. The reporting team fields questions from the class and then researches and reports on all those raised that the team cannot immediately resolve. Other students, outside the reporting team, are encouraged to research the same questions. They as well as the reporting team are given credit for referencing information. Questions that arise from class proceedings (fig. 1) and are not directed to a reporting team are open for all students to research. A report of findings is given during the next class period. An added point-incentive is given if any student can prove that some misinformation has been presented. Report-team members can decline to research a question raised in class. If no class member wishes to undertake the research, the question is dropped.

Student report teams select articles of their own choice on the topic of animal behavior. The report team is responsible for explaining the content to the class and for referencing questions that occur as a result of its presentation. Report teams go through brainstorming sessions to offer hypotheses for the class to select and then to test by experimentation.

Table 1. List of goals for the research approach. The advantages of this form of instruction to the student are presented here in no particular order.

1. The development of analytic skills
2. The use of the inductive method in true experimentation
3. The involvement of students in library research
4. The use of current and relevant teaching materials
5. The examination of current issues related to science, to analyze opposing viewpoints and to exercise the right to form individual opinions
6. The learning of lab procedures and content as a need in order to achieve objectives based on student questions
7. The basic use of students' questions and "interest areas" to conduct class
8. A better understanding of how the act of science is accomplished
9. The practice of reasoning, so that decisions will be more skillfully made
10. The exercise of analyzing materials to separate fact and opinion and to increase critical thinking
11. The development of a philosophy of pragmatism (Peirce, 1905) based on the application of the scientific method to science and related problems, especially in the social sciences
12. The understanding and awareness of past research
13. The individualization of matters of personal interest within the framework of science
14. The basic use of student-student interaction to develop learning and tutoring situations
15. The stress on individualism for creativity

Logbook; Grading; Lab Format

At times a logbook is maintained to record such information as what teams are reporting and who is next, what questions are being referenced and by whom, and what hypotheses or research designs have been advanced. The logbook can be kept by the teacher or rotated through the class from student to student. A logbook would be essential if several classes were being taught by this method.

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The grading system for the class is based on five equal factors: referencing and presenting materials; laboratory reports of original research and other class projects; the in-class project system; interest-area work; and written tests over basic concepts. (For some of these grading elements see below, "Evaluation and Testing.")

The referencing and presenting grade is based on a point system. For information contributing to the solution of class-raised questions 5 points are given for a book reference and 10 points for a periodical. There is no per-person limit to the number of references cited in answer to a single question. The grade for this category is based on percentages derived from the highest individual point totals. All references submitted for credit are written out, stating the source and summarizing the findings. A 20-point maximum can be earned by a student each time he presents his critique of an article. These points are treated as reference points.

The laboratory reports of original research follow a format that states the following: the question; possible answer or answers (null and alternate hypotheses); experimental design and choice of confidence level; data; analysis of data; and summary of results. It is helpful but not essential for the teacher to have some background in statistics. Lab exercises and other projects done by the entire class are kept in individual student folders. The folders are turned in periodically for grading.

Table 2. Topics chosen for study in the research approach. The following aspects of biology have been chosen for direct coverage by research and other relevant papers.

1. Introduction to the laboratory operation of equipment, methods, and techniques. (No research paper)
2. The scientific attitude
3. Ecology
4. The cell; bioenergetics
5. Genetics
6. Evolution and diversity among protists, plants, and animals
7. Animal behavior. (No centrally used paper; student report team selects its own paper)
8. The human animal: anthropology, human anatomy, human and physiology (including sex education), and social and environmental problems of man. (See text for explanation)
9. Field work in the environmental lab (no paper) or alternative interest-area work

Fig. 2. This student is a member of a research team that became interested in imprinting. The team wanted to know whether chicks exposed to the barking of a mechanical dog, just before and just after hatching, would be imprinted by the sound rather than by the form and movement of the dog. (Control chicks did not hear the barking.)

Examples: Two Ecology Papers

To illustrate how experiments and content coverage occur from the articles, there follows a brief description of what evolved from two articles chosen to cover ecology.

The first article, "Population Density and Social Pathology" (Calhoun, 1962), discussed experiments on the effects of overcrowding on rats. From this article arose discussions of such topics as limiting factors, population-growth curves, choosing experimental organisms, and dominance orders in animals. An experiment was designed by the class to see if population density affects the hatching rate in fruit flies.

The second article, "Bird Mortality Following DDT Spray for Dutch Elm Disease" (Wurster, Wurster, Jr., and Strickland, 1965), was used to introduce the ideas of succession, food web, energy pyramid, biogeochemical cycles, niche, evolution, and speciation. These topics were brought out as discussion proceeded on what changes were occurring or might occur in the vegetation, particularly the elms, and the effects of DDT directly and indirectly on birds. DDT also served to induce discussion of the kinds of pollutants, state and federal pollution controls, and chemical nomenclature. The class experiment that was developed from this article centered on differences noted between male and female birds' death rates due to DDT. Research teams used a variety of sexable invertebrates in separate experiments to see if there was a difference between the sexes in tolerance of DDT.

At times papers are used to look at different viewpoints on a subject. For instance, students examined two papers on environmental problems: one by an ecologist, the other by a writer for an industrial magazine. The purpose was to separate what is fact and what is opinion. The logic behind the statements contained in both articles was analyzed by the class, with students stating their own opinions and viewpoints.

The in-class project system has been described in detail (Jernigan, 1971) in this journal. It allows students to care for a new room-project each week, by rotation. Projects vary from caring for animals to room cleanup. Approximately the last 10 minutes of each class period are given to in-class project work. Students also sign out at this time to go to the library.

Table 3. "Human animal" study format. Copy of a sheet (slightly modified here) that is supplied to the students.

PROBLEM DIMENSIONS

On examining a problem of man, be able to identify the following items, if they exist:

1. The problem that is being pointed out
2. The alleged cause or causes
3. Effects
4. Conflicting values
5. Possibilities of vested interest or of personal gain in the groups that represent conflicting values
6. The name and qualifications of a person, such as the author of an article, who is a source of information
7. Possibilities of vested interest or of personal gain on the part of the reference source
8. Economic, social, or military obstacles standing in the way of a proposed solution
9. Facts
10. Opinions
11. Possible solutions

GROUP ROLES

Work roles	*Maintenance roles*	*Blocking roles*
Initiator	Harmonizer	Aggressor
Informer	Gatekeeper	Blocker
Clarifier	Consensus-tester	Dominator
Summarizer	Encourager	Playboy
Reality-tester	Compromiser	Avoidance behavior

GROUND RULES

1. Everyone who is here belongs here just because he is here, and for no other reason
2. For each person what is true is determined by what is in him, what he directly feels and finds making sense in himself, and the way he lives inside himself
3. Everyone is listened to

Days Devoted to Student Interests

"Interest days"—that is, days devoted to student interest areas—occur in pairs three or more times in a nine-week period. Usually these days come in the middle of an involvement with an article. Students can regroup as teams or else work alone. These days allow for study of topics that are of individual interest. Students become familiar with several topics as a result of these days. Before the interest days students are exposed to a variety of ideas and information, the emphasis being on the aspect of biology currently under study. Students then select and state what they intend to do. They may form and test their own hypotheses (fig. 2), do BSCS or other lab exercises, research a topic in the library, or use other resource materials, such as film loops or strips. A day or two after the interest days students have the opportunity to explain to the class what they did and any benefits they obtained. They also answer class questions about their topic. Students can turn in a written report; however, most prefer to comment orally.

One subject of study in which research papers or other papers are not used is that of the human animal. This subject is approached by having each student list five problems of man that most concern him. These problems are combined in a list, with each student choosing two with which to begin library research. The class is made aware of group roles so that a problem can be more efficiently examined. In this situation, roles represent behavior patterns that people can be categorized as performing within a given situation. Simulation techniques, such as giving students the opportunity to represent contrasting interest in a biosocial problem situation, also are helpful in illustrating the role behavior of people and the complexity of such problems. The examination of the problem follows the format given in table 3. At this time in the course, interest days center on lab exercises and resource materials concerning man. Original research usually is carried over to this section from previous work. New hypotheses can be generated by group brainstorming sessions.

Table 4. Team-evaluation form. Each member of the team completes this form as an aid in deciding whether the team is functioning effectively in "interest-area" work.

Team __________ *Hour* __________ *Date* __________

1. List all team members, including yourself, in alphabetic order by last name.
2. Look at each category and determine to what degree each member of your team contributed to the total effort.
3. Each category has 100 points as the total effort. Therefore, you must divide that 100 points among the team members, including yourself.
   Example 1: There are four members, and you feel each did an equal share. You will then give each 25 points.
   Example 2: There are three members, and you and Fred do all the work. Gladys does nothing. You therefore give yourself and Fred 50 points each and Gladys zero.
4. Each category then will total 100 points, and the grand total will be 500 points.
5. Note: you do not need to identify your paper.

To what degree did the student—	NAMES				
1. Come prepared to work					100
2. Contribute to the undertaking of the project					100
3. Actually work					100
4. Contribute by not goofing off or encouraging others to goof off					100
5. Contribute to the harmonious relations of the team					100
Totals					**500**

Evaluation and Testing

As an aid in evaluating the in-class project and interest-area work a team evaluation form is used (table 4). Each member of a team rates the other members but remains anonymous. Each category (such as "contributes to harmonious relation of the team") has 100 points that must be distributed among team members. If student *A* feels he and the other team members contributed equally, each gets 25 points. Student *B* on the same team may divide up the 100 points for each category differently among team members. By totaling each person's points for various categories as he assesses himself and as others assess him, a profile emerges. This method has been successful in helping with the evaluation of team-work. It is important that the teams be self-selected.

The final fifth of the grade is based on a written test. The test is more of a diagnostic tool: it helps determine what topics may need to be reemphasized, in future, by the use of articles. The test asks the student to comment on the major biologic ideas presented in class. Students are given a list of the concepts brought out in the article in advance of the test. Each student adds to the list two items of his choice that he alone will explain. The student is encouraged to reference the list as needed in order to communicate a general understanding of the concepts listed.

Also asked on the test but not graded is the following question: "Do you have any comments or criticism (with alternatives) about the class? Express any attitudes or opinions you wish." All comments are listed and discussed in class for their value. Later tests stress forming hypotheses and designing experiments to test them.

Appraisal of the Method

This method was developed last school year in a class of 31 students with mixed abilities. It is my intention this year to research the effectiveness of this method, using the BSCS Green Version as the control instructional method. A Solomon Four-Group Research Design will be followed to see if differences occur in achievement, degree of understanding science, ability to think critically, several attitude measures (such as students' attitudes toward science), and the way the students view me as an inquiry teacher. A factorial analysis of variance will be used to determine if any significant interaction exists between the variables (i) method and sex and (ii) method and upper–middle–lower thirds of the samples as measured on the Differential Aptitude Test (DAT).

I have found that teaching the research approach has taken less preparation time than BSCS and less in the way of equipment.

In the past I have always been against science fairs. This probably was because it interfered with my schedule and compelled me to cultivate the act of science outside of class. With the teaching method I have described I could involve the entire class if the students desired. It is not necessary to stop the prepared classroom activities so someone can do something original.

With this teaching method the teacher becomes a director, consultant, catalyst, critic, student, philosopher, and scientist. Too often, I think, science teachers separate themselves from the act of science. Would it be better to take a philosophy course from a philosopher teaching a philosophy class or from a teacher teaching a philosophy class? Why should students be "turned on" to poetry in English if the teacher is not a poet? In science is it not the same?

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Birth Rate at New Low

The country's birth rate has reached an all-time low of 15.6 babies born per 1,000 people (March 1972). This compares with the lowest birth rate of 18.4, registered in 1936, and the highest, 25.3, in 1957.

This latest figure represents a total fertility rate of 2.136 children per woman of child-bearing age. A zero-population-growth rate would occur if the total fertility rate were maintained at 2.110.

In March there were 800,000 more women of child-bearing age than last year—yet there were 31,000 fewer births.

Behind Those Neon Arches

Housewives Involved in Pollution Solutions (HIPS —one of the swingier acronyms) figured out something we'd always wanted to know: what's the environmental impact of 8 billion hamburgers? Answer: 3 billion kilowatt-hours of energy and 890 square miles of forest to make the paper cups, bags, wrappers, and napkins accompanying that many snacks from McDonald's.

Costs of Curbing Pollution

The government has released two reports dealing with the effect of environmental concerns on industry.

The first, by the Environmental Protection Agency, notes that private expenditures on pollution-abatement equipment will greatly exceed earlier predictions. The second, compiled by the Council on Environmental Quality and other agencies, predicts that a pollution clean-up will not have disastrous effects on most corporations, despite claims to the contrary.

In its annual study of the economics of clean air, EPA stated that estimates of the amount that industry expects to spend in the next five years to control emissions total about $42 billion. In its report last year the agency's estimate was only $31 billion.

In its report 10 days later, CEQ assessed the impact that compliance with the Clean Air Act and with general secondary water treatment standards would have on 14 industries and the economy as a whole. In its conclusion the report said "no industries will be severely impacted" and "most plants will continue to produce and be profitable."

Environmental Education