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THE INFLUENCE OF STRUCTURED VERSUS UNSTRUCTURED LABORATORY ON STUDENTS' UNDERSTANDING THE PROCESS OF SCIENCE

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Introduction

At the college level, laboratory teaching has long been considered an integral part of science instruction. There are indeed few introductory physics courses that do not incorporate some type of laboratory experience into their presentations. The instructional objectives for these laboratories may vary somewhat, but nearly all laboratories are intended to provide the student with experiences that will aid him in understanding the process of science as well as the content of science. The present study is concerned with the objective of understanding the process of science.

Instructional strategies in laboratory teaching may be separated into two categories: those that place emphasis on verification of physical principles, and those that require inquiry into or discovery of the various physical principles (Nedelsky, 1965). Both strategies emphasize the physical principles being taught, but they require differing student involvements. The first, called a structured laboratory, provides detailed procedures, while the second, called an unstructured laboratory, merely specifies the objective and leaves the procedures to the discretion of the student. Research concerning the merits of these two strategies has dealt with the usefulness of the strategies as methods of teaching concepts (Gunsch, 1972; Murphy, 1967; Tanner, 1969) as aids in the development from concrete- to formal-operational thinking (McKinnon & Renner, 1971), and as aids in changing attitudes towards science (Gunsch, 1972; Murphy, 1967). As of yet, however, no studies have attempted to contrast the two strategies with respect to their effectiveness in teaching an understanding of the process of science.

This question of the effectiveness of structured and unstructured laboratories has been raised with the increasing popularity of inquiry modes of teaching. It should be noted here, however, that we are dealing specifically with the use of inquiry modes to teach a process rather than a concept. Thus, we are asking whether a student who engages in some degree of scientific activity learns to better understand the process of science as a result of that activity. More specifically, we are asking whether the instructional structure of that activity will influence the

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degree of understanding of the process of science. We have limited ourselves to laboratory structures which are inherently inquiry based; that is, the structured laboratory is not "cookbook," but rather encourages the student to actively think about the procedure he has been given. The decision to limit this study to a comparison of structured versus unstructured laboratories leaves unanswered the broader question of whether laboratory involvement itself contributes to an understanding of the process of science.

If we assume that a student must, to some extent, engage in scientific inquiry in order to understand the nature of scientific inquiry, we then embrace the theoretical arguments by Bruner (1961). However, little guidance has been presented regarding the manner in which activities in scientific inquiry ought to be presented to the student. "Practice in inquiry, in trying to figure out things for oneself is indeed what is needed, but in what form?" (Bruner, 1961.) The arguments of Gagne (1963) suggest that some type of structure is important. Thus, he would expect that the students exposed to a structured laboratory would gain a better understanding of the process of science than those left to "rediscover the wheel." The intellectual model of Piaget also leads one to hypothesize that some structure must be provided for students. If the student cannot apply formal operations to his study of physics, he cannot be expected to devise and understand the process of science, a formal-operational procedure.

Research Design

The research design used in the study was the standard two-treatment design. The type of laboratory experience was the independent variable, and student scores on an inventory which measures the students' understanding of the process of science represented the dependent variable. The Welch Science Process Inventory Form D (SPI) (Welch, 1966b) was used to measure students' understanding of the process of science. Pre- and posttesting were included to control for the variables associated with past experience and maturation. Because the pretest score is generally responsible for the most variance in the posttest scores, it is the best possible measure of maturation in understanding the process of science. The variables that may be considered to contribute to this pretest score are reading ability, mental ability, past experience in science courses, knowledge in physics, and degree of intellectual development (Welch, 1966a). The pretest scores, major subject, year in college, lecture grade, and laboratory grade were all collected in an effort to control for past experience and intellectual maturation in science. These cannot, of course, be considered to be independent of one another.

The other variable of concern was the lecture presentation that accompanied the laboratory section. The students were exposed to one of four lecturers, each of whom differed in the degree to which they discussed the scientific process. While none of the lecturers were permitted to see the SPI before or during the study, different instructional procedures and content could contribute to variance in the SPI scores. Hence this variable was included in the study.

Considering now the independent variable, two types of laboratory involvement were provided. One strategy was the rather traditional format in which the student was provided instructions with which he attempts to verify principles presented in lecture. The second strategy was based on the inquiry model in which the student discovers or inquires into principles discussed in lectures. The experiments were written to conform to the design of structured and unstructured laboratory activities stated by Romey (1968).

Table I shows the basic steps of each type of laboratory experiment. The first two steps were identical for the two laboratory sections. The third step represented the major difference in the two strategies. In the structured situation, the students were given somewhat specific instructions on how to perform the experiment and treat the data, while in the unstructured

TABLE I

The Basic Steps in Each Laboratory Experience

	Structured Laboratory	Unstructured Laboratory
1.	Pose a problem before the class meeting.	Pose a problem before the class meeting.
2.	Inform students of equipment to be available.	Inform the students of equipment to be available.
3.	State a procedure to solve the problem.	Ask students to solve the problem.
4.	Require students to answer questions about the data.	Require students to draw conclusions from their data.
5.	Require students to generalize from their data and defend their generalizations.	

situation little or no instruction was given. For example, in an experiment about the gas laws, the student in the structured laboratory was told: "... To investigate more carefully this relation (between temperature and volume), place the syringe in water of at least three different temperatures, recording the temperature and volume of the gas." For the same experiment, the student in the unstructured laboratory was told: "Investigate the relation between temperature and volume." Thus, the student in the unstructured laboratory was free to investigate anything about the problem at hand in any way he desired. Both strategies asked students to collect data and draw conclusions or inferences from the data in a manner consistent with our knowledge of students in the concrete operational stage. However, students in the unstructured laboratory were asked to make their own decisions about how to take data, how much data to take, how to treat the data, how to interpret the results, how to present the results, etc.

The dependent variable, students' understanding of the process of science, was measured using the Science Process Inventory (SPI). This is a dichotomous rating scale requiring the respondent to agree or disagree with 135 statements concerning the process of science. Using the Kuder-Richardson formula, reliability of the instrument has been established as 0.86 for a sample size of 171 respondents. Validity has been established through both predictive and constructive measure (Welch & Pella, 1967). The inventory was tested using populations ranging from high school students to professional scientists. Thus, its suitability for college students is justified.

The SPI measures within the limitations of its reliability and validity the individual's understanding of the methods and processes by which scientific knowledge evolves. Factor analysis performed on the instrument has provided justification for the use of the total score as a measure of the individual's understanding of the process of science (Welch, 1973). However, the instrument was constructed by considering four major elements of the scientific enterprise as (1) Assumptions, (2) Activities, (3) Nature of Outcomes, and (4) Ethics and Goals (Welch, 1966). Each of these elements is divided into four to six smaller categories. Thus, a measure is obtained of the respondent's understanding of different elements of the process as well as the overall understanding represented by the total score.

The population chosen for study was comprised of the students in four lecture sections of Man's Physics World I during the spring semester, 1973. Ninety-six percent of these students were freshmen or sophomores, taking this course to fulfill a general science requirement in their curricula. The vast majority were majoring in fields such as elementary education, business administration, home economics, and the social sciences. Very few were working toward degrees in the physical or biological sciences. Results from earlier departmental studies show that over 90% of these students completed high school biology, but only 58% and 23% reported having completed high school chemistry and high school physics, respectively. For the majority of these students, their exposure to college science courses had been in either biology or geology. This is typical of the group of students called nonscience students by college instructors.

The study was performed using all sections of Man's Physical World I during the spring semester, 1973. Students were randomly assigned to the four lecture sections and optional laboratory sections using the computer assignment procedure at Kansas State University. The two different laboratory strategies were not specified in the course listings. The SPI was administered in the lecture sections as a pretest during the first week of the semester and as a posttest during the last week of the semester. Since some students were absent for either the pretest or posttest, and others failed to complete the form, about 50% of the students returned usuable data.

The data obtained was treated statistically using analysis of covariance. Student scores on the SPI were used as the dependent variable. In order to obtain a clear picture of any differences that might occur, a separate analysis of each component of the SPI was performed. Of the variables initially included in the study, the pretest score, laboratory grade, and lecture instructor were found to contribute substantially to the posttest score, and hence were retained as covariates. The adjusted posttest scores were finally compared as to type of laboratory involvement.

Results

The results of the study are shown in Table II. The adjusted scores indicate that no differences occurred in the components of Assumptions, Nature of Outcomes, and Ethics and Goals. Differences ($\alpha = .05$) did occur in the fourth component, Activities. Students in the structured laboratory scored higher in this area.

Interpretations and Conclusions

The students in the structured laboratory were led through the activities performed by scientists many times. For example, the students would perform an experiment on single-slit

TABLE II

Adjusted Means for Components of Science Process Inventory for Laboratory Students Only

Component	Structured Laboratory	Unstructured Laboratory	F
Assumptions	18.6	18.1	1.2
Activities	46.3	45.0	4.7*
Nature of Outcomes	27.6	26.9	2.1
Ethics and Goals	15.8	15.7	0.03

*Significant at $\alpha = 0.05$.

diffraction with razor blades to make the slit. They were then asked to predict the result for different sizes of pinholes. Following the prediction, they tested their "theory." The unstructured laboratory, however, provided no specific instructions. Thus, the students in the unstructured laboratory conducted the experiment in a manner which they chose. Since many of these students did not as yet apply formal-operational processes to physics (Parnell, 1974), they seldom followed the steps of observation, model building (predicting), and testing of the model. They seldom hypothesized or predicted because they were not intellectually prepared to do so. In general, students in the unstructured laboratory described their observations and cited the lecturers or lecture textbook for the explanations of the observations. Such an approach is consistent with Piaget's concept of the concrete-operational student.

We conclude that the structure provided examples of the Activities of scientists and, as a result, caused the students to learn better the process of science. This result seems consistent with our present understanding of the intellectual development of college students. The Activities of scientists do follow procedures which Piaget calls formal operations (Piaget, 1964). We would not expect a student who is not formal operational in his approach to physics to devise his own procedure which would help him understand a formal process.

This study is limited by the type of course offering in which it was performed. The laboratory-lecture approach in Man's Physical World is a very traditional one. As such, the laboratory is seldom mentioned by the lecturer. We cannot say that our conclusions would hold in a course where the laboratory was actually integrated into the total course offering. By the same token, our results cannot be extended beyond the population of liberal arts students studied. Unstructured laboratories can provide useful experiences for students having prior experience in scientific experimentation. But the average college freshman or sophomore taking his first physics class apparently requires a structured experience and training in the scientific process before he will understand it.

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