Modeling Teaching Strategies for Biology Laboratory Experiences

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Introduction

In order to develop an effective teaching scheme in the teaching laboratory we have found it necessary to first determine our teaching goals and then design laboratory exercises to fit these goals. We conducted surveys of laboratory manuals in the biological sciences (1,2) and found that often laboratory exercises maximized factual learning rather than meeting clearly defined teaching objectives. As science educators we believe development of scientific literacy among students should be a priority. Students should be given laboratory exercises that will help them develop scientific literacy. Our purpose is to model the relationship between scientific literacy and the laboratory experience.

Scientific Literacy

The term scientific literacy has been defined in various ways. We have chosen to use the description of Simpson and Anderson (3) which restates the dimensions of scientific literacy developed by Victor Showalter and his colleagues into objectives. This version facilitates linking the laboratory situation to an achievable objective. Simpson and Anderson designate that a scientifically literate person:

1) Has knowledge of the major concepts, principles, laws, and theories of science and applies these in appropriate ways.

2) Uses the processes of science in solving problems, making decisions, and other suitable ways.

3) Has developed science-related skills that enable him or her to function effectively in careers, leisure activities, and other roles.

4) Understands the nature of science and the scientific enterprise.

5) Has developed interests that will lead to a richer and more satisfying life and a life that will include science and life-long learning.

6) Understands the partnership of science and technology and its interaction with society.

7) Possesses attitudes and values that are in harmony with those of science and a free society.

Analysis of laboratory exercises enables the instructor to determine those objectives from Simpson and Anderson's list which apply. Often, individual exercises meet several objectives concurrently. For example, observations of cheek cells teaches cell structure (objective 1) and facility with a microscope (objective 3). More elaborate exercises can incorporate greater numbers of these objectives. For example, an experiment which involves chlorophyll extraction from spinach leaves, chromatographic separation of the pigments, and spectrophotometric determination of the absorption spectrum trains students to understand photosynthesis (objective 1), learn new techniques (objective 3) and interpret the data in a meaningful way (objective 2).

The Role of Experimentation

Exercises which have a pre-planned protocol primarily strive to fulfill objectives

1, 2, and 3 but fail to portray an accurate picture about the nature of science (objective 4). It is true that science involves lab techniques, data gathering, and interpretation, yet science is also a creative endeavor that moves through a series of steps that begin with a question and lead, ultimately, to a conclusion. Each step necessitates that choices be made, the success of the experiment depending on the ingenuity of the investigator. Cookbooked labs do not challenge the creative mind because the critical decisions, except for data analysis, are already made. Moreover, the experimental process as opposed to the cookbooked approach, more accurately depicts the events that lead scientists to establish an hypothesis as fact. By challenging the student to create an experimental design, the student develops the ability to process new information in their daily life (objectives 6 and 7).

Since experimentation is a critical adjunct for attaining scientific literacy, we need to look more closely at the dynamics of these processes. In order to address all components of scientific literacy an effective teaching laboratory needs to:

Identify those objectives being taught within an exercise.

Clarify the interactions between the desired objectives and the components of the experimental process.

The Model

Experiments are the mechanism through which new scientific information is generated and, therefore, all seven objectives flow directly or indirectly from it (Figure 1). An understanding of the nature of science and a meaningful appreciation (interest) in science stems from knowing what scientists do and how they do it. Consequently, these objectives fit within a hierarchial scheme in which understanding of the experimental process is an important prior step. In other words, one must understand how science works before one can fully appreciate its meaning and, in turn, apply that knowledge. The application of science (objectives 6 and 7) hinges on the ability to assemble facts within the context of making decisions that involve values and society. It is hard to imagine someone who is truly insightful about science and feels comfortable in applying scientific information, who is unfamiliar with the experimental process. Indeed a major problem in society today lies in the difficulty of conveying scientific information to a scientifically illiterate public.

Individually, objectives 1, 2, and 3 are not dependent on each other or the experimental process. It is typical of science courses to teach concepts, experimental techniques, and to include word problems independent of the laboratory. However, hands-on experimentation integrates the necessary technical skills, cognitive abilities, and knowledge in a unique way that synergistically helps achieve all of these objectives. By analyzing these three objectives within the experimental process, we will show how each is involved with an understanding of experimentation.

The objectives represented by boxes in Figure 2, are attained by input from various steps in the flow diagram of the experimental process. A student who completes the entire process (i.e. conducts an experiment of their own design) will have been challenged more than once for each objective and several objectives are involved in some steps. The rationale for each interaction between objective and experiment is given below:

Objective 1) The initial phase of experimentation, (1) definition of the problem and (2) formulation of an hypothesis, draws upon pre-existing knowledge. Satisfactory completion rests on the student having a clear understanding of the direction the experiment will take. Experimental design can not proceed until there is mastery of these two steps.

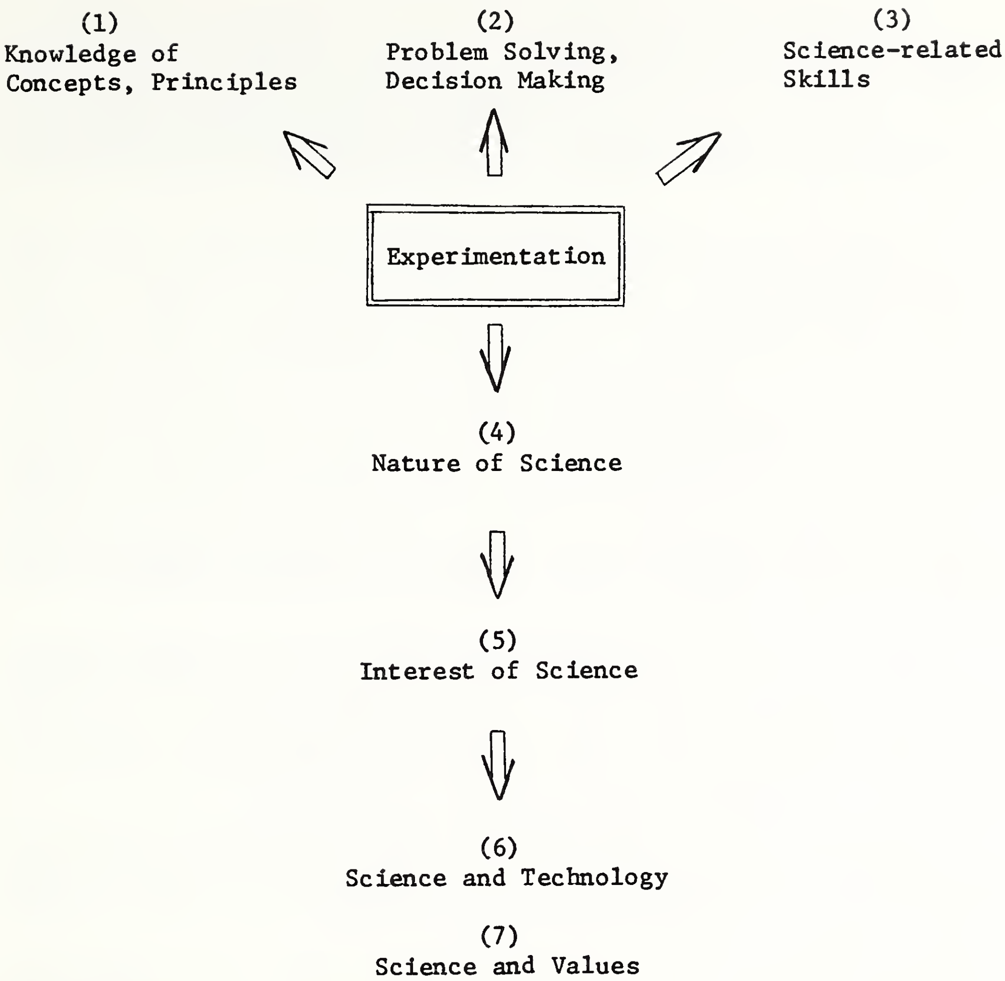

FIGURE 1. *Model depicting the relationship between experimentation in the teaching laboratory and Simpson and Anderson's seven objectives for scientific literacy.*

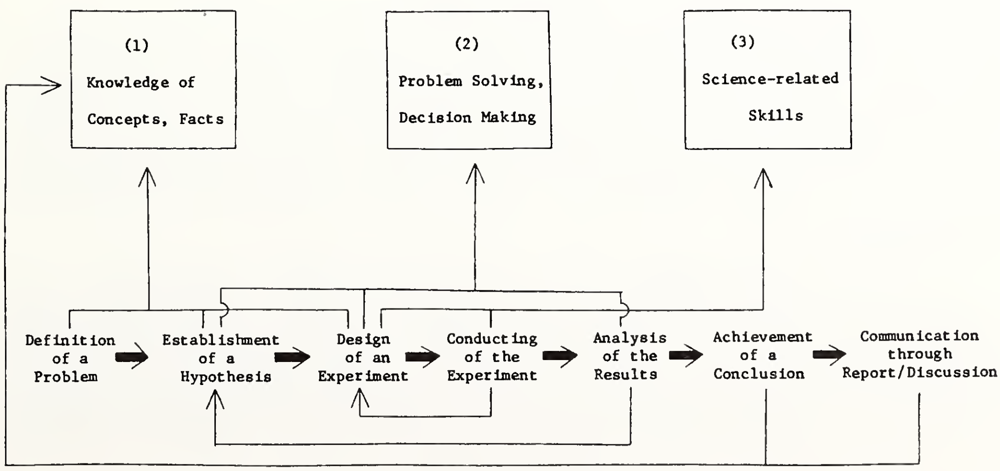

FIGURE 2. *Interaction between objectives 1, 2, and 3 and the stepwise experimental process.*

This objective also receives input in the form of a feedback loop from the conclusions. This signifies new information resulting from the outcome of the experiment. Because the loop flowing from knowledge back to knowledge is continuous, it is useful to have students propose a follow-up experiment that stems from their results and conclusions. This reinforces the idea that experimentation often leads to further experimentation.

Objective 2) This is the most difficult of these three objectives to attain and to teach. Typically, the weakest links in the experimental process lie in experimental design and data analysis. In both cases, a background in statistics and an ability to sort out variables become factors that limit success of beginning students. Lack of statistical expertise can be circumvented by emphasizing the need to carefully quantify observations, the value of including replication, and the importance of reaching objective decisions. Designing experiments to isolate variables can be a challenge to the veteran researcher, let alone the novice. Usually, students understand why this is important, but are often unaware of the vast array of circumstances that can influence biological processes. Most importantly, design and analysis of actual experiments is first hand experience that helps students to appreciate the influence of technical limitations, random variation, and human bias.

Objective 3) This is the capacity to utilize laboratory skills, particularly equipment, within the context of an experiment. It is an essential ability when conducting an experiment and for mapping out strategy for the design. Realization that technical problems can affect the success of an experiment encourages students to critique the strengths and weaknesses of their own plan.

Feedback loops within the flow diagram indicate that experiments sometimes need refinement before a meaningful conclusion can be drawn. Starting over can be frustrating for students and time consuming as well, but is a realistic component of the scientific method.

The final step in the flow diagram is important because scientific information is not useful unless it is communicated in some fashion. For the student, this may mean a data sheet, lab report, or class discussion. Students can achieve new insights and reinforcement via the act of writing and/or through the mutual exchange of ideas in discussion.

The Outcome

Attempts to teach the scientific method sometimes shortcuts the process by eliminating student-directed experimental design. Students begin by conducting the experiment and finish by drawing conclusions (and sometimes writing a report). Stunting the process eliminates involvement by the student in one of the most creative and important aspects of the experiment—the design. Further, the pre-planned experiment is so constraining that students never really sense the excitement of laboratory investigations.

The outcome of teaching science is, hopefully, a deeper understanding of the nature of science (objective 4) and indirectly objectives 5, 6 and 7. Direct experimentation is essential for developing scientific literacy. No one step in the experiment develops this understanding; rather all are mutually reinforcing. Students who have experienced the complete experimental process will be more sensitive to the creativity needed by a scientist, and the difficulties of interpretation.

Literature Cited

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