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ABSTRACT

In evaluating whether the laboratory guides for Project Physics and for PSSC are consistent with the goals of their designers in demonstrating the interplay between experiment and theory in the development of physics, a system was developed for analyzing physics laboratory investigations, and the laboratory activities in the "PSSC Physics Laboratory Guide" were compared to the "Project Physics Course Handbook" according to the proposed system. All experiments (N=96) in both sources were analyzed with an 18-item task analysis instrument and a 10-item instrument identifying the integration of the laboratory work with other components of the course. Tables listing various comparisons of the two texts are provided. Results confirm that the developed instrument is useful in analyzing physics laboratory manuals and that, although both texts exhibit progress in the development and utilization of laboratory activities, there are deficiencies in the development of experiential awareness of scientific inquiry. (CS)

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AN ANALYSIS OF LABORATORY ACTIVITIES IN TWO MODERN SCIENCE CURRICULA: PROJECT PHYSICS AND PSSC

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The central role of the laboratory in the teaching of physics has been highlighted by the authors of both PSSC Physics (Haber-Schaim, et al., 1971a and 1971b) and Project Physics (Rutherford, et al., 1970a and 1970b). In the words of the Introduction to the Project Physics Course Teacher Resource Book (Holton et al., 1970, p. 9), one of the purposes of laboratory experiments is to cause students to "learn something about the nature of experimental inquiry and the role of the laboratory in the advancement of scientific knowledge." In the words of Uri Haber-Schaim (1967), the Physical Science Study Committee set out to create a course in physics that included the following goals:

> to demonstrate the interplay between experiment and theory in the development of physics . . . to have the students learn the basic principles and laws of physics by interrogating nature itself, thus learning not only the laws but also the evidence for them as well as their limitations.

While the laboratory has long been used to provide experiences with objects, concepts, and experiments, one of its major contributions that is consistent with the goals of contemporary science programs lies in providing students with opportunities to engage in the process of investigation and inquiry. Are the laboratory guides for Project Physics and for PSSC consistent with the goals of their designers? Do they reflect an appropriate attention to scientific inquiry? The purpose of the study reported in this paper was to:

1. develop a system for the analysis of physics laboratory investigations;

2. analyze and compare the laboratory activities in the third edition of the PSSC Physics Laboratory Guide (Haber-Schaim, et al., 1971a) and The Project Physics Course Handbook (Rutherford, et al., 1970a) according to the proposed system;

3. discuss the implications of the analysis for instruction and for curriculum development in physics.

Laboratory activities in the new curricula of the sixties were supposed to be a primary vehicle for helping students to solve problems and to think scientifically. Consistent with these goals and with helping students to understand "the way of the scientist," the Commission on College Physics (1972) published a monograph entitled The Divergent Laboratory which included the following general statements:

> 1. The student should have the opportunity to make personal investigative decisions. . . .
> 2. The laboratory should broaden a student's exposure to the behavior of nature and to physicists' descriptions and predictions of that behavior. . . .
> 3. The laboratory instruction should provide an environment in which discovery by the student, is both possible and encouraged. . . .
> 4. The laboratory, the lecture, the recitation, the textbook, etc. should provide learning experiences which complement and reinforce each other. . . .

Another conclusion of the contributors to that monograph was that the laboratory should not be used merely to confirm physical laws. Experiments should often encourage active inquiry.

Yet Shulman and Tamir (1973), following criteria developed by Schwab (1962) and Herron (1971), have pointed out that the overwhelming proportion of laboratories at schools using the new curricula of the 1960's still provided students with the definition of a problem, gave them a set of procedures to employ, and often gave them a key against which to check their answers. While several recent studies have attempted to analyze the kinds of instruction occurring in the laboratory, no attempts to follow and to refine the kind of analysis of laboratory manuals performed by Herron (1971) could be found in the literature. While the laboratory manual is only one of many ingredients in a science classroom, there is evidence that it plays a major role for most teachers and students in defining goals and procedures for laboratory activities. It also helps to focus observations and development of inferences, explanations, and other activities in a laboratory investigation.

Method

An 18-item task analysis instrument and a 10-item instrument identifying the integration of the laboratory work with other components of the course were developed.[1] The tasks were formulated in terms of the inquiry skills and actual behaviors required to perform the prescribed laboratory work. The latest edition of the instrument, with instructions for the user and category definitions and examples, is included in Fuhrman, Novick, Lunetta, & Tamir (1978). All 47 of the PSSC "experiments" and all 49 of the Project Physics "experiments" were analyzed. Other relevant activities such as the Film Loops and Activities in the Project Physics Handbook and the activities suggested in Home, Desk, and Laboratory sections of the PSSC textbook were not analyzed. For each laboratory investigation one of the 28 items was checked if the instructions to the student called for it at least once. No more than one check for each category was made for each laboratory investigation. Hence, the highest possible number of checks for each laboratory investigation was 28 (the number of items in the two instruments) and the largest possible number of checks for each category was 47 for PSSC and 49 for Project Physics (the number of "experiments" in each course). Frequency counts were compiled for each unit and for each entire course. The present analysis examined the nature of the laboratory activities as presented in the respective laboratory handbooks. Reference in the data analysis was not made to the teachers' guides or to any other external source of information. While the reader must recognize that not all of the activities are generally used in any particular course, the analysis provides a representation of what is presented to the student and an indication of the potential of that curriculum.

Results and Discussion

Table 1 presents the relative frequency of laboratory "experiments" in different units of the two physics courses. PSSC and Project Physics have

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Insert Table 1 about here.

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approximately the same number of formal "experiments" for the total physics course. In PSSC there are on the average 1.7 "experiments" for each of the 28 chapters, and in Project Physics there are approximately 2 experiments for each of the 24 chapters. The table shows, however, that these averages are not consistent from one topic and unit to another. In Project Physics, for example, 13 experiments have been prepared for Unit One while only five are presented in Unit Five and in Unit Six. In both courses there are fewer experiments per chapter in the study of electricity and the nature of the atom than there are in the study of mechanics and motion.

The analysis of the organization and integration of laboratory work within each course revealed a number of interesting relationships. While the teachers' guides indicate that many laboratory activities ought to precede presentation of the topic in the text, this information can not be ascertained from reading the PSSC Laboratory Guide and the Project Physics Handbook, both written for student use. A careful reading of laboratory instructions, however, does indicate that 13 experiments (28%) in PSSC and 9 experiments (18%) in Project Physics have been designed to follow presentation of the ideas in the respective texts. If the authors really want students to "discover" selected concepts through an inquiry process that precedes presentation of the concepts in the text, then this information could be communicated directly to the student in the laboratory guide or handbook in addition to making the suggestion in the teachers' guide. Some curriculum projects, such as Biological Science: An Inquiry into Life (Biological Sciences Curriculum Study, 1973), make this point clear by inserting the laboratory activities or references to them at selected points within the text.

The designers of both courses have advocated that laboratory activities be closely coordinated with the text, thereby enhancing the possibility of an integrated learning experience. However, evidence in the laboratory guides alone does not make this integration particularly obvious. The two textbooks, on the other hand, do cover similar topics and concepts with laboratory photographs that occasionally portray apparatus identical or very similar to that used in the student laboratory. Yet in the PSSC text there are no specific references to student laboratory experiments. In fact, since the PSSC text provides data analysis and generalizations from similar experiments, teachers and students could even use the PSSC textbook as a self-contained course without accompanying activity in the laboratory.

Insert Table 2 about here

Table 2 presents the results of analysis of seven organizational categories including information on simulated data and on recommendations for student cooperation. In 6.4% of the PSSC experiments and in 16.3% of the Project Physics experiments, the narrative suggests a division of tasks among groups of students facilitating the pooling of results of an entire class for analysis and interpretation. Unfortunately, however, little or no specific guidance is given regarding post-laboratory discussions. No reference to such discussions was evident in the PSSC guide, while post-laboratory discussions were suggested in 3 out of the 49 Project Physics experiments. Although many teachers use the results of laboratory work for discussion, many others assume that the students' written responses to the questions in the laboratory exercises are sufficient. Teachers often feel too pressed for time to conduct post-laboratory discussions. Unless the laboratory instructions explicitly encourage such discussions for the processing of generalizations and alternative explanations, some of the potential value of inquiry-oriented laboratory work may be lost.

Analysis of the physics laboratory activities using the task analysis instrument was enlightening in several ways. Among other things, the analysis revealed many statements and questions in the student manuals that could have been written more effectively. For example, the PSSC

Laboratory Guide includes the following question at the end of Experiment 6 (p. 10):

"Could you make a 'lens' that would focus rolling balls?"

And Experiment 9 in The Project Physics Handbook (p. 45) asks:

"Could you write an algebraic expression for the relationship?"

Since a student can answer either question with a simple "yes" or "no," more direct and appropriate ways to state the questions would be:

"Make a 'lens' that will focus rolling balls, or describe how you would go about making such a 'lens.'"

"Write an algebraic expression for the relationship between mass and period."

A variety of inadequacies in communication can be identified through this kind of task analysis.

Insert Table 3 about here

Table 3 presents the results of the task analysis. Some important inferences from the data in Table 3 are:

1. In almost all of the laboratory activities students carry out observations, measurements, and experiments, and record results. A large number of the laboratory activities in each course involve the learning and practicing of specific laboratory techniques. A large proportion of activities in each of the two courses involves the processing of quantitative data, and 34.0% of the PSSC experiments and 46.9% of the Project Physics experiments involve the graphing of data. Students are asked to determine relationships

from the data in 93.6% of the PSSC experiments and 79.6% of the Project Physics experiments. They are asked to explain relationships in approximately 53% of the experiments in both courses.

2. Students are asked to predict experimental results in 14.9% of the PSSC experiments and in 8.2% of the Project Physics experiments. They are asked to make predictions based upon their experimental analyses in 23.4% of the PSSC and in 6.1% of the Project Physics laboratory activities, and in both courses they are encouraged to apply the new experimental techniques they have developed to new problems or variables in approximately 23% of the investigations. In 23.4% of the PSSC experiments and in 36.7% of the Project Physics experiments students are asked to make some quantitative determination of the accuracy of their experimental data, but in only 4.3% and 16.3% of the investigations respectively are they asked to discuss limitations or assumptions that underlie the acquisition of experimental data. One may reasonably question whether the laboratory guides focus sufficient attention on these important areas of scientific inquiry and understanding.

3. A number of the skills assessed are, in our judgment, insufficiently represented in courses that purport to develop understanding of the nature of scientific inquiry. Students are asked to design observation and measurement procedures and to design an experiment in only one PSSC experiment. Project Physics scored slightly better in these categories, suggesting that students design observation and measurement procedures in five experiments (10.2%) but encouraging students to design an experiment at only one point in the

> Handbook. Even worse is the situation regarding opportunities for students to recognize and define problems and to formulate hypotheses.

In spite of a growing awareness of the importance of investigative inquiry for science students at introductory levels, the <u>PSSC Laboratory Guide</u> and the <u>Project Physics Handbook</u> generally exemplify a rather conventional approach in which the problems and the ways to perform the investigations are provided rather explicitly by the text. Detailed guidance is often given to eliminate difficulty and to guard against student "mistakes" that may lead students to obtain unanticipated results. While the specification of investigative procedures can be justified for certain instructional goals and situations, it is difficult to justify the limited number of opportunities for the student to define problems and procedures and to formulate hypotheses and explanations.

Differences in orientation between the <u>PSSC Laboratory Guide</u> and the <u>Project Physics Handbook</u> are not as easy to detect from the results of this analysis as might have been expected. Project Physics instructions do encourage more group work ~~in some~~ experiments and do call for a few post-lab discussions. They also focus greater attention on limitations and assumptions that underlie the data collection effort and on the accuracy of data in certain experiments. In Project Physics there has been some progress with the introduction of a few more experiments that encourage students to design their own observation procedures. But in general the laboratory guides for the two courses are still lacking in instructions and questions that might stimulate such inquiry activity as the formulation of hypotheses, the definition of problems, and the design of experiments.

Conclusions and Implications

1. The task analysis instrument and the organization instrument appear to be of use in the analysis of physics laboratory manuals; they have the potential to be useful also in the selection and development of curricula and of teaching styles.
2. Laboratory work plays a central and indispensable role in both the PSSC and the Project Physics courses. Perhaps more laboratory activities or simulated activities can be added to topic areas such as electricity and atomic structure where such activities are now in relatively short supply.
3. Numerous experiences in carrying out laboratory activities are provided. Students perform and manipulate materials, gather qualitative as well as quantitative data, make inferences and generalizations, and communicate the results of their activities in a variety of ways.
4. Six important deficiencies have been identified: a) students do not engage in identifying and formulating problems or in formulating hypotheses; b) students have relatively few opportunities to design observation and measurement procedures; c) they have even fewer opportunities to design experiments and to work according to their own design; d) students are not encouraged sufficiently to discuss limitations and assumptions underlying their experiments; e) students are generally not encouraged to share their efforts in laboratory activities where that might be appropriate; f) explicit provisions do not exist for post-laboratory discussions to facilitate consolidation of findings and understanding.

The PSSC Laboratory Guide and the Project Physics Handbook exhibit very impressive progress in the development and utilization of laboratory activities when compared with other laboratory guides of their period. In concert with other supporting materials such as the Project Physics film loops and activities, they are excellent contributions to physics teaching resources and curricula. Yet, in the development of experiential awareness of "scientific inquiry," the experiments do not live up to the goals of their designers. Until the deficiencies described have been corrected, the full potential of the physics laboratory in these introductory courses will not be achieved. Some of the deficiences can be remedied by knowledgeable teachers, but changes should be embodied in the printed texts and laboratory guides to have broadest consequence.

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Footnote

1. The authors wish to acknowledge the help of Shimshon Novick and Marlene Fuhrman in developing the categories and the instrument used in this analysis.

Table 1

Relative Frequency of Laboratory "Experiments" in Different Topic Areas

Topic Area		Number of Chapters	Number of "Labs"	Lab Index[a]
PSSC Physics	1. Introduction, Light, Particle Model, Wave Motion	9	18	2.00
	2. Mechanics Kinematics Dynamics Heat	9	15	1.67
	3. Electricity and Atomic Structure	10	14	1.40
Whole		28	47	1.68
Project Physics	1. Concepts of Motion	4	13	3.25
	2. Motion in the Heavens	4	8	2.00
	3. The Triumph of Mechanics	4	10	2.50
	4. Light and Electromagnetism	4	8	2.00
	5. Models of the Atom	4	5	1.25
	6. The Nucleus	4	5	1.25
Whole		24	49	2.04

[a]Lab index = $\frac{\text{Number of "Labs"}}{\text{Number of Chapters}}$

TABLE 2

Selected Organizational Categories:

Number of "Experiments" and Percent of Total for Each Course

Category	PSSC		Project Physics	
	Number of "Labs"	Percent of Total	Number of "Labs"	Percent of Total
C. Cooperative mode				
C.1 Students work on a common task and pool results	2	4.3	2	4.1
C.2 Students work on different tasks and pool results	1	2.1	6	12.2
C.3 Postlab discussion required	0	0.0	3	6.1
D. Laboratory simulations				
D.1 Student performs "dry lab" -- data given by authors	1	2.1	3	6.1
D.2 Student performs task that simulates or models phenomenon being discussed	10	21.3	3	6.1
D.3 Student performs experiment by gathering data from a secondary source provided by authors	1	2.1	3	6.1
D.4 Student performs simulated experiment by interacting with a program	0	0.0	0	0.0

TABLE 3

Laboratory Task Analysis Summary

Percent of Total "Experiments" in which the Activity Occurs

Task categories	Percent	
	PSSC	Project Physics
1.0 Planning and design		
1.1 Formulates a question or defines problem to be investigated	0.0	0.0
1.2 Predicts experimental result	14.9	8.2
1.3 Formulates hypothesis to be tested in this investigation	0.0	0.0
1.4 Designs observation, measurement, or calculation procedure	2.1	10.2
1.5 Designs experiment	2.1	2.0
2.0 Performance		
2.2 Manipulates apparatus, develops technique	97.9	95.9
2.3 Records result, describes observation	97.9	95.9
2.6 Works according to own design	0.0	4.1
3.0 Analysis and interpretation		
3.1a Transforms result into standard form (other than graphs)	53.2	85.7
3.1b Graphs data	34.0	46.9
3.2 Determines relationship	93.6	79.6
3.2b Determines quantitative relationship	74.5	65.3
3.3 Determines accuracy of experimental data	23.4	36.7

3.4 Defines or discusses variables, limitations, or assumptions that underlie the experiment	4.3	16.3
3.5 Formulates or proposes a generalization or model	34.0	26.5
3.6 Explains a relationship	53.2	53.1
4.0 Application		
4.1 Makes predictions based on this investigation's results	23.4	6.1
4.3 Applies experimental technique to new problem or variable	23.4	24.5