A Survey and Comparison of Majors and Non-majors Introductory Biology Laboratory Manuals Emphasizing Content and Inquiry

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Introduction

Considerable recent attention has been focused on the role of non-majors science instruction within an overall college curriculum (5,6,15). Much of this concern relates to providing opportunities, within the framework of a college course, to engage in critical thinking. A logical corollary of this concern has been the role of the laboratory in non-majors science instruction. Within those introductory biology courses for non-biology majors that offer laboratories there are often the same conflicting goals that plague majors biology laboratory instruction. Specifically, these are the goals pertaining to breadth of coverage of biological topics, depth of content within each topic, and student involvement in the scientific method as they examine a particular topic.

The latter goal, that of student involvement in the scientific method, indicates that instruction in method (i.e., providing analytical tools) and not substance alone (i.e., providing factual data) should be a part of any introductory biology laboratory course. The recent literature abounds with advocates of the inquiry approach to laboratory instruction at both the secondary (1,3,16,17) and college level (2,8,12,14,18) as well as to courses that emphasize science as a dynamic process.

Fogle and Mould (4) recently surveyed twenty published general biology laboratory manuals for use in one- or two-term general biology courses for majors. They identified the major topics emphasized and determined the degree to which student involvement in experimentation existed for this series of manuals. As part of their studies Fogle and Mould concluded that while some of these manuals provided the student opportunities to generate and manipulate data, they rarely allowed them to become involved in original experimental design.

As a means of determining the current status of laboratories for non-majors biology instruction a similar survey study was conducted with seventy-five published laboratory manuals. These manuals represented the existing resources available for supporting majors, combined majors/non-majors, and non-majors introductory general biology laboratory courses. Within each of these three categories the survey 1) identifies the major topics included in the manuals and 2) estimates the level of possible student involvement in experimentation. Comparison between each user category, with regards to the above two parameters, is then possible.

Methods

Seventy-five general biology lab manuals were reviewed (listed in Appendix). These manuals represented an exhaustive collection (based on titles in Books in Print, 1982 edition) of published lab manuals designed for use in majors and non-majors biology courses of a one- or two-semester duration. Although each lab manual was evaluated individually, the data are analyzed holistically with no judgements being made on any one manual.

The seventy-five manuals were divided into three basic categories based on their

intended usage: 1) biology majors, 2) either biology majors or non-biology majors, and 3) non-biology majors. For analysis of content the biology majors category of forty manuals was further divided into one-term (15 manuals) and two-term (25 manuals) course lab manuals. For the inquiry analysis the majors lab manuals were considered as one group (40 manuals).

Since the organization of topics in lab manuals is somewhat arbitrary, there is no one consistent way of subdividing the possible topics in the biological sciences that would easily coincide with the organization of all of the published manuals. For reasons of comparison I chose to utilize the hierarchical division of biology utilized by Fogle and Mould (4). This system was flexible enough to permit listing a particular lab under more than one entry in the hierarchical list of topics. Six major areas, twenty-one topics, and thirty-six topics were identified. When evaluating a lab exercise it was not possible to indicate depth or breadth of coverage of that topic in this survey, merely whether present or not in the particular manual.

Assessment of the level of scientific inquiry based on analysis/evaluation of individual followed a similar pattern to that of Fogle and Mould (4). Each exercise was classified into one of three categories:

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

The first category includes observational kinds of experiences. Dissections and observation-demonstrations that follow a precise, step-by-step set of instructions would be included in this category. The second category includes data manipulation. Data collection, rearrangement, and analysis are included in his category. The third category includes experiences in which the student designs an experiment, conducts the experiment, collects data, analyzes the data, and makes conclusions based on data collected.

Fogle and Mould (4) point out that this scheme is not aimed at measuring "components of higher level thought" (e.g., need to conceptualize, synthesize, or use abstract reasoning) as one goes from category one to three-type exercises. Although this learning theory may correlate well with these types of exercises, the major goal has been to separate the exercises based on their level of student involvement. Category one has the student as observor, category two as participant, and category three as designer and participant.

Results

Table 1 shows the coverage of topics in each of the four categories of lab manuals analyzed. A number of generalizations concerning topical coverage were suggested or apparent after scanning these data and notes made while reviewing each lab manual. First, within the majors manuals, topics occur more frequently in two-term manuals than in one-term manuals. Second, topics in majors/non-majors manuals occur with similar frequency to topics in a two-term majors manual, with specific exceptions. Third, when a topic is covered in all categories of manuals the frequency of inclusion of subtopics of a more quantitative nature is highest among majors manuals and lowest among non-majors manuals. Fourth, certain topics in vertebrate anatomy and physiology occur most frequently in non-majors manuals. Fifth, majors and majors/non-majors manuals usually follow the hierarchical scheme of topics as listed in Table 1; non-majors manuals are quite unpredictable in the arrangement of topics within a manual.

The Cellular/Molecular Biology area is generally well represented in all types of manuals. This is probably owing to the preception of many of these topics as examples

TABLE 1. *Coverage of Topics in Published Lab Manuals*

Major Area / Topic / Subtopic	Percent of Manuals Covering Topic			
	Majors		Majors/Non-Majors	Non-Majors
	One-Term (15)	Two-Term (25)	(20)	(15)
Cellular/Molecular Biology				
Use of Microscope	87	77	85	93
Magnification/Measurement	53	72	55	33
Slide Preparation	60	98	95	40
Dissecting Scope	8	48	60	40
Oil Immersion	15	21	10	7
Biochemical Analysis	95	75	60	73
Carbohydrates	95	38	60	20
Lipids	78	30	35	13
Protein/Amino Acids	95	36	35	13
Nucleic Acid	8	24	30	7
Enzyme Analysis	75	6	60	40
Simple Kinetics	42	49	15	0
Parameters Affecting Activity	56	85	65	27
Cell Biology	97	100	100	100
Plant/Animal Structure	100	100	100	100
Diffusion	62	88	90	93
Osmosis	81	88	95	87
Active Transport	26	36	35	13
Organismal Biology				
Metabolism	79	84	80	93
Aerobic Respiration	19	62	65	40
Anaerobic Respiration	72	76	75	93
Vertebrate Anatomy	69	100	100	100
Digestive System	74	94	95	93
Respiratory System	26	79	95	93
Nervous System	22	70	80	87
Circulatory System	61	88	95	93
Skeletal System	14	44	75	87
Muscular System	16	52	60	93
Vertebrate Physiology	58	88	95	93
Human Senses	42	52	50	93
Stimulation	6	44	45	13
Behavior	45	52	65	67
Taxis	26	41	20	53
Vertebrate Observation	21	52	55	53
Invertebrate Observation	28	30	15	40
Embryology/Development	79	96	100	93
Cell Division/Genetics				
Mitosis/Meiosis	95	100	100	100
Gentics	100	94	100	100
Human Genetics	55	86	85	93
Mendelian Genetics	84	75	50	67
Drosophila	15	43	45	27
Population	39	34	30	40
Botany				
Plant Structure	98	100	95	67
Photosynthesis	100	100	100	87
Isolate Pigments	94	98	90	67
Physiology	26	68	80	53
Growth	52	66	40	47
Diversity				
Animal Survey	44	92	75	47
Plant/Fungi Survey	40	94	75	20
Bateriology	40	80	60	40
Use of Dichotomous Key	24	36	25	20

TABLE 1.—Continued

Major Area / Topic / Subtopic	Percent of Manuals Covering Topic			
	Majors		Majors/Non-Majors	Non-Majors
	One-Term (15)	Two-Term (25)	(20)	(15)
Ecology/Population Biology/Evolution				
Ecology	58	76	90	93
Outdoor Experience	14	62	45	75
Monitor Population	40	68	55	20
Ecosystem Modeling	20	36	5	7
Evolution	24	28	30	20

of extremely basic or fundamental biological principles. The compound microscope, being a very basic biological tool and its use was explained in varying detail in almost all lab manuals. Related microscopic skills like slide preparation and use of the oil immersion lense were more frequent in majors or majors/non-majors manuals than non-majors manuals.

Biochemical analysis also was routinely included in most lab manuals. While some sort of biochemical exercise was present across-the-board the specificity varied greatly. One-term majors emphasized specific biomolecules, two-term majors decreased this specificity; combined majors/non-majors maintained the decreased specificity, and the non-majors had very few molecule specific exercises. Fogle and Mould (4) explained the decrease in specificity observed in going from one-term to two-term majors labs by suggesting a greater likelihood that such topics were included in the context of another topic in the two-term manual. I did not observe this during my analysis of these lab manuals. The choice to become less specific in biochemical coverage decreased despite increased space (pagination) is indeed difficult to explain.

Enzymes, with their very important role in living systems, were routinely included topics in majors or combined lab manuals. They were less frequently included (40%) in non-majors manuals. The quantitative or semi-quantitative sub-topics were covered with decreasing frequency as one went from majors to non-majors lab manuals.

Basic animal and plant cell structure were uniform components of almost all manuals. Diffusion and osmosis were also routinely treated. The topic active transport was rarely included, with non-majors manuals being least likely to include this particular subject.

Metabolism is usually included in majors or combined-use lab manuals; it is less likely to be included in non-majors manuals. When the topic is included, anaerobic respiraton, using yeast, is almost always part of the exercise. Aerobic respiration is less likely to be included. This is especially noticeable in the non-majors manuals.

Vertebrate anatomy, involving the dissection of either pig, frog or rat, were routinely included in all manuals. Exercises involving individual systems were least likely included in majors one-term manuals, and most likely to be found in non-majors manuals. While the selection of organ systems can often be influenced by the choice of organism (4), this was almost never the case in the non-majors manuals. All body systems were covered by use of a particular organ from another vertebrate, microscope slides, or in-text diagrams with few exceptions.

Vertebrate physiology was routinely and almost exclusively included for the non-majors by use of a lab on human senses. The physiology exercises in the other three

categories utilized a human senses lab and often added an exercise on electrical stimulation of the muscle.

Behavior exercises were included in all manuals about half the time. The non-majors manuals showed the greatest frequency of inclusion of each of the three behavior subtopics.

Embryology/Development was included in almost all manuals. Wtih rare exception this included a study of one or two organisms (frog, chick, starfish, or sea urchin) early stages of development. The non-majors manuals usually included (75% of the time) a section on human development. This topic was not usually covered in the other two categories of manuals.

Mitosis and Meiosis were included in almost all manuals and generally consisted of examining prepared microscope slides (onion root tip and whitefish blastula) for the former and model-making for the latter. Occasionally the models were supplemented with prepared microscope slides of meiosis in the grasshopper testis. A genetics lab or two is included in almost all manuals. A human traits exercise is almost always included, as well as an additional Mendelian exercise (often using *Drosophila* for major or combined, corn for non-majors). The inclusion of a number of Mendelian Genetics problems is high amongst majors and combined manuals and very low among non-majors manuals.

Most of the botanical topics are included with less frequency (especially plant structure) amongst the non-majors manuals. The basic process of photosynthesis is most regularly included in all manuals.

Surveys of organismal diversity are included less than half the time in non-majors manuals. If included, they usually deal with a few representatives of the animal kingdom. Often bacteria and their role in human life is a featured exercise. The more traditional survey exercises, in tremendously varying depth and numbers of exercises, are usually included in majors and combined manuals.

Ecology exercises were included more frequently as one moved from majors to non-majors labs, while evolution was not usually included in any of the manuals. The ecology exercises of a more quantitative nature (population monitoring and ecosystem modeling) were rarely used in the non-majors lab manuals.

Table 2 compares biological topics with respect to the level of student involvement in experimentation. It should convey a sense of the level of independence required by students when completing a particular exercise. The percentages listed are computed from the manuals that included each particular topic. The topics are placed into three broad groupings based on the combined percentage of categories two and three, and ranked from highest to lowest. The majors lab manuals showed that many topics were confined to conceptual and informational experiences, while others facilitated data manipulation and interpretation. Student-designed experiments were, however, found in very few manuals, coming from only eight of the forty majors manuals surveyed and confirms earlier, similar conclusions (4).

Evaluation of the combined majors/non-majors manuals shows the incidence of category two and three-type student experience to be even further decreased. While some data manipulation and analysis is included, student-designed experiments are a rarity, occurring in only a few of the twenty combined-use lab manuals.

The trend suggested above becomes acute as the last group of lab manuals is evaluated in Table 2. The non-majors lab manuals evaluation shows that there is almost no category two or three experiences included. Almost all exercises provide for con-

TABLE 2. *Biological Topics Categorized for the Level of Student Involvement in Experimentation*

	Percent of Lab Manuals Found in Each Category								
	Majors (40)			Majors/Non-Majors (20)			Non-Majors (15)		
TOPIC	1	2	3	1	2	3	1	2	3
Enzyme Analyses	10	80	10	25	70	5	93	0	7
Ecology	25	55	20	40	40	20	86	7	7
Plant Physiology/Growth	28	50	22	75	55	0	93	0	7
Metabolism	31	66	3	60	40	0	93	7	0
Behavior	44	41	15	65	30	5	93	0	7
Genetics	47	50	3	65	35	10	93	0	7
Biochemical Analyses	50	50	0	55	40	5	86	7	7
Photosynthesis	56	41	3	80	15	5	87	0	13
Cell Properties	66	31	3	75	20	5	93	0	7
Mitosis/Meiosis	82	18	0	100	0	0	93	0	7
Plant Structure	87	13	0	95	5	0	93	7	0
Vertebrate Physiology	87	13	0	95	5	0	93	7	0
Plant/Animal Surveys	100	0	0	100	0	0	100	0	0
Embryology/Development	100	0	0	95	5	0	100	0	0
Anatomy	100	0	0	100	0	0	100	0	0
Cell Structure	100	0	0	100	0	0	100	0	0
Evolution	100	0	0	100	0	0	100	0	0

ceptual or informational experiences. Two manuals of the fifteen examined provide some data manipulation or student-designed experimental analysis for some topics.

Discussion

Analysis of breadth of coverage between one-term and two-term majors manuals confirmed an earlier conclusion (4): Despite shorter time periods (one-term) few topics were sacrificed. The depth of coverage differs, but very few manuals exclude a topic simply because they were designed for one-term use. Those manuals designated for use in majors or non-majors courses show a small but noticeable decrease in topics covered from the major's more comprehensive list. These include biochemical analysis (and certain specific analyses), enzyme analysis, and organismal diversity. They further show a trend for inclusion of a slightly higher rate (than an major's manuals) of the following topics: Some aspects of vertebrate anatomy, vertebrate physiology, behavior and ecology. This trend is further exemplified by the non-majors lab manuals where there is a substantial decrease, as compared to major's manuals, in the appearance of these topics: Some aspects related to use of the microscope, various biochemical analyses, enzyme analysis, botany, and diversity. Concomitant with this decrease in topic emphasis is substantially increased emphasis on these topics: Most aspects of vertebrate anatomy, vertebrate physiology, behavior, and ecology.

A careful analysis of the decreasing and increasing emphases in the non-majors lab manuals, that takes into account the changes in subtopic coverage, lead me to the following comments: 1) Non-majors biology courses often emphasize human biology and their laboratories might be expected to de-emphasize botany and organismal diversity-related topics; 2) Non-majors biology laboratory manuals avoid traditionally specialized or semi-quantitative/quantitative topics that might require basic computational skills. These reasons might explain the decided differences in topic coverage noted between majors and non-majors lab manuals.

The desirable role of utilizing inquiry methods in biology or other science lab instruction has been clearly stated by many authors (2,3,5,6,8,9,10,11,12,13,14,16,17,18). Kennedy and Hickman (7) stated the recent advocacy of inquiry clearly:

> Students should have experience in seeking knowledge in the same way that research scientists do. Science should not be taught as a rhetoric of conclusion but as a dynamic process of asking questions and seeking answers. Students should investigate real questions; they should not simply demonstrate the verity of principles already established. They should become skilled in using the tools of the scientist: hypothesis, experimental designs (controls and variables), and methods and protocols of data collection, analysis and interpretation.

Despite the fact that some authors question the transferability of problem-solving skills attained by students through the use of inquiry-based methods of instruction (reviewed in 17), the vast majority of authors still favor this mode of instruction for improved laboratory instruction. They further indicate that future studies will eventually show evidence of gains in reasoning and general problem-solving ability following use of discipline-specific inquiry methods of instruction (17).

While the current literature abounds with suggestions for implementation of inquiry methods into general biology lab instruction (10,11,12,13), there is little evidence of its general adoption as evidenced by this survey of published lab manuals. Fogle and Mould (4) commented that all of the majors lab manuals surveyed by them fell well below an acceptable level (i.e., 20% of lab time) for independent student investigations. This meager level of inquiry is further reduced in combined majors/non-majors manuals and is almost nonexistent in non-majors lab manuals. One can argue that this is the level of instruction where teaching problem-solving (as these inquiry methods are supposed to accomplish) is most needed (1,15). Unlike courses for the biology majors, where these sorts of desirable skills can be achieved in a series of courses/experiences in following the introductory general biology course, it is often the only opportunity for science instruction in these students' college education.

Thus, it becomes apparent that most available published lab manuals cannot adequately support development of a general biology lab program, at any level, that is based on inquiry methods of instruction. To provide student-oriented independent investigation for general biology alternative sources of information will have to be sought or independently generated.

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