A BSCS-Style Laboratory Approach for University General Biology

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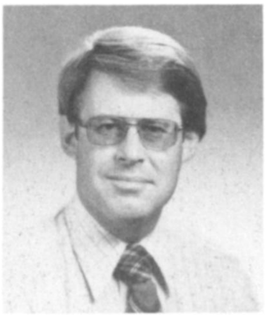

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Laboratory work has for decades been a regular part of instruction in introductory biology courses at the college and university level. Typically, a student takes one three-hour laboratory session and three lectures of approximately one hour each during a week. Justifications for laboratory instruction in biology are deeply rooted in scientific methodology and in educational psychology. Pickering (1980) and Gardner (1979) argue that the student must experience firsthand the spirit and processes of science rather than be told passively about science concepts and processes. Bruner (1969) makes a psychological case for discovery learning in science strong enough to have had a significant impact upon the development of public school science curricula of the 1960s. Among the best known of these curricula were a number of widely adopted programs for high school biology generated by the Biological Sciences Curriculum Study (BSCS) under funding by the National Science Foundation. Resulting BSCS textbooks contained, among other innovations, a strong laboratory component, and were accompanied by resources for discovery and inquiry-based teaching strategies (Schwab 1963; BSCS 1978).

But how is laboratory instruction to be carried out? Are there accepted and proven methodologies for laboratory instruction in biology? As with so many questions in science education, there appear to be no definitive answers either qualitatively or quantitatively.

The BSCS movement has had little lasting direct effect upon biology curricula and instruction at the university level.

The use of BSCS curricula in secondary schools was widespread from the middle 1960s to the middle 1970s, but there has been a gradual decline ever since (Mayer 1978). Among the reasons given for failure of BSCS materials to maintain a strong hold in secondary science are a lack of convincing research support (Saadeh 1973), a significant decline in NSF funding for teacher training in and further development of BSCS-style instruction, and a more conservative political and educational climate, seen in an emphasis on "back to the basics" (Hurd 1979).

The BSCS movement has had little lasting direct effect upon biology curricula and instruction at the university level (Shulman and Tamir 1973; Humphreys 1978). No specific BSCS materials were ever developed for post-secondary biology courses. There are some cases of indirect influence where BSCS-style strategies are used as part of the traditional lecture/laboratory format or with an individualized approach (Tamir 1978; Postlethwait 1977; Leonard 1980; Manteuffel and Laetsch 1981). However, there appear to be no reports in the science education research literature of studies testing laboratory approaches based upon the BSCS model at the university level. The purpose of the research reported here was to test experimentally the effects of a BSCS-style laboratory program in a university general biology course against a popular traditionally oriented program.

The Experiment

The sample in this study consisted of 24 laboratory sections with an average of 20 students in each section of General Biology at a large mid-western university for which there were no entrance requirements except graduation from high school. This course is representative of many university-level introductory biology courses in that it is at the freshman level and satisfies part of the natural science requirement for graduation, yet is an entry course for majors in biology, health, agriculture, and other related biological sciences. It enrolls large numbers of students (approximately 10% of the student body annually) and represents an extremely heterogeneous population of university students. Laboratory classes were randomly sorted into experimental (BSCS) and comparison (traditional) treatments. General Biology students participated in one laboratory activity for each of 13 weeks of the semester taught by instructors who were advanced biology majors or graduate students. Each instructor taught at least one experimental and one comparison class.

Laboratory instructors were not specifically trained in BSCS philosophy or methodology. However, each week a one-hour meeting was held between the instructors and investigator to review the laboratory activities for the next week. At that time, expectations for their instruction regarding both laboratory programs were carefully defined.

The experimental treatment consisted of laboratory investigations based upon the BSCS model. This new program was prepared to create an alternative to a perceived lack of commercially available programs for university general biology which were less prescriptive, were inquiry oriented, and which engaged students in science processes. In developing the new program, emphasis was placed upon: 1) extensive use of science processes, especially hypothesizing, planning an experiment, manipulating and controlling variables, collecting and organizing data, and inferring from data; 2) a systematic development of biology concepts by the use of extensive questioning; 3) considerable responsibility on the part of the student for exercising discretion in selecting procedural options and in the use of resources at hand. Many of the experimental investigations were adapted from those in the 4th edition of The BSCS Green Version (BSCS 1978). Examples of such activities from BSCS Green Version are Investigations 4.3: Diversity of Animals; 5.2: Primitive Characteristics; 8.2: Biomes; 11.2: Diffusion; and 12.4: Biochemical Reactions. All laboratory activities adapted from BSCS Green Version were rewritten for the university level and for an approximate 2½-hour laboratory period. In addition, some additional activities were created, but every attempt was made to have them conform to the BSCS methodology. The resulting BSCS-style laboratory program consisted of 13 three-hour investigations to develop laboratory skills and concepts in microscopic techniques, cell structure and function, cell transport, metabolism, genetics, and science processes and can be found in its entirety in Leonard (1980).

Table 1 is a summarized comparison of the format and activities of the student between one of the experimental BSCS-style investigations and its corresponding comparison investigation. In both cases, the

A group of General Biology students at the University of Nebraska working on a BSCS-style laboratory investigation of plant starch production.

TABLE 1. Summary of Comparison of Format and Activities

Comparison Investigation on Cellular Respiration	*BSCS-Style Investigation on Cellular Respiration*
1. Introduction: 720-word discussion of the significance of respiration.	1. Introduction: 380-word discussion of the importance, reactions, and evidence of cellular respiration.
2. Directions for setup and data collection (352 words) and four illustrations.	2. Objectives: Five statements indicating behavioral outcomes from the investigation.
3. Collect data on table given.	3. Setup information (280 words) with two illustrations.
4. Graph results on graph given.	4. Six questions, asking the student to identify the independent and dependent variables, to state a hypothesis, to identify the experimental controls, and to select variables to be manipulated.
5. Questions: Three questions about the physical setup.	5. Collect data on table given.
6. References: Related written materials available.	6. Graph results on graph given.
	7. Three follow-up questions asking student to examine graph and accept or reject hypothesis, to summarize experiment, and to state generalizations learned about respiration rate.

general purpose of the investigations is for the students to find the effects of environmental temperature upon the respiration rate of germinating pea seedlings.

It is important to note that, in addition to the differences listed, the comparison investigation did not require the student to do anything after the data were collected. I believe that the three most salient differences between this pair of investigations are that the BSCS investigation: 1) has significantly less direction; 2) has students participate more in science processes; and 3) guides students more into concept formation following their data collections.

The comparison treatment consisted of 13 laboratory exercises selected from the Freeman Separates (Abramoff and Thomson 1972) which matched conceptually but not methodologically each of the 13 experimental investigations. The Freeman program was selected as a comparison treatment for three reasons: 1) it was a well-established, successful, and widely used commercial program; 2) it was judged to be considerably more directive (traditional) and less inquiry-oriented than a BSCS-style approach; and 3) it had been used for the past several years with the population under study here.

The matched investigations were run the same week but in different rooms during the spring semester 1980. During the semester all students attended one of three lecture sections three times each week. The lecture material was the same for all sections even though the three sections were taught by different faculty members. There were nearly equal proportions of students from experimental and comparison laboratory treatments in each lecture section.

The criterion measure was a 60-question multiple-choice test designed around six concept areas of laboratory skills and instruction. The exam was intended to measure both science processes and concepts common to both laboratory programs. The multiple-choice format (five possible choices per item) was adopted so that data could be easily quantified and so that scoring could be as objective and consistent as possible. The test was given the prior semester to a different group of students and subsequently underwent both content face validity and statistical item analysis. The final version had an internal reliability of .66 using the Kuder-Richardson 20 formula. This test was given to students in this study as a pretest at the beginning of the semester to check for equivalency between experimental and comparison groups. The pretest scores for experimental and comparison groups were 20.72 and 20.50, respectively (t-value of .49, probability $>.30$). Thus, the two groups were considered to have equivalent knowledge of these biological concepts at the beginning of the study.

The same exam was given as a post-test after 13 weeks of laboratory instruction. Post-test results and statistical analysis for each of the concept areas tested for are shown in table 2. Differences were significant in favor of the experimental group for all concept areas except for the use of the microscope. Overall test scores were also significantly higher in the experimental group ($t=7.51$, probability $< .005$).

Student reaction to less instructor direction was not particularly noticeable. Laboratory instructors reported no perceptible differences in reaction or attitudes between students using the different approaches. The in-

TABLE 2. Data and Analysis for Concept Areas of a Laboratory Post-test

	Instructional Approach					
	BSCS-Style		*Traditional*			
	N=210		*N=218*			
Concept Area	$\overline{X}$	*SD*	$\overline{X}$	*SD*	*t-value*	*Probability*
Microscopic Technique	5.36	1.31	5.31	1.26	1.04	>.60
Cell Structure and Function	3.43	1.27	2.83	1.42	9.18	<.005
Cell Transport	3.74	1.44	3.12	1.34	8.95	<.005
Metabolism	7.21	2.33	6.60	2.42	5.34	<.005
Growth	7.14	2.56	6.61	2.40	4.37	<.005
Genetics	5.43	2.10	4.69	1.96	5.70	<.005
Science Processes	7.09	2.26	6.66	2.32	3.99	<.005
Overall	39.40	9.35	36.04	9.24	7.51	<.005

structors believed the students to perceive that whichever approach was taken set the expectation for the laboratory work. According to the laboratory instructors, students appeared to be very accepting in general of both methodological approach and performance expectations in the laboratory, providing these parameters were communicated to the students early in the semester. In reality, since the vast majority of these students were taking their first university laboratory course, they had no other approach (other than that experienced in high school) with which to compare their activities during this experiment.

Inferences and Applications for Teaching

A BSCS-style laboratory approach for university general biology was tested against a popular commercial program judged to be highly prescriptive under closely controlled experimental conditions for a field-based educational study. Equivalent groups of students participated in laboratory exercises using one of the two approaches for nearly a full semester in a typical university setting. Although learning gains for both the BSCS-style and prescriptive approaches were significant, students using the BSCS-style investigations scored, on the average, significantly higher on a post-test of laboratory concepts common to both approaches than did students using a more prescriptive and traditional approach.

One of the questions arising out of any educational experiment finding statistically significant differences between learning approaches is if those differences are actually educationally significant. In other words, are learning differences great enough to consider employing one approach over the other? One way to view this question is to compute how much difference a given approach would make over another in an assessment of student performance such as a letter grade. In this case, if the post-test were used to determine the student letter grade and an instructor were to grade all students on an absolute percentage system (such as 90-100=A, 80-89=B, etc.), the students using the BSCS-style laboratory approach would have an average score of 66% whereas the students using the prescriptive approach would have an average grade of 60%. Whether grading is based on a criterion standard, a percentage of the highest score, or upon a standard curve, students using the BSCS-style laboratory approach would earn on the average approximately one-half grade higher. This difference would be significant to any student.

The fact that there were no significant differences between groups on the post-test for microscope skills may indicate that a general inquiry approach is not any more productive than a directive approach for the learning of laboratory techniques or manipulative skills. These results do indicate that an inquiry or less directive approach is more productive for learning laboratory concepts and science processes. Based upon this study, it is recommended that laboratory learning approaches characterized as inquiry, problem solving, investigative, discovery, indirect, or discretionary be seriously considered for university general biology. If you use such an approach you will want to present the student with the following:

1. A well-identified problem and just enough guidance and information to attack the problem.

2. A "wet" lab environment with objects to manipulate and measure.

3. Opportunity to utilize science processes.

4. A systematic attempt to develop concepts via questions based upon data collected.

Due to the large sizes and heterogeneity of the samples in this study, these results should be generalizable to introductory biology laboratory programs at most large universities. It is possible that the experimental approach used here would also be applicable to other university laboratory subjects and to secondary science courses.

There is an obvious lack of BSCS-style biology programs at the university level and especially among introductory principles of biology courses. It is the observation of this investigator, based upon examination of existing commercial materials for university general biology, that development of laboratory curricula away from overly directive and factually oriented learning, and toward that of guided inquiry to develop biological themes and process skills, is far behind that available for secondary school biology. Yet historically there has been strong support of BSCS efforts by university biologists and educators. It is encouraging, however, that a laboratory approach philosophically similar to BSCS is shown experimentally to be promising.

Recognized goals in science education include developing critical thinking and independence in learning. It is argued that a laboratory learning approach such as the one tested here is consistent with the nature and spirit of scientific inquiry. If it is important for students to develop scientific inquiry skills, provisions must be made for students to earnestly engage in these activities as opposed to merely following directions and filling in blanks on a paper. It appears that the BSCS-style approach used here would foster the development of these skills. It is recommended that university biology faculty involve students in inquiry laboratory learning whenever possible.

Given that the laboratory will continue to be an integral component in biology instruction, it is desirable to identify variables contributing to successful laboratory instruction. Continued research similar to the study described here should be conducted in other biology laboratory settings. Instructors of biology are encouraged to develop and evaluate further attempts to engage students in productive laboratory learning.

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