The Investigative Laboratory in Introductory Biology Courses: A Practical Approach

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THOSE OF US who teach introductory biology courses in either high schools or colleges are charged with the difficult task of communicating the nature of biology as a branch of knowledge to an exceedingly diverse group of students. While we encourage capable students to choose careers in science or related fields, we know that the training of new scientists is not our primary task. Most of us, therefore, teach out of the conviction that biology will be relevant to our students throughout their lives, regardless of their career choices. It follows that our students should gain not only an appreciation of the major concepts of biology, but should also begin developing realistic attitudes toward the utility of science, the strengths and limitations of the scientific approach, and the value of public support for scientific research. Further, we must provide students with opportunities to develop their creative and critical abilities and to exercise precision, thoroughness, objectivity, and other attributes of scientific thinking which they can apply in their daily lives.

To fully accomplish these ambitious goals we must turn to our most valuable educational resource—the laboratory—and allow our students to engage personally in scientific investigation. As investigators, students are challenged to identify biological problems, to hypothesize answers, to investigate their hypotheses experimentally, and to analyze their work in written reports. More than a decade ago the authors of the CUEBS position paper on investigative laboratory programs (Holt, *et al.*, 1969) asserted that the best use of the teaching laboratory is to engage the student in scientific investigation, and that large-scale implementation of this learning strategy is critical to the future of biology education. Today, despite the efforts of numerous individuals and groups, scientific investigation by students is still not a common activity in teaching laboratories. It is particularly rare in those laboratories which serve beginning-level students. As biology educators we must ask why the investigative laboratory has not become a widely used learning strategy in introductory courses. Why is the opportunity to experience biology in its fullest sense as scientific inquiry denied to the great majority of biology students? Certainly there are problems associated with any investigative laboratory program. Some of them are difficult, but none is insoluble. It is the purpose of this article to propose that all biology students can be allowed to conduct laboratory investigations within the existing framework of courses, facilities, schedules, and budgets. The following sections present a series of tried and tested ideas for making the laboratory a place where students can become investigators in introductory biology courses in either high school or college.

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Building a Foundation For Investigation

Students must be provided with an appropriate experiential background for designing and executing investigations. The typical biology student, accustomed to being told step-by-step what to do in the laboratory in order to achieve some pre-arranged result, is likely to be overwhelmed by the task of designing an investigation unless the assignment is preceded by a set of experiences which define a general biological topic and suggest some methods and choices. This principle can be put into practice in a variety of ways. A good strategy in introductory classes is to use standard laboratory exercises as a foundation for investigation. As an example, consider the following format for a two-semester general biology course. The course is composed of six subject-matter modules (table 1), each of which requires about six weeks for completion. Class activities during the first four weeks of each module consist of the usual mixture of reading assignments, pre-lab discussions, standard laboratory exercises, post-lab analyses, and quizzes.

TABLE 1. Titles of Subject-Matter Modules For a Two-Semester General Biology Course

I.	Ecology, Environment and Us
II.	The Functioning Organism
III.	Genetics: The Science of Heredity
IV.	The Biology of Living Cells
V.	Microbiology: The Invisible World
VI.	The Human Animal

Near the end of the fourth week the students are assigned to choose problems for investigation. The problems must be related to the topic of the current module. With this frame of reference the students typically have little trouble proposing reasonable and interesting problems. As might be expected, many of the ideas come directly from curious results obtained during standard laboratory exercises used in the first part of the module. (Typical examples: "Why is my body temperature lowest at 7:00 A.M., while my friend's is lowest at midnight?" and "Why did the elodea plant release oxygen bubbles faster when it was 20 cm away from the light source than when it was only 10 cm away?")

After the problems have been discussed and approved, the students develop hypotheses and plan experimental procedures. At this stage the instructor functions as a discreet advisor. The natural inclination to provide direct answers to the students' problems must be strictly avoided or the opportunity for investigation will be wasted. Instead, the instructor advises students regarding effective ways to seek their own answers. During the first investigation of the course a great deal of advice is required to insure that adequate controls are planned and that the investigations conform to the limits of time and facilities; however, in succeeding investigations most students require only occasional technical advice.

Once planning is complete, students spend about one week's class time executing their experiments. Investigation reports are then prepared and the module ends with a "sharing session" during which students present brief oral descriptions of their work and respond to questions from their peers. In these sessions students frequently provide each other with surprisingly astute critiques and advice for future investigations. Table 2 lists the titles of a representative group of student investigations which were conducted during a microbiology module. Clearly, these brief studies involved little original research, but it should be remembered that these investigators were beginners, many with limited academic enthusiasm. To them, the ideas and techniques involved in their investigations—if not original—were certainly fresh and exciting. Each student who completes this biology course has conducted six miniature laboratory investigations of his or her own design, and has experienced firsthand both the frustrations and triumphs of the investigative process of biology.

TABLE 2. Sample Student Investigations Carried Out During a Module on Microbiology

How many bacteria exist in pasteurized and unpasteurized milk samples of different ages?
How does temperature affect the growth of a yeast population?
Can the alcohol content of fermented honey be increased by adding various mineral salts during fermentation?
How effective are mouthwashes in killing bacteria in the mouth?
What is the level of sewage pollution in Logan Creek as measured by fecal coliform populations?
In what kinds of fruit juices do yeast cells grow best?
What are the effects of household disinfectants on bacteria?

Infusing Investigative Labs Into Existing Courses

Laboratory investigation should be an integral part of a biology course. For too long investigation has been regarded as a sort of extracurricular activity, reserved for those students who are willing to work at it in their spare time. Such an important and effective educational technique deserves to be written into the course syllabus, and it certainly deserves an allotment of time in the laboratory schedule. A reasonable rule of thumb seems to be that students in introductory biology classes (high school or college) can profitably spend at least 20% of their laboratory time on independent investigations.

In most courses, the prospect of introducing greater opportunity for laboratory investigation will mean discontinuing the use of substantial numbers of non-investigative laboratory activities. This is not as great a problem as it may appear. An honest evaluation of our biology course content usually reveals certain activities which could be deleted without impeding our students' progress toward course goals in any way. For example, the standard "cookbook" osmosis lab which uses cellulose membranes or various biological materials to illustrate osmosis tends to require a good deal of laboratory time and often yields results which are inconsistent and ambiguous. Attractive classroom displays or demonstrations could more effectively illustrate osmosis while saving considerable laboratory time. In general, the illustrative facet of laboratories could be largely replaced by displays and other imaginative classroom techniques (Holt, *et al.*, 1969). In most cases this would free ample time for laboratory investigation. In the event that a choice must be made between investigative activities and other laboratory activities deemed essential for the achievement of the course's learning goals, an examination of the learning goals themselves might be in order. One of the major advantages of laboratory investigations is that they not only enable students to learn biology by doing, but that they encourage creativity, objectivity, thoroughness, and precision. The development of these skills should be a principal learning goal of our courses.

Laboratory Equipment For Investigative Labs

A laboratory does not need to be stocked with expensive equipment in order to be an effective place to investigate. While a well-equipped lab expands the range of investigative options available to students, too much paraphernalia can obscure the real essence of investigation, especially for beginning students. The wise instructor will remember that the best investigations are those which discover simple ways to attack complex problems.

As an example, I recall two students in a tenth-grade general biology class who decided to investigate the role of cotyledons in plant growth and development. Their experimental materials consisted of bean seeds, paper towels, a bag of vermiculite, razor blades, metric rulers, and styrofoam drinking cups. The students soaked the seeds, removed carefully measured portions of the cotyledons, and then planted the seeds in cups of moistened vermiculite. They monitored growth of the plants by periodically measuring the lengths of epicotyls and hypocotyls and by determining the plants' increase in dry mass. This might have been nothing more than an elementary exercise on seed germination, but with some clever ideas, careful planning, skillful manipulation of the plants, and patient observations, these students executed an outstanding and fruitful study.

This example of an investigation conducted with minimal equipment should not imply that laboratory funding is unimportant. On the contrary, the pedagogical value of the teaching laboratory should be reflected in budget priorities. We must realize, however, that if economic pressures result in reductions of laboratory budgets, investigative laboratory programs can continue.

Student Capabilities

Every biology student has the ability to design and conduct laboratory investigations. The idea that only the brightest, most highly motivated students can profit from this type of experience simply doesn't withstand close scrutiny. In fact, those instructors who regularly employ laboratory investigations in their courses consistently point out that this is one of those rare educational activities which is sufficiently versatile to afford everyone a chance for success, regardless of one's aptitudes and abilities.

I have worked with students who, because of learning disabilities or deficiencies in basic educational skills, could not begin to comprehend a chapter from their textbooks or pass an ordinary quiz. I have shared these same students' pride and enthusiasm at having successfully completed laboratory investigations which they conceived, designed, and carried out. Of course, not all students achieve the same level of sophistication in their investigations, but they all learn about biology and about themselves, and they are likely to remember what they learn.

Instructor Time

Some laboratory instructors may fear that the task of preparing equipment and materials for investigative laboratories would be exceedingly difficult, especially for classes with large enrollments. When students are instructed to build their investigations around a common theme, however, preparation becomes quite simple. As an illustration, consider the format followed in an introductory biology course at the college level: at several points in the course the students are introduced to new laboratory procedures which they are then assigned to use in a mini-investigation of their own design.

For example, during a unit on enzymes, the students are taught to extract alpha amylase from wheat seedlings and to assay the enzyme's activity using the method described by Richter and Muir (1970). They are then directed to define a research problem involving the enzyme and to design an experiment incorporating the extraction and assay procedures which they have learned. Outlines of the proposed experiments are submitted to the lab instructor for approval, and the mini-investigations are carried out during the following week's laboratory session. The titles of some representative enzyme mini-investigations which were designed and successfully executed by students are given in table 3. In spite of the obviously limited scope of these studies, they nevertheless allow each student to experience in minature the process of science. We find that one laboratory instructor can easily handle the preparation for this type of investigative laboratory for a class of about 120 students equally distributed in six lab sections.

TABLE 3. Sample Enzyme Mini-Investigations

How does the activity of salivary amylase compare to the activity of amylase from wheat seedlings?
At what temperature is the catalytic function of amylase destroyed?
Is the activity of amylase inhibited by sodium fluoride?
What is the optimum pH for amylase activity?
What substrate concentration "saturates" the enzyme?
At what stage of germination is amylase activity greatest in wheat seedlings?

Attitude and Philosophy

The idea of doing laboratory investigations typically elicits a skeptical initial response from both instructors and students. Investigations are viewed as being subtly threatening, perhaps because they represent a largely unfamiliar kind of endeavor or because they may turn out to require a good deal of work. My experience indicates that for most participants in investigative labs, the skepticism soon dissolves into enthusiasm. Laboratory investigations are without question the most stimulating aspect of my own teaching, and I often find myself learning along with my students. Very few students express dislike of investigative labs, and many of them emphasize on their course evaluations that they perceived the investigations they did as the most interesting and important parts of the course.

In the final analysis, the success or failure of investigative labs as teaching devices depends upon the attitude of the individual instructor. If it bothers you to be unable frequently to answer your students' questions, or if you are unwilling to undertake a reading program to keep up with the problems your students have chosen to investigate, you probably will not like investigative labs—at least not at first—and this attitude will certainly be reflected in your students. On the other hand, if you find the uncertainty which exists in science challenging and stimulating rather than frustrating, and if you agree with the idea that it is more important for students to learn to ask perceptive questions than to always know the "right" answer, then both you and your students are likely to have exciting and rewarding experiences with investigative labs.

Conclusion

This article has focused on ideas and methods for involving beginning biology students in the scientific process of laboratory investigation. The strategies discussed have been successfully used in introductory classes with large enrollments at both high school and college levels. Students who have conducted miniature laboratory investigations during introductory courses should be encouraged to undertake full-scale investigations if they elect to take additional biology courses. There are a number of excellent references available to the educator who desires information on methods for organizing major laboratory investigations. These include Burke (1979), Gubanich (1977), and Thornton (1972).

The need to involve all biology students in the processes of science is so compelling that biology educators as a group should apply their problem-solving skills to the task of overcoming obstacles to the use of investigative laboratory programs.

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