A Survey of Introductory Biology Laboratory Manuals for Content and Experimental Inquiry

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Introduction

A laboratory experience in the sciences can serve to: teach or reinforce concepts, learn techniques, develop inquiry skills, and convey how science is carried out. The techniques and concepts employed in the lab will depend on the subject matter, whereas inquiry and general scientific understanding do not. The latter two educational goals are interrelated; inquiry is an integral part of the methodology of science. Recent investigations on pre-college science curricula (6) and secondary laboratory handbooks in science (5) have detailed the role of inquiry. Essays by Mills (2) and Postlethwait (4) have focused attention on this goal in college biology courses.

Reports on the subject matter of introductory biology laboratory exercises and the extent to which scientific experimentation is used as a vehicle to convey scientific inquiry are sparse. As a means of assessing the direction taken in laboratory education for college biology courses, we have conducted a survey of published laboratory manuals to 1) identify the major topics emphasized and 2) ascertain the degree to which experimentation is utilized.

Sample

Twenty published laboratory manuals, organized to complement an independent course in introductory biology, were chosen for review (see Appendix). In order to make meaningful comparisons, manuals designed expressly for non-majors were not considered. The manuals sampled have all been published between 1977 and 1982 and represent authorship from three junior colleges, five colleges and, twelve universities. It is reasonable to assume that by virture of being published, the exercises have been well thought out, tested in the laboratory, and are actively used. No conscious effort was made to select manuals based on content or style. Although the manuals were evalutated individually, the data were analyzed collectively and judgements were not made on any one manual.

Method of Survey

The manuals designed for one-term and two-term courses in biology were analyzed separately for content, but not for inquiry. Since the organization of manuals varies widely, no one system of subdividing the discipline would satisfy all manuals. Therefore, a hierarchial division of biology was chosen for convenience, and any given laboratory unit could be listed in more than one topic. This scheme allows generalizations to be made about content without detailing endless minor differences between manuals.

Six major areas, twenty-one topics, and thirty-six subtopics were identified. Many additional subtopics could be listed, but this set has the distinction of being easily definable and readily comparable from manual to manual. No attempt was made to objectively measure depth of coverage within topics or subtopics.

The level of scientific inquiry, as reflected by experimental analysis, was classified into one of three categories:

1. conceptual or informational experience;
2. data manipulation and interpretation exercise; and
3. student designed experimental analysis.

Category one situations consist of well outlined procedures for students to follow and would include, among other things, demonstrations, dissections, and observations of cell types or representative organisms from different phylogenetic groups. Category two is characterized by student involvement in a planned experiment which must be interpreted utilizing gathered data. Category three is defined as a student formulated experimental design that is carried out to its conclusion. This scheme is not intended to measure components of higher order thought, such as the need to conceptualize, synthesize, or use abstract reasoning. Rather, the focus is on the application of the scientific method by the student. This subsumes higher order thinking to a lesser degree in level two and to a higher degree in level three. Level one may or may not entail higher levels of thought, but is distinguished by the fact that the student is not expected to conduct an experiment and gather data.

Results

Table 1 provides a breakdown of the discipline into six major areas within which topics and subtopics are listed. In general, topics occur more frequently in two-term manuals with the exception of those in the cellular/molecular biology area but, both sets of manuals show a similar hierarchial type of organization.

Heavy emphasis is given to proper use of the microscope in most manuals with greater detail provided in most two-term manuals. No other instrumenta-

TABLE 1. *Coverage of topics in published lab manuals designed for one or two-terms of majors biology*

Major Area / Topic / Subtopic	Percent of Manuals	
	One-Term	Two-Term
Cellular/Molecular Biology		
Use of Microscope	83	79
Magnification/ Measurement	50	64
Slide Preparation	50	100
Dissecting Scope	0	43
Oil Immersion	0	14
Biochemical Analysis	100	57
Carbohydrates	100	57
Lipids	67	50
Protein/Amino Acids	100	50
Nucleic Acid	0	21
Enzyme Analysis	67	71
Simple Kinetics	33	57
Parameters Affecting Activity	50	71
Cell Biology	100	100
Plant/Animal Structure	100	100
Diffusion	67	100
Osmosis	83	100
Active Transport	17	29
Organismal Biology		
Metabolism	67	93
Aerobic Respiration	17	79
Anaerobic Respiration	67	57

TABLE 1.—Continued

Major Area / Topic / Subtopic	Percent of Manuals One-Term	Two-Term
Vertebrate Anatomy	67	100
Digestive System	67	86
Respiratory System	17	71
Nervous System	17	71
Circulatory System	50	100
Skeletal System	17	64
Muscular System	17	43
Excretory/Reproductive	50	79
Vertebrate Physiology	50	79
Human Senses	50	64
Stimulation	0	36
Behavior	33	43
Taxis	17	36
Vertebrate Observation	17	36
Invertebrate Observation	17	29
Embryology/Development	67	93
Cell Division/Genetics		
Mitosis/Meiosis	83	100
Genetics	100	93
Human Genetics	67	79
Mendelian Problems	100	79
Drosophila	17	57
Population	33	29
Botany		
Plant Structure	100	100
Photosynthesis	100	100
Isolate Pigments	100	86
Physiology	17	71
Growth	67	57
Diversity		
Animal Survey	33	100
Plant/Fungi Survey	50	100
Bacteriology	50	86
Use of Dichotomous Key	17	29
Ecology/Population Biology/Evolution		
Ecology	50	79
Outdoor Experience	17	50
Monitor Population	17	50
Ecosystem Modeling	17	14
Evolution	17	21

tion is so consistently designated for special explanation. Biochemical testing is not as commonly incorporated in two-term manuals as compared to one-term manuals, but this difference maybe is due to the greater liklihood that such methods would be included within the context of some other topic. For example, a glucose determination or analysis of starch breakdown might be found in an exercise on digestion. No doubt the bias toward certain biomolecules, is based on a conscious choice that certain methods are more amenable to laboratory exercises than others. The central role that enzymes play in coordinating rate of reactions, and therefore living processes, is reflected in the pervasive application of enzyme analyses in the two sets of manuals.

Universal inclusion of cellular observation is not surprising since cells are fundamental units of life, wet mounts are easy to make, and prepared slide collections are available in most institutions. Similarly, diffusion and osmosis concepts are deemed important, while being simple and cost-effective to perform in the laboratory. However, experiments on active transport are much less commonly included. Usually the experiment suggested is the effect of congo red dye on live and dead yeast cells.

Aerobic metabolism experiments can be tested with plants (two manuals), animals (two manuals), or both (seven manuals), while experiments in anaerobic metabolism typically utilize yeast. Experiments from one-term texts tended to do either an anaerobic or aerobic exercise, but not both.

The frog and fetal pig are used with equal frequency for vertebrate dissection. Among the biological systems, circulation and musculature are the most and least commonly dissected, respectively. Selection of organ systems can be influenced by the choice of organism. The respiratory, excretory, and reproductive systems are more often analyzed if the fetal pig is used, whereas the skeletal, muscular and nervous systems are more typical of frog dissections. The investigation of the digestive and circulatory systems was apparently not biased by the choice of specimens.

With the exception of aerobic metabolism exercises, vertebrate physiology exercises receive less emphasis than vertebrate anatomy. Physiological processes, when included, often entailed a study of human senses. More sophisticated experiments, such as electrical stimulation of muscle tissue, are the rare exception. Here again, there is a tendency to use simple, inexpensive exercises which necessitate a modicum of equipment.

Embryology is incorporated into all but two manuals. Inclusion of more than one type of organism is common; three manuals use three organisms each and eight use two, yet only two manuals have the same combination of specimens. The number of manuals using each type of specimen are; chick 10, frog 10, starfish 7, and sea urchin 4.

Both genetics and mitosis-meiosis labs are highly represented in our sample. Most commonly, genetics labs demonstrate human genetics traits and, to a lesser degree, utilize *Drosophila* exercises. Most exercises are supplemented with a heavy dose of Mendelian problems.

Plant structure and photosynthesis are found in every manual sampled. However, physiological processes other than photosynthesis do not receive the attention afforded structure.

Phylogenetic surveys of either plants or animals are extremely diverse in depth. On the one hand, one-term manuals may demonstrate one or two organisms from each phyla, on the other hand two-term manuals often devote one whole unit to a single phylum. Of the two-term manuals, 12 of 14 recommend invertebrate dissections. Among this group, dissections of the earthworm, crayfish, clam, starfish and grasshopper are each suggested in 67% or more of the manuals. Other dissections, such as *Ascaris* (30%) and the squid (9%), were also recommended as well as a diverse group of chordate dissections (other than the frog and fetal pig) including the bird, shark, eel, rat, and *Amphioxus*. Plant diversity and plant reproduction are generally intertwined so that a unit bearing either title often serves as the vehicle to teach the other. For the purposes of this survey, both are listed under plant diversity.

Table 2 compares biological topics with respect to the level of independence required by students when performing experiments. The percentages listed are computed from the set of manuals that included each topic. The topics are placed into three groupings according to the combined percentage of categories two and three, and ranked from highest to lowest. It is evident that data gathering and interpretation permeate most lab topics, but that student originated experimen-

TABLE 2. *Biological topics categorized for the level of student involvement in experimentation.*

Topic	Percent of Lab Manuals in each Category		
	1	2	3
Enzyme Analyses	13	80	7
Ecology	23	62	15
Plant Physiology/Growth	29	57	14
Metabolism	32	68	0
Behavior	38	50	12
Genetics	42	53	5
Biochemical Analyses	47	53	0
Photosynthesis	50	45	5
Cell Properties	55	40	5
Mitosis/Meiosis	85	15	0
Plant Structure	90	10	0
Vertebrate Physiology	94	6	0
Plant/Animal Surveys	100	0	0
Embryology/Development	100	0	0
Anatomy	100	0	0
Cell Structure	100	0	0
Evolution	100	0	0

tation is rare. Indeed, most of the category three experiments were clustered in three of the twenty manuals. Ford *et al.* (10) lists "challenges" at the end of many units, some of which fit category three; but, since these are relegated to optional status, they were not tabulated.

Discussion

When one-term and two-term manuals are compared, both place a high priority on broad coverage rather than emphasizing depth in a limited range of topics. This is supported by the fact that time constraints are much more severe for a course using a one-term manual, yet the reduction in the percent of lab manuals teaching most topics is small. Despite the fact that depth and organization vary considerably, 90% of the manuals included exercises on cell structure, use of the microscope, and biomolecules among two of the first three units and 60% concluded with exercises on ecology or population biology. This suggests a hierarchial scheme, although the sequence of topics between the beginning and the end is so variable as to preclude any trend. Except for the light microscope (and to a lesser degree a spectrophotometer), lab equipment necessary to complete most all exercises is minimal. Perhaps this is related to the predominance of exercises on structure (e.g. dissections) over those involving processes (e.g., organismal physiology).

The inquiry method of learning has been touted by educators for years (1). Welch et al. (6) defines inquiry as a way of thought in which "human beings seek information or understanding." They recognized scientific inquiry as a subset of general inquiry and designated three themes within this subset, one of which, "science process skills," comes closest to the categories two and three we have outlined. Their study of pre-college science education reaffirmed their view that scientific inquiry was needed in the classroom, but that the current state of affairs was less than desirable. An evaluation of secondary school laboratory handbooks using a scaling system comparable in goals to our own (5), resulted in strikingly similar findings. The findings reported that students are often expected to gather data and interpret results, but seldom are asked to "work according to their own design."

There is concern for scientific inquiry in college science courses as well, though the methods to tackle the problem are varied. Molls and Allen (3) have found that students in introductory biology display improvement in critical thinking ability and content knowledge when confronted with data to interpret. The students use short video tape presentations followed by planned, but non-directive discussions. Postlethwait (4) has opted for a multifaceted approach which includes, among other things, an extended research project, oral presentations, readings in journal articles, and written reports. Mills (2) reports his laboratory experiences in introductory biology in which he integrates student originated experiments throughout a two semester course. He argues persuasively that this method is highly motivating to students without limiting breadth, being expensive, or causing a severe drain on the instructor's time. He finds that 20% of laboratory time can feasible be spent on independent investigations. Although Table 2 cannot be translated into a distribution of laboratory time, our subjective opinion is that all manuals in the survey fall well below this level.

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Appendix

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Two-term manuals

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