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AUTHOR	Sutman, Frank X.; And Others
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ABSTRACT

The series of three sets of companion studies reported in this presentation addresses the need for seeking more effective outcomes from science laboratory experiences, which is indicated by conflicting outcomes of earlier reported research related to laboratory instruction at two different academic levels--grades 7-12 and beginning college. Four of the studies reported are based on actual on-site observations of laboratory based science instruction, while two are the results of meta-analysis of earlier statistically based studies related to learning outcomes of science laboratory experiences. Each meta-analysis included 55 studies conducted and reported during the period from 1970-94 and concluded that non-traditional approaches to laboratory instruction produces significantly improved content learning, reasoning ability, and skills and attitudes. The second set of studies considered the emphasis given to specific teaching strategies during pre-laboratory and post-laboratory instruction. Results indicate that students experience laboratory-based experiences as an add-on to lecture rather than as the driving force for later instruction. The third set of studies investigated the impact of an inservice model on classroom science teaching with results indicating that the teachers adopted the model approach and made significant changes in their course organization. Contains 144 references. (JRH)

Seeking More Effective Outcomes From Science Laboratory Experiences (Grades 7-14): Six Companion Studies

CONDUCTED THROUGH THE CENTER FOR LABORATORY STUDIES,
TEMPLE UNIVERSITY

<u>Presenters:</u>

Frank X. Sutman	Temple University, Philadelphia, PA & Rowan College, Glassboro, NJ
Joseph S. Schmuckler	Temple University, Philadelphia, PA
Alexandra B. Hilosky	Harcum College, Bryn Mawr, PA
Holly D. Priestley	Temple University, Philadelphia, PA
William J. Priestley	Temple University, Philadelphia, PA

<u>Discussant:</u>

Richard W. Moore	Miami University of Ohio, Oxford, OH

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Paper Set:

Presentation 1: "Meta-analyses of Learning from Laboratory Based Experiences (9-14)"

Joseph S. Schmuckler, (schmuckl@VM.TEMPLE.EDU)

Presentation 2: "Analyses of Teaching Behaviors During Laboratory Based Instruction (13 & 14)"

Frank X. Sutman, (reahm@MARS.ROWAN.EDU)
and Alexandra Hilosky, (alehil@HSLC.ORG)

Presentation 3: "Impact of Modeled Teacher Enhancement on Instructional Behaviors (7-12)"

Holly Priestley, (hollyp@VM.TEMPLE.EDU)
and William J. Priestley, (wpriest@VM.TEMPLE.EDU)

Table of Contents:

Objectives and Significance:

The series of three sets of companion studies reported addresses the overall objective stated in the title; the need for which is indicated by conflicting outcomes of earlier reported research related to laboratory instruction (Hofstein and Lunetta, 1982) and by the emphasis given to hands-on based science instruction throughout the reform movement in science instruction. [See for example: NSF In a Changing World: The National Science Foundation's Strategic Plan (1994).] The need also results from a plethora of definitions for inquiry and discovery based instruction throughout the science education literature and disagreement over the role that teaching students to follow directions should play within the context of science laboratory experiences. The term "cookbook approach" is referred to negatively in much of the science education literature when, in fact, following directions can be a significant component of inquiry based science activities.

These studies were also driven because of concern by the profession that laboratory based experiences must play a major role in instruction because students "need to experience science as scientists practice it." In reality earlier opinion based reports, (Tamir, 1983) indicated that these experiences, as practiced, are in fact not experienced in the way they are practiced by scientists. A major assumption, made by the researchers reporting in this session, is that this condition is not so much the result of the nature of laboratory experiences themselves, but rather the result of how science courses are structured or organized, and the result of teaching behaviors emphasized in pre- and post- laboratory sessions. A second assumption is made that even though high value is verbally placed by the science teaching profession on laboratory experiences, very little weight is given to the result of this component of instruction in determining students' final course grades.

The Studies:

In order to address the overall objective and the above stated assumptions, six companion studies were designed and carried out in pairs of two. Each pair addresses the same issue at two different academic levels: the grade 7-12 level and the beginning college level (13-14). These two levels of science instruction were studied because of the conflict between what school level science teachers believe students should learn through their courses to prepare them for further science study and the expectations held by college level science faculty as to students' academic backgrounds.

The net result of the studies being reported here, as well as, the eventual results of at least two more sets of two studies to be completed at a later date, will be the development of a guidebook for teachers for designing science instruction that gives special attention to the effective inclusion of laboratory experiences. This guidebook will be directed to both levels of 'schooling' and will contain a section devoted to the preparation of science teachers.

Four of the studies to be reported at NARST in 1996, are based upon actual on-site observations of laboratory based science instruction; while two are the results of meta-analyses of earlier statistically based studies related to learning outcomes of science laboratory experiences.

All of the studies were originally planned to be conducted within each of the major science disciplines. However, four of the studies had to be conducted across the science disciplines because either too few appropriate studies were available from a single discipline for effective analyses or because the structure of inservice courses called for the inclusion of teachers across science disciplines. Where studies were conducted within one field (chemistry) the premise is tentatively accepted that the conclusions apply across the several science disciplines.

The first pair of studies to be reported are "The Meta-Analyses of Results of Studies that Compared the Effectiveness of Various Approaches to Laboratory Instruction In Beginning Secondary and College Level Science Courses." These meta-analyses developed the basis for the remaining studies.

Each meta-analysis included 55 studies conducted and reported during the period from 1970-1994. The studies selected from a pool of 600, met the following criteria. They: (1) examined the learning outcomes of traditional and various non-traditional approaches to science laboratory based instruction at the grade 7-12 and 13-14 levels; (2) included appropriate validated statistical data; (3) included a control group; and (4) included an appropriate student population. The meta-analyses followed the methodology established by Hedges, Shymansky and Woodworth (1989), in that individual and combined or weighted effect sizes were determined, and p values were established for each category.

The major conclusions from both of these meta-analyses are: (1) the learning results from non-traditional approaches to the laboratory component of science instruction (with the exception of the use of the learning cycle approach at the beginning college level), when compared to the results from traditional approach produces significantly improved: content learning, reasoning ability, improved attitudes towards science and/or scientists as well as improvement in laboratory manipulative skills only at the 13-14 level; (2) significantly improved cognitive and noncognitive student learning across the biological and physical sciences, especially when computer technology was employed and when the instruction was labeled inquiry-discovery, learning cycle oriented, or independent laboratory. Conclusions from one of the later studies, however, indicated that some of the improved learning may have resulted from teachers' enthusiasm rather than from the actual practice of inquiry.

The second two related studies: "Analyses of Teaching Behaviors Practiced During the Laboratory Component of Chemistry Instruction Grades 9-12 and 13-14", considered the emphasis given to specific teaching strategies during pre-laboratory and post laboratory instruction within the various courses. At the high school level these courses included college preparatory, chemistry and the community or Chemcom, and advanced placement or AP chemistry. At the college level the courses included chemistry for non-majors, chemistry for majors, and those who were preparing to enter the health sciences profession. The teaching by 12 instructors at the high school level and 26 instructors at the higher education level was observed, videotaped and analyzed using a modified-reformed version of the Vickery Science Teacher Behavior Inventory (1968; modified in 1971 by Clark and Giese and reformed in 1994 by Hilosky and Wang). The analysis of teaching was supported by the results obtained from an ethnographic survey and the Inventory of Pigetian Development Tasks (Furth and Youniss, 1980).

Both of these studies indicate that: (1) students experience laboratory based experiences as an add-on to lecture rather than as the 'driving force' for later instruction; (2) a very high percentage of the laboratory instructors' time is spent listening to and responding to students' procedural questions, with almost no time available for calling upon strategies designed to develop or strengthen higher order thinking. Instructors are the sole source of procedural information and students are never sent back to reread directions even though they were assigned to read and understand the directions as a major part of the pre-laboratory activity. Post laboratory experiences almost never include follow-up discussion or analysis of the laboratory findings. In some instances student groups were asked to combine their data with that of other groups and the combined data was never referred to.

At the secondary school level laboratory activities were designed to 'fit into', or be completed in a designated period of 45 to 90 minutes and from 3 to 4 hours at the college level. There were never additional opportunities for students to extend the basic study. These experiences were structured so that students never had to go to sources other than the laboratory manual for direction or information. Cooperative group work was observed only in laboratory instruction associated with the Chemistry in the Community course and in Germany where the entire course was conducted within the laboratory environment.

Student record books were seldom used except in Germany; and reports of laboratory experiences were graded and returned to students. The reports were never used diagnostically nor did the grades have significance in determining final course grades.

Even though the observations of laboratory instruction were made later in the school or college academic year, there was no evidence of an investigative approach to laboratory experiences in response to the constructivist description of learning.

The third set of related studies: "Impact of Longer Term Modeled Laboratory Driven Inservice Instruction on the Teaching by Biology and Physical Science Teachers" determined how this inservice model impacted classroom science teaching. Twenty-five urban inservice middle and high school science teachers who were enrolled in an inservice science methodology course that offered experience in using the findings from laboratory investigations as the driving force for further science instruction. This instructional approach was modeled by the course instructors, followed by the teachers working in small groups to design and teach lesson sequences structured in the same way. This inservice instruction occurred over a 13 week period and was followed by observations and videotaping the instruction being carried out in the inservice teachers' school classrooms. The Modified Reformed Science Teacher Behavior Inventory (MR-STBI) was used to analyze the teaching to determine the extent that their instruction followed the model.

The analyses of these two studies indicate that, the teachers adopted the modeled approach and made significant changes in their course organization. The Moore-Sutman Inventory of Science Attitudes (1970), revised in 1995 by Moore and Foy was used to determine changes in students' attitudes about science. No significant changes in attitudes were determined over the short term.

Literature Base for the Reported Studies:

Following is a sampling of the literature that served as the underpinning for the reported six studies. This review is presented under several subheadings.

Inquiry Approach:

Norland (1990) notes, "Science is an objective, problem solving process during which scientists strive to observe and seek explanations for what they observe. These explanations often lead to new problems to be addressed" (p. 151). To meet this definition requires that students must be involved in activities in line with science as a process.

Giddings, Hofstein and Lunetta (1991), call for changes in instruction that de-emphasizes memorization and emphasizes the activities that develop positive science attitudes. To support this understanding, Rutherford (1964), wrote: "When it comes to the teaching of science it is perfectly clear where science educators and scientists stand: they are unalterably opposed to the rote memorization of mere facts and minutiae of science. By contrast, we stand foursquare to enhance the teaching of the scientific method, higher order thinking, scientific attitudes, problem-solving, the discovery method, and of special interest, the enhancement of the inquiry method" (p. 80).

Tobin (1990) indicated that an outcome of inquiry based experiences is that students and teachers work collaboratively and have "opportunities to experience what they are to learn in a direct way as well as the time to think and make sense of what they are learning. Science laboratory experiences are a mechanism whereby students learn with understanding and at the same time engage in the process of constructing knowledge by doing science" (p. 405). According to Sutman (1995), "allowing time to engage in science, means initially less content coverage. The end result, however, is uncovering more knowledge and covering less or fewer facts."

The National Science Standards (1996) view "time, space and resources as critical components in the creation of an effective science environment that promotes sustained inquiry" (p. 44). Building scientific understanding takes time and teachers need blocks of time so that students will have the opportunity to engage in serious scientific inquiry investigations as an integral part of their science learning.

Laboratory Based Activity in Science Instruction:

Inclusion of laboratory work, particularly within the context of secondary science courses, has a long and uncertain history. Although science laboratory experiences have been a component of science instruction in the United States since the acceptance of science as a subject in the curriculum in the late 1800's, a clearly defined central capacity for it in instruction did not appear until the curriculum reform movement that began in the early 1960's. This movement described the role of laboratory instruction in student learning as evolving from one of verification and supplementing instruction in the 1920's to placing inquiry-discovery in the forefront in the 1960's curriculum development era. In 1970, Ramsey and Howe (1969) argued that the laboratory experience should be an integral part of any science course. This argument had (at the time) somewhat wide acceptance in the science teaching community.

In 1982 Hofstein and Lunetta (1982) questioned the case for laboratory instruction and "suggested further research might be needed to assess its value" (p. 201). They also were critical of past practices in laboratory based instruction and criticized the research in this area of concern. Hofstein and Lunetta also cite reports by Connelly (1979) and Silberstein (1979) that earlier studies failed to examine teacher behaviors and how teachers translate the curriculum into teaching practices. They called for objective information about the teachers and teacher-student interactions within laboratory-based instructional settings.

Egleston, Galton and Jones (1976) found that "teaching styles (of teachers) tend to be consistent no matter what form of activity is to take place; deductive-oriented teachers, for example, teach practical [laboratory] work authoritatively, while more inquiry-oriented teachers always call upon investigative methods of learning."

Bates (1978) reported "that continuing research on the role of science teaching in nurturing cognitive development may, in the relatively near future, provide important new science teaching strategies in which properly designed laboratory activities will have a central role" (p. 75), yet Hofstein and Lunetta argued this point, questioning whether the research at that time was inferred from data or resulted from the mere acceptance of a Piagetian viewpoint. Many research studies since Hofstein and Lunetta's analysis have not shown a clear relationship between laboratory work and its effectiveness in increasing science knowledge (Woolnough and Alsop, 1985; Millar and Driver, 1987; Hodson, 1990).

Roth and Roychoudhury (1994) and Tobin, Kahle and Fraser (1990) report that a learning environment focusing on hands-on concept constructing activities, complemented by follow-up periods of discussion leads to improvement in student attitudes and improved cognitive learning. This 'non-traditional' approach to the inclusion of laboratory based instruction, as indicated in the report of a meta-analysis of research by Zhou (1994), improves learning at least in the physical sciences at the high school level. Regardless of the effectiveness issue, most secondary science students spend 50 to 60 percent of "science instructional time" engaged in laboratory activities (Woolnough and Alsop, 1985; Denny and Chenell, 1986; Kempa and Ayob, 1991). Therefore, it is essential that laboratory experiences and the science courses that they are a component of, be designed to produce significantly improved learning outcomes.

The National Science Education Standards (1996) clearly describes what role the laboratory should play within science teaching. The 'Standards' propose further the use of inquiry as the methodology to achieve this long sought improvement in learning. Yet most laboratory experiences continue to be either isolated from the remainder of science courses and / or they do not serve as the basis or driving force for further instruction (Hilosky, 1995 and Wang, 1996).

A wide variation in the implementation of laboratory methods has existed since the beginning of the present 'Federal effort' to reform science instruction. In the traditional approach, experimentation is often labeled as 'cookbook', an approach in which students follow detailed directions, without a definite sense of purpose. According to Tobin and Gallagher, (1987) this form of laboratory activity makes low cognitive demands on students, and much time is spent by students off task. In addition, according to Brown, (1992) this traditional approach does little to alter misconceptions that students bring to the laboratory.

The traditional overall, so-called, didactic approach to science instruction, of which the above form of laboratory based experience is a part, focuses on the direct transmission of propositions that should instead be tested empirically. Using both whole class interactive and non-interactive strategies has made didactic transmission only 'effective' in covering large amounts of content. Tobin and Gallagher, (1987) found that the norm, at least in physical science instruction, is the teacher explaining phenomena to the entire class as well as the procedures for solving word problems; this followed by seat work practice emphasizing completion of problems with little demand for comprehension. If small group activities follow they are typically simple data-collecting laboratory exercises used to verify already known laws or principles. To rephrase Brown (1989), transmission of facts may be appropriate when students have no initial contact with the concept to be studied. This transmission approach is, however, ineffective when students already have conceptualized within accepted norms, to some level of understanding.

Laboratory Activities and Constructivist Strategies:

Laboratory based activity continues to be typically arranged so that students work in small groups of two; even three. Wang's study (1996) indicates that research has suggested a need to explore extended group structures. The general acceptance of 'cooperative learning' (Johnson and Johnson, 1991; Slavin, 1990) has provided the mechanism to implement the practice of group learning. Tobin (1990) drawing upon the research on cooperative learning considers this to be a rich area for research as it would be the framework for "asking the right questions" about learning in science instructional laboratories. The research suggests the social constructivist perspective of learning where knowledge is personally constructed yet socially mediated by the cultural experience of the individual and the interaction with others in the culture (von Glasserfeld, 1993; Tobin, 1993).

"Students who learn science, while being involved in laboratory based experiences in groups, are functioning as individuals and as members of the learning groups and their perspective on laboratory learning will be constructed as a dialectical interaction of the group and individual views" (Christensen and McRobbie, 1995, p.31).

In order to more thoroughly address student misconceptions in the realm of science concepts, a number of instructional methodologies and contents are continuing to be developed and tested. These methodologies include: "Bridging analogies" (Clement, 1988); disequilibrium techniques (Dykstra and Minstrell, 1988); learning cycles (Karplus, 1981); microcomputer based laboratory experiences (MBL) (Thornton and Sokolof, 1990); and constructivist physics laboratories (Roth, 1994). It would seem that none of these strategies will be effective in developing higher order thinking if not introduced using hands-on data collection oriented activities followed by related discussions, lectures and data analysis as well as culminations. This is a premise upon which the studies to be reported were based.

Teacher Beliefs:

Hilosky's research (1995) found that at the beginning college level chemistry instructors have not formally constructed learning objectives for the laboratory activities that involve students. Her research also showed that physical science laboratory instructors (chemistry) spend most of the time in laboratory instruction listening to and answering students low level procedural questions. To meet the demands for improving student cognition, it seems essential to diminish this 'procedural' emphasis making more time for higher order thinking and its development. It also appears to mean that both physical science and biology laboratory instructors need to learn how to revise their instructional approaches to emphasize facilitation of learning by their students. However the facilitator role in itself is not enough in enabling hands-on data collection. Instructors, in addition, need to follow the data collection activity with ample analyses as well as explanation based activities, if the goal of developing higher order thinking skills is to be met.

Earlier attempts at this kind of restructuring may have failed until now because teachers usually have not considered that students do not learn how to learn. Hilosky (1995) found that college instructors do not view developing students' skills toward self-learning as part of their domain. In fact, many of the science curriculum reform projects of the 60's and 70's were abandoned because teachers, themselves, could not learn how to change their teaching style (Hurd, 1986).

Inservice Education of Teachers:

In order to facilitate changes called for by both the science education research community and the National Science Education Standards, the process of teachers' professional enhancement needs to be, itself, enhanced. Two of the research projects reported investigated the impact of enhanced teacher enhancement on the ability and commitment of practicing science teachers to change their teaching strategies to embrace an inquiry based laboratory approach that includes data collection as a driving force.

Anderson and Mitchner (1994) viewed teacher education programs as providing alternate or reformed theoretical frameworks, instructional content and modes of instruction to meet the demands of the National Science Education Standards. They call for teacher education programs that will allow teachers to "reconceptualize their roles and develop collegial relationships with teacher education faculty" (p. 3). Within the scientific disciplines, altering the traditional model for inservice education to accomplish this goal may be more complex and involved than in other content areas. In the sciences, in particular, to produce such adjustment calls for consideration of both classroom and laboratory components of instruction. As part of the process, teachers as students, may need to become engaged in modeled laboratory based experiences "to generate answers to the questions rather than merely to illustrate what is pronounced or asserted to be true in the textbook or by the teacher" (Norland, 1990, p. 151). Implementing Norlands's assertion strongly suggests that inquiry-discovery type science laboratory experiences be utilized to introduce the topics for learning, followed by student analysis of data and discussion of the analysis; this approach to be led by instructor facilitated teacher-student interactions. If carried out this approach could lead to reversing the finding by Hilosky (1995) that "... the results of laboratory investigations, seldom if ever, serve as the basis for the next lecture and/or discussion session" (p.81).

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11

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15