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Correction

In the How-to-Do-It article "An Instructional Approach to Modeling in Microevolution" (January 1988, pg. 29), the graph in Figure 2 should be deleted and replaced with the one in Figure 3; the graph in Figure 3 should be replaced with the one in Figure 4. The new Figure 4 is available from the author (Steven Thompson, Biology Department, Ithaca College, Ithaca, NY 14850).

Labs

What Research Says About Biology Laboratory Instruction

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There is a modest yet revealing body of research on laboratory instruction in biology. The vast majority has been done during the past three decades, and probably the most significant has been reported during the 1980s. This literature ranges from philosophical/historical studies, to in-depth case studies, to relatively well controlled experiments.

The research gives us some clues as to what are the most educationally productive and meaningful strategies for laboratory instruction. I will examine some of this research and discuss what appears to be state-of-the-art in biology laboratory instruction.

During the 1950s and early 1960s there were a fair number of Method X versus Method Y studies of various laboratory teaching approaches. Most of these compared either a traditional (very directive) or non-laboratory approach with an innovative (more inquiry, inductive or discretionary) approach.

Even the best of the experimental studies of this time were not very conclusive because of various methodological problems. These included not controlling for contributing variables other than laboratory teaching method and not employing statistical tests that would identify to what extent the method contributed to student learning.

Most were done with relatively small numbers of students, so that statistical significance was difficult to achieve. Few employed random assignment to treatment groups, so group equivalence was in question. None documented the independent variable(s), making it difficult to replicate or write curricula based upon the particular method used in the study. The sum of all these earlier experiments produced nearly a draw between "old" and "new" laboratory teaching methods. It is no wonder that few conclusions or consistent patterns about what works best in the biology laboratory resulted from this period of research.

From about the middle 1960s to the present, research experiments on different laboratory teaching approaches continued, but their methodology improved greatly. Much of this was due to the use of computerized data analysis, but also because these studies became more scientific and avoided the problems of earlier studies.

An extensive comparative review of most studies up until the mid-1970s can be found in the *Biology Teacher's Handbook* (BSCS 1978) and several more are cited here. My interpretation of this more recent research is, almost without exception, that the newer or innovative approaches were more student-involved or more inductive and that they generally produced significantly greater educational gains than the more traditional approaches (Ali

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1980; Schellenberg 1980; Oloke 1981; Leonard, Cavana & Lowery 1981; Tofte 1982; Leonard 1983, to name but a few).

The innovative approaches also gave the student more responsibility for determining procedural options, required more extensive use of science process skills and used significantly more components of inquiry instruction. They also appeared to work equally well for secondary and college students of all ability levels, not just the academically talented. It appears that students were able to handle much more discretion in a laboratory learning setting than they were accorded by the teacher (Cavana & Leonard 1985).

The curricular products of the BSCS movement beginning in the early 1960s have undergone extensive evaluation, both short and long term, comparing them to the existing, traditional programs. Although many of the single studies are inconclusive, very few favor the traditional programs. Many favor the BSCS programs for producing greater student learning of biological information, more extensive development of science process skills and more positive attitudes toward science (Tamir & Jungwirth 1975; Montgomery 1969; Coulter 1966; Riggs 1971; Sorensen 1966; Barnes 1967).

A recent and extensive meta-analysis indicates that the long term effects of the process-oriented biology programs developed by BSCS were measurably superior to those of traditional curricula in student understanding of biological concepts and scientific thinking skills (Shymansky 1984).

Some recent studies have focused on what may be most appropriate learning strategies for students who are either developmentally capable of abstract thought (formal operational) or not (concrete operational). It appears that about one-third of 10th grade biology students consistently demonstrate concrete reasoning and only about one-fifth consistently show formal reasoning. The vast majority of 10th grade biology students are thought to be advanced concrete or transitional: they operate concretely in some tasks and formally in others (Lawson & Renner 1975; Lawson & Blake 1976). Whether these inconsistencies depend upon the content, past experiences, or brute intellectual capability is unclear. However, high school biology students who were not formal were found to understand very little of required formal concepts (Lawson & Renner 1975). Many major concepts including evolution, genetics and ecology, taught in high school biology, require formal operational thought to understand. Since students were found to be unable to develop appreciable understanding of abstract concepts, it appears that a science course that deals extensively with abstractions may be inappropriate for this population. It also appears that use of typical, traditional biology laboratory exercises does little to foster the achievement of abstract concepts (Fields 1985).

These generalizations also hold for a surprisingly sizable fraction of students enrolled in introductory biology at the college level as well, where approximately one-half of students are believed to be not fully formal operational (Lawson 1980).

Fortunately, there is evidence that students can be taught to improve their use of formal operational thought. It has been found that some students designated as concrete thinkers can develop an understanding of concepts considered to require formal thought (Lawson & Wollman 1975).

What can we as teachers do to foster the development of formal concepts? Research shows that to teach concrete or transitional thinkers formal operational concepts, they need first to work with the principle in concrete terms, especially with manipulative activities provided in a laboratory environment. The students can then be supplied with symbolic representations of the principles so the principles can be progressively internalized by gradually reducing the need for perceptual and motor supports.

Students should initially be allowed to use their own words to describe the principle relationships and should be allowed to solve problems in a variety of ways and contexts. This allows students to gradually abstract the principle from its concrete exemplars (Wollman & Lawson 1978; Lawson 1985). At the college level, an inquiry-based hands-on biology course, in which a series of laboratory investigations to teach formal reasoning formed the major mode of instruction, was found to significantly improve students' ability to use formal operational thought (Lawson & Snitgen 1982).

Very diverse populations of college students have to be taught strategies to use formal reasoning in their science courses (Nesbett, Fong, Lehman & Cheng 1987). Given that the ability to reason is so important for success in the out-of-school world, a very convincing case can be made for emphasizing this skill in science courses at the expense of teaching science content.

Some research supports matching laboratory work to be done by students with the students' developmental level (Hofstein & Lunetta 1982). Most attempts to teach scientific reasoning skills by actually practicing them were found to be productive. Tamir and Amir (1987) have found that laboratory process skills, such as taking measurements, formulating problems, identifying variables, or drawing conclusions, appear to be skills that are learned independently of each other. They also argue that the 21 or so traditional process skills appear to be factored to only 7:

1. Handling quantitative relationships,
2. explaining and assessing data,
3. conceptualizing and planning investigations,
4. summarizing results,
5. interpreting and concluding,
6. selecting form of presenting findings, and
7. designing experiments.

Perhaps we need only to focus upon these seven skills.

There has recently been a noticeable increase in published biology laboratory activities that depend heavily upon engaging the student in manipulative experiences to discover concepts rather than to verify them. High correlations have been found between the amount of student experience in manipulating laboratory apparatus with practical laboratory skills and with positive attitudes toward biology. Transmitting knowledge, listening and non-lesson student behaviors had low correlations with measures of laboratory skills (Okebukola 1985).

In one interesting study, hands-on, manipulative teaching approaches in biology produced consistently greater learning of concrete concepts for concrete or transitional learners. Neither concrete nor formal teaching approaches were superior for instruction of formal concepts. Students classified as concrete or transitional learned very few formal biological concepts, regardless of the teaching method employed (Purser & Renner 1983).

Adaptations of the Learning Cycle, originally designed for elementary science education (Karplus & Thier 1967) have shown promise in secondary biology (Purser & Renner 1983). This form of discovery instruc-

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tion has three sequential phases:

1. student exploration of the phenomenon in a laboratory setting,
2. student invention of the concept, frequently under the direction of the teacher in a discussion-style mode, and
3. student application of the concept, frequently through solving problems or answering key questions.

As support for discovery learning increases in research literature, strategies such as the learning cycle will be adapted to commercial biology laboratory programs.

The recent advent of microcomputer interfacing of laboratory measurement devices has added a promising new dimension to the laboratory classroom. It is now relatively inexpensive to link a simple microcomputer to sensors for temperature, pressure, pH, light, absorbance, movement, sound, force and other laboratory instrument output. These measures can be displayed instantly on the video screen, statistically analyzed and graphed. The microcomputer's clock can accurately time a variety of biological (and physical) phenomena and make it unnecessary to wait long periods of time for changes in output variables.

Microcomputer-based laboratories (MBL) used for real time data gathering have demonstrated effective teaching of graphics skills and provide powerful motivators for students in a laboratory classroom (Mokros & Tinker 1987; Nachmias & Linn 1987). MBLs taught selected science concepts more effectively than traditional instructional strategies (Brasell 1987). It is likely that microcomputers and other recent technologies, such as the laser videodisc (Leonard 1987), will have dramatic effects on the roles of both the student and teacher in future laboratory instruction.

Meaningful laboratory instruction in biology appears to be distinguished from other instructional strategies in at least three ways. First, the student is engaged in a number of the science inquiry processes: observing, classifying, measuring, communicating, collecting and organizing data, inferring from observations, hypothesizing, manipulating experimental variables, analyzing data and drawing conclusions from data. Second, the student has the opportunity to manipulate experimental apparatus to provide a "hands-on" experience. Laboratory investigations are especially productive in biology because students can experience the excitement of biology through a study of living organisms. Third, the laboratory teaches in a very experiential manner specific biological concepts, such as "plants have cell walls and animals do not" or "both plants and animals carry out cellular respiration."

What is the state-of-the-art in biology laboratory instruction? A wide range of laboratory teaching strategies are available to the biology teacher, ranging from structured (cookbook) and factually oriented to experimental investigations which are open ended (inquiry and discretionary). The more structured laboratory strategies tend to be very predictable and secure, but are often dull and tedious to the student because little is left to the imagination. Although cookbook-type laboratory activities are by far the most common among commercial biology curricula, they have limited opportunities for students to engage in science processes and develop their own ideas (Tamir & Lunetta 1981).

Inquiry approaches are especially appropriate for science teaching because they center around developing answers to interesting or puzzling situations. They can be extremely motivating to students because they allow for significant student participation in the learning process. However, high school biology teachers do not appear to be using inquiry as originally envisioned. Among the major reasons given for not using inquiry teaching are that the approach lacks sufficient structure and is too difficult for most students (Costenson & Lawson 1986).

A variation of inquiry, which I will characterize as Guided Inquiry approach, lies somewhere in the middle of the spectrum of structured to unstructured activities. It is a very workable strategy because it takes into account that most high school biology students are basically curious, but that they have limited abilities to deal with abstract concepts, have limited attention spans and have limited abilities to work without some direct guidance.

The Guided Inquiry laboratory approach has four distinct characteristics which are described below. It is the last two characteristics that make Guided Inquiry especially unique.

1. Introduction

A brief written or verbal introduction. Sets the stage for the inquiry by stating the context of the investigation in relation to existing work in the course and by stating the goals of the lesson.

2. Materials

Materials or other resources needed are identified so the student will know the parameters of the activity.

3. Procedure

These are usually numbered steps, each of which are relatively brief, discrete directions, one leading sequentially to the next. Each gives the student sufficient direction to proceed, but not so much as to get bogged down following directions. Occasionally, steps which may be complex or abstract are illustrated for the student. Thus, the procedure maintains the inquiry nature of the investigation, yet gives enough direction to allow nearly all students to proceed successfully. A key aspect of the Guided Inquiry procedure is the opportunity for students to engage in science processes. Frequently included are more difficult skills, such as identifying variables, controlling for and manipulating variables and quantifying data.

4. Discussion

This component requires students to respond to carefully constructed questions. The first questions deal with a review and analysis of the data and extend the process skill involvement to graphing, inferring and concluding. Subsequent questions will systematically lead the student into the development of the desired biological concepts as the data are related to the biological problem being studied. These are extremely important for most high school students because they allow them to utilize the concrete experiences of data collection to bridge the gap to the development of the more abstract biological concepts. Since the development of concepts is experiential, it becomes more meaningful and lasting for the student. A few remaining questions may ask the student to respond to possible relationships between this immediate experience and the real world of biology, technology, society or personal experiences. The student is therefore guided through the entire investigation while the curious and interesting aspects of the inquiry are maintained.

The Guided Inquiry approach is based upon years of development and research in science education and has been found to be especially valuable for typical high school biology classes of mixed-ability students. It is central to programs developed by the Biological Sciences Curriculum Study, such as the BSCS Green Version high school biology textbook, *Biological*

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Sciences: An Ecological Approach. The 1987 edition of BSCS Green Version contains more than 40 laboratory investigations, most of which employ this approach. Importantly, the investigations in this program are placed in appropriate sections within each chapter of the textbook, thus providing a systematic basis for the development of biological concepts and science inquiry skills.

There are criticisms of the Guided Inquiry approach. It does a respectable job of illustrating or allowing the student to discover a biological concept, but it is weak in providing the necessary experiences for development of problem solving and reasoning skills. These skills are a focus of much current research in science education. Hopefully, the research will lead to the development of curricula which effectively teach these important life skills

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