



A case study of student learning in a microcomputer-based chemistry laboratory
by Bruce Earl Ivey

A thesis submitted in partial fulfillment of the requirements for the degree of Doctor of Education
Montana State University
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Abstract:

The Chemistry Department at Montana State University has designed and implemented a microcomputer-based laboratory (MBL) for freshman chemistry. The purpose of this study was to examine how students learned to use the computerized Laboratory Interface package and to determine what they perceived its strengths and weaknesses to be. Interview data were collected through a series of focus groups; other measures were Kolb's Learning-Style Inventory (LSI), Okey and Dillashaw's Test of Integrated Process Skills (TIPS), and a questionnaire. The participants were approximately 300 students enrolled in freshman chemistry labs and their teaching assistants.

The main focus of the study was the learning strategies students used as they became familiar with the Lab Interface. LSI results indicated that the student population had an even mix of all four learning styles, but the teaching assistants showed a strong tendency toward abstract conceptualization. The test of science skills (TIPS) indicated similar results between the four learning style groups. In contrast, focus group comments revealed distinct differences in the learning strategies used by students with different learning styles. Two groups relied on active experimentation to learn the Interface system, the third group learned by studying the printed manual, and the fourth group learned best by studying and modifying examples. Thus, even though the four groups attained the same learning outcomes, their learning strategies were different.

Other learning strategies were shared by all students. Many wanted to know more about why they were doing certain steps. Students used the manual as a reference and found the examples in the manual helpful. However, some learning style groups preferred exercises in which they had to modify the examples. Overall, 17 learning strategies were identified.

All respondents were pleased with the speed, accuracy, and ease with which the Interface acquired data. They found the Laboratory Interface system to be a powerful aid in the collection and analysis of laboratory data. Those whose learning style emphasized reflective observation found it easier to learn to use the Interface than those who preferred active experimentation, but students from all learning styles thought that "the benefits clearly outweigh any costs" of learning to use the computerized equipment.

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IN A MICROCOMPUTER-BASED
CHEMISTRY LABORATORY**

by

Bruce Earl Ivey

**A thesis submitted in partial fulfillment
of the requirements for the degree**

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This thesis has been read by each member of the thesis committee and has been found to be satisfactory regarding content, English usage, format, citations, bibliographic style, and consistency, and is ready for submission to the College of Graduate Studies.

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Date July 15, 1992

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ABSTRACT

The Chemistry Department at Montana State University has designed and implemented a microcomputer-based laboratory (MBL) for freshman chemistry. The purpose of this study was to examine how students learned to use the computerized Laboratory Interface package and to determine what they perceived its strengths and weaknesses to be. Interview data were collected through a series of focus groups; other measures were Kolb's Learning-Style Inventory (LSI), Okey and Dillashaw's Test of Integrated Process Skills (TIPS), and a questionnaire. The participants were approximately 300 students enrolled in freshman chemistry labs and their teaching assistants.

The main focus of the study was the learning strategies students used as they became familiar with the Lab Interface. LSI results indicated that the student population had an even mix of all four learning styles, but the teaching assistants showed a strong tendency toward abstract conceptualization. The test of science skills (TIPS) indicated similar results between the four learning style groups. In contrast, focus group comments revealed distinct differences in the learning strategies used by students with different learning styles. Two groups relied on active experimentation to learn the Interface system, the third group learned by studying the printed manual, and the fourth group learned best by studying and modifying examples. Thus, even though the four groups attained the same learning outcomes, their learning strategies were different.

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CHAPTER 1

INTRODUCTION

The State of Science Education

According to the 1983 report of the National Commission on Excellence in Education, "our once unchallenged preeminence in commerce, industry, science, and technological innovation is being overtaken by competitors throughout the world" (p. 5). Not only is the country declining compared to other nations, it is not even equalling its own performance of one or two decades ago (pp. 8-9). At the same time that test scores are declining, the number of college students entering scientific and technical fields is also falling (National Science Foundation, 1987, pp. 41-42). This trend is causing increased concern about the future of science in the U.S. (National Science Foundation, 1988, p. 4).

The decline in science education is coming at the same time much of society is becoming more technological. "It seems to be getting to the point where there is no avoiding computers" (Arthur & Hart, 1990, p. 457). About one-fourth of all workers regularly use computers on the job (Moursund, 1988, p. 4), and that proportion can only increase. "Computers and computer-controlled equipment are penetrating every aspect of our lives--homes, factories,

and offices" (National Commission, 1983, p. 10).
Compounding the problem for adults is their often-negative attitudes towards computers (Morris, 1988, p. 77).

The shift is especially pronounced in scientific fields such as chemistry, and colleges and universities that do not modify their approach to teaching "do not present a realistic picture of modern chemical instrumentation" (Rosenthal, 1984, p. 34). Leslie Fundakowski, a chemist turned science teacher, says that "we still teach chemistry with textbooks and little test tubes and that's not the way chemistry is done anymore" (quoted in Mageau, 1990, p. 16). In the last two decades, college students have "struggled to learn both the rapidly accumulating knowledge of chemistry and equally rapidly changing techniques of the science" (Lewenstein, 1989, p. 42).

A century ago Thomas Huxley (1896) stated the unique advantages enjoyed by training in the sciences:

The great peculiarity of scientific training, that in virtue of which it cannot be replaced by any other discipline whatsoever, is [the] bringing of the mind directly into contact with fact, and practising the intellect in the completest form of induction; that is to say, in drawing conclusions from particular facts made known by immediate observation of Nature. The other studies which enter into ordinary education do not discipline the mind in this way. (p. 126)

In chemistry the "immediate observation of Nature" (i.e., the physical world) happens in the laboratory, and

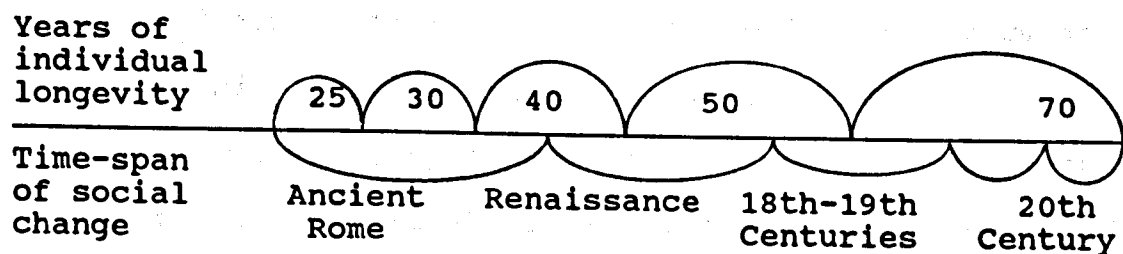
laboratory exercises have been an integral part of college chemistry courses for the last century (Lewenstein, 1989, pp. 38-39). In many cases, however, labs were merely "cookbook" drills--the student followed a prescribed set of steps in the hopes of coming close to a predetermined "correct" value. In contrast to this approach, there are two new parallel threads running through the recent literature on laboratories in science education--the need to bring students into direct contact with nature (Winders & Yates, 1990, p. 13) and the need for the student to experience "the methods of scientific inquiry and reasoning" (National Commission, 1983, p. 25, underlining added). The tools students use in the laboratory should "encourage an inquiry approach to science" (Thornton, 1987, p. 100).

The basis for the need to emphasize methods over facts is clarified in a diagram by Malcolm Knowles, a leader in the field of adult education (see Figure 1). The chart shows that for the first time in history the time span for social change is considerably shorter than the human life span (1980, pp. 40-41). In former ages ideas learned during early education could be expected to last a lifetime; today one can expect the need to relearn much of what was learned early in life. For example, the field of physics has undergone two major changes since 1900 (relativity and quantum mechanics) and may be about to

undergo a third (chaos, or nonlinear dynamics) (Kuhn, 1970, Ch. 12; Gleick, 1987, pp. 306, 314). Even though the content and techniques of science are currently short-lived, the processes of scientific inquiry remain relatively stable. Thus, laboratory courses need to involve students in the methods of science and not just the facts.

The traditional laboratory brought students into contact with nature, but practice in the methods of science was often overlooked. This situation was due in large part to the logistical problems of doing exploratory work in a typical laboratory period. Today there is a better way.

Figure 1. The Relationship of the Time-Span of Social Change to Individual Life-Span
(Knowles, 1980, p. 41)



Montana State University's
Laboratory Interface

In response to the need to involve students in the process of science while becoming more proficient in the use of computerized equipment, the Chemistry Department at Montana State University (MSU) developed the Laboratory

Interface. This unit integrates a desktop computer, measurement probes, and data analysis software in a single package (Amend, Furstenau, Howald, Ivey, & Tucker, 1990, p. 334), a combination which has come to be known as a microcomputer-based lab (MBL) (Stein, Nachmias, & Friedler, 1990, p. 185).

Traditionally, many separate instruments are used in a chemistry laboratory such as thermometers, pH meters, voltmeters, and Geiger counters. Readings are noted and recorded manually, often at prescribed time intervals. Later the data are examined and perhaps graphed in various ways in an attempt to discern relationships between the variables. However, with an MBL the various sensors are connected to a computer through interfacing circuitry. Measurements are taken and recorded automatically at user-determined time intervals, and the supplied software is used to manipulate and graph the data.

Some uses of computers in education remove the student from nature. Computer-based simulations, for example, can be used when the actual experiments would be too time-consuming, expensive, or dangerous for student use. Sometimes this is appropriate, but simulations should not be used as convenient substitutes for actual experiences with nature. A microcomputer-based lab, on the other hand, connects the student with nature in a way that allows the freedom to explore and measure the physical world

(Thornton, 1987, p. 101). "In the MBL, computers are in the laboratory, not outside of it" (Furstenau, 1990, p. 11). "It is difficult to overestimate the impact of reality on a student: first-hand experience is indeed first-hand knowledge" (Winders & Yates, 1990, p. 13).

To understand [science and technology] as ways of thinking and doing, as well as bodies of knowledge, requires that students have some experience with the kinds of thought and action that are typical of those fields. (Rutherford & Ahlgren, 1990, p. 188)

Montana State University was among the first to develop an integrated laboratory interface for use by large numbers of students (Amend, Briggs, et al., 1990, p. 96). This combined hardware-software package offers three major advantages to students: (a) it uses simple menu-driven software to flexibly control the computer and sensors; (b) it automates the data acquisition process, thus eliminating tedious manual recording; and (c) it provides powerful data analysis software to manipulate and graph the acquired data. This combination allows students to collect accurate, voluminous data and then search for relationships between variables. The power of the Laboratory Interface allows students to be directly involved in the process of science (Amend, Tucker, & Furstenau, 1989, p. 20). Thus,

MBL constitutes a new class of technology which allows students to use the computer much as research scientists do: to collect, record, and manipulate data. (Friedler, Nachmias, & Linn, 1990, p. 176)

As the use of computers in society becomes more common, it is important that the use of computers in science laboratories keep pace. However, this use must be in ways that are appropriate to the subject area and the learners. Rather than acting as "teachers" to students, computers should serve students in their quest to understand nature and the processes of science. The microcomputer-based lab should be a tool in the hands of students similar to the way a word processor is an aid for writers. However, this goal highlights a dilemma of technology--people must learn to use the technology before it can benefit them. One must learn to use a word processor before the word processor can be a benefit. Students must learn to use the Laboratory Interface before the Laboratory Interface can benefit them. Yet, little is known about how this interaction works for students using the Laboratory Interface. Information is needed regarding the ease of learning to use the interface compared to its perceived benefit by students.

When developing a new classroom technology such as the Laboratory Interface, the first order of business is to design the hardware, software, and courseware to make it useful. Now that these are in place, it is time to examine carefully how students learn while using the interface. An emerging theme in higher education is the consideration of the different cognitive styles of students (Kolodny, 1991,

p. A44). If different students approach the task of learning new information in different ways, this should be known and taken into account.

Conceptual Framework

Learning Styles and Academic Disciplines

The Laboratory Interface was designed to be used in chemistry labs, but students from many disciplines besides chemistry are in those labs. The reasons for this situation stem from the historical development of the departmentalized university. Over the years the academic disciplines have become increasingly specialized, and the differences between disciplines have become more pronounced. To counteract the narrowness brought about by specialization, some institutions require all students to enroll in a small number of "core courses" (Kolb, 1981, p. 251). These are courses which, taken together, give a broad overview of the present state of human knowledge, infuse that knowledge with meaning, and give a "common universe of discourse" for graduates.

Another way to try to overcome the narrowness of specialization is to develop lists of representative courses from each discipline and require all students to enroll in a certain number of these "distribution requirements." At MSU the term "core courses" refers to these distribution requirements (Montana State University,

1991, pp. 26-27). Freshman chemistry laboratories at MSU are on the list of core courses, so students from many disciplines enroll. This raises a problem. The purpose behind the distribution requirements is to approximate something of the breadth of a classical education, but disciplines are now separated by a gulf of differences.

Different methods of inquiry and communication in the various disciplines produce strong selection and socialization pressures towards homogeneity within disciplines (Kolb, 1981, pp. 233-234). Among traits which have become homogeneous within disciplines through this self-selection is "learning style," a term which refers to "the individual's preferred ways of grasping and transforming information" (Dixon, 1985, p. 16). Significant variations have been found between the dominant learning styles of people in different academic disciplines (Biglan, 1973; Kolb, 1981).

Because chemistry labs are core courses which draw from the entire student body, one would expect to find students with widely varying learning styles in those labs. However, little is presently known about what those differences among MSU chemistry students actually are, and it is not known if any differences which might be present are related to the students' academic majors.

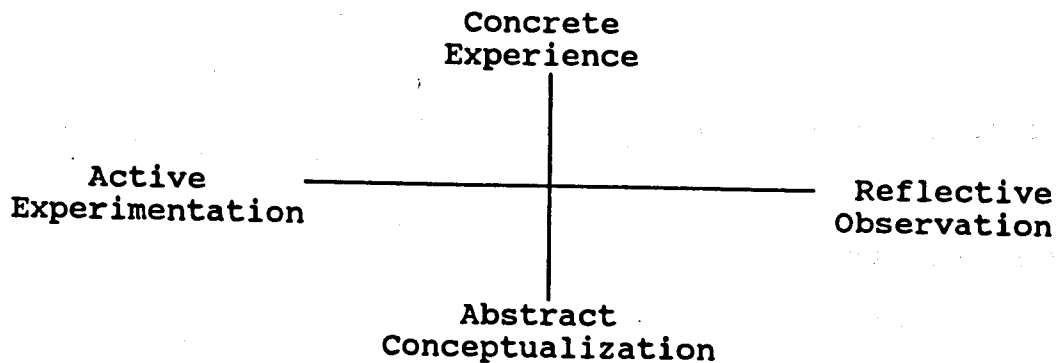
Descriptions of Learning Styles

It is not surprising that with a topic as complex as human cognition there are many different explanations. Several descriptions of the specifics of learning style have been proposed, and instruments have been developed which are designed to measure the different traits. One way to organize these different descriptions is by the level at which they examine the learning process (Curry, 1983). Descriptions at the most personal level deal with the cognitive personality of the individual (Myers, 1962; Oltman, Raskin, & Witkin, 1971). At the most external level are theories and instruments dealing with the learning environment (Canfield, 1983; Riechmann & Grasha, 1974). Between these two levels are theories dealing with the way external information is perceived and processed by the learner (Entwistle, 1981; Kolb, 1981).

One description of learning styles which falls in the middle category is that of Kolb (1985). He identifies two dimensions along which individual learning preferences vary (see Figure 2). The vertical dimension varies from concrete experience ("feeling") to abstract conceptualization ("thinking"). It describes the way the learner apprehends or perceives information. The horizontal dimension is a continuum from active experimentation ("doing") to reflective observation ("watching"). This dimension describes the way the learner

comprehends or processes information and transforms it into knowledge.

Figure 2. Kolb's Dimensions of Learning Style



The combination of these two dimensions onto a single graph yields four quadrants into which a person's preferred learning style could fall. All four approaches are often required for successful learning in a given situation, but individuals tend to prefer some over the others (Kolb, 1974, p. 28). The strength of Kolb's approach

Lies in the fact that he actually starts with human beings and he assumes that the process of thought is not a delusion nor completely controlled by the environment. (Jarvis, 1987, p. 6)

Kolb's description of learning styles, with its contrasts of active versus reflective and concrete versus abstract, is well suited for studying learning in a laboratory setting. Laboratory activities are more active and concrete than many learning environments in a college setting. However, it is not known whether the structure of

these activities interacts with a student's preferred learning style to affect learning. Likewise, it is not known whether students with different learning styles approach the use of the Laboratory Interface differently.

Learning Strategies

In contrast to learning styles, which are relatively persistent traits (Conti & Welborn, 1986, p. 20), learning strategies are techniques and skills students use as they learn. If there are learning style differences among students, these differences should manifest themselves in the actions students employ for learning in the lab.

Five key areas have been identified where learning strategies come into play. "These are the constructs of metacognition, metamotivation, memory, resource management, and critical thinking" (Conti & Fellenz, 1992). Strategies listed under these categories constitute actual skills students use while learning. These learning strategies are situational and specific to the task at hand and thus tend to be rather flexible. However, it is not known whether students with different learning styles will actually use different strategies while learning to use technical equipment like the Laboratory Interface. Neither is it known if the exercises in the interface manual, which are intended to help students learn to use the interface,

employ a range of learning strategies suitable for different students.

Adult Learning Principles and the Laboratory Setting

The college population is aging; it is predicted that by the year 2000 half of the college population will be adults (Aslanian, 1989, p. 7). From the standpoint of college science education, this shift means more attention needs to be given to the way older students learn. As the proportion of older students increases in college classes, the unique characteristics of adult learners should be considered. Malcolm Knowles (1980) has contrasted the ideas of pedagogy, the teaching of children, with those of andragogy, the teaching of adults (Ch. 4). While there is no overall theory of adult learning (Fellenz & Conti, 1989, p. 1; Simpson, 1980, p. 45), Knowles has outlined principles of practice which are widely acknowledged (1980, pp. 45-55). Several of these principles closely match the normal practice in a university science laboratory and therefore make the lab a close fit to the adult education model.

First, laboratories tend to be rather informal with a free exchange of ideas between student and instructor. Usually there is some task or experiment to perform. The instructor is present to give suggestions and guidance but not to dispense knowledge in lecture form. The teacher

guides rather than "teaches" (Knowles, 1980, p. 48). Note, however, that the level of dependence the student places in the instructor is a function of the student's present competence and can vary depending on the situation (Pratt, 1988, pp. 164-165).

Second, laboratories are inherently experiential. The underlying concept behind laboratory instruction is to bring students into direct contact with nature and then to have them draw conclusions about things observed. Thus, student exercises in the laboratory are examples of what Knowles calls "participatory experiential techniques" (1980, p. 50).

Third, normal laboratory practice is to focus on phenomena which can be immediately observed, leaving theoretical overviews for separate lectures. This focus matches with the adult learner's desire for learning which is immediate and concrete as opposed to that which is delayed and theoretical (Conti & Fellenz, 1992; Knowles, 1980, pp. 50-52).

Finally, evaluation in laboratories usually concentrates on written reports by the student. Thus, the student has a great deal of control over that which is evaluated. This falls short of Knowles' "redagnosis" in place of "evaluation" (1980, p. 49), but it does involve the student in the process of evaluation and increases the student's responsibility for the final grade. Thus, it is

in accord with findings that "adults are perceived as more . . . self-directed and task-oriented than pre-adults" (Beder & Darkenwald, 1982, p. 142).

The Need for Research Regarding the Laboratory Interface

Currently the only research done on MSU's Laboratory Interface has been through anecdotal remarks and with a simple questionnaire. There is a danger of a new technology such as the Laboratory Interface becoming just a passing fad like many other technological aids to education "if we don't do research: if we don't know when and if technology is effective, if we don't know how it changes kids or how it changes how teachers teach or how the teaching-learning process goes on" (Bruder, 1989, p. 23). In a technology as new as this, there are bound to be areas which need improvement, but these can never be identified, much less corrected, unless research is done. The introduction of the Laboratory Interface has produced an ideal environment to study how students learn to use computerized equipment, but again, research must be done. The question now becomes "What kind of research?" Taken on average,

Most . . . research studies have shown no significant differences between [laboratory and lecture] methods as measured by standard paper-and-pencil tests in student achievement, attitude, critical thinking, and in knowledge of the processes of science. . . . However, it is

important to note that similarly poor evidence for success has been found for almost all attempts to improve schooling. (Hofstein & Lunetta, 1982, p. 202)

Perhaps the dismal research findings are the result of asking the wrong questions. "Research . . . should be more focused on the student and less focused on the subject matter. . . . We should figure out what the students have in their heads" (McKeachie, 1988, p. 10). One obvious question which is often overlooked is "What is the student really doing in the laboratory?" (Hofstein & Lunetta, 1982, p. 209). In the context of the Laboratory Interface the question could be rephrased as "How do students learn to use the Laboratory Interface?"

Research Questions

The purpose of this study was to examine how students learned to use the Laboratory Interface package and what they perceived its strengths and weaknesses to be. The following research questions were asked:

1. What learning strategies did students use as they learned to use the Laboratory Interface package?
2. What was the students' assessment of the interface package as a laboratory tool?
3. To what extent did students improve in their use of the skills and processes of science while using this equipment?

4. How did student interest in chemistry as a field of study upon completion of a course using a Laboratory Interface compare with their initial interest?
5. Was there a connection between the learning styles of students and their views and uses of the Laboratory Interface?

Significance of the Study

The results of this study are significant in several ways. First, as computerized equipment pervades society, it is important to know how people learn to use such equipment. Such information is an important step toward improving instruction in its use and can add to knowledge of the learning process itself. If some strategies are found to be useful by a wide variety of students, instructors could teach these strategies to all.

Feedback from students regarding strategies they found helpful and unhelpful can serve as practical guidelines to those writing instruction manuals and designing laboratory exercises. Knowledge of such strategies can also add to the pool of information regarding the use of learning strategies themselves. For example, the statement "I tried to find the answer in the manual, but couldn't" reveals two important items of information--the manual was deficient either in its information or its indexing, and the student

was trying to use the strategy of looking in a reference manual for answers.

Second, it is important to know student perceptions regarding the ease of use and usefulness of the Laboratory Interface. In the final analysis, the package will only be accepted by students if they find it easy to learn and if they appreciate its power. Improving the package is possible only if strong points are identified and improved upon and if weak points are identified and changed.

Third, a core course like freshman chemistry aims to improve both the student's knowledge of chemistry and the student's knowledge of science in general. It is important, therefore, to determine whether students are improving in their use of the skills and processes of science while using this equipment.

Fourth, it is important for both the Chemistry Department, which needs to attract and retain students, and for society at large, which needs the services of trained chemists, to track student interest in chemistry as a field of study. Tracking such interest systematically could require an expanded longitudinal approach which would constitute a complete project in itself. The preliminary information provided by this study, however, should prove useful to the department as a starting point.

Finally, it should be known whether connections exist between student learning styles and the ways students learn

to use the interface. The concepts to be learned are to a large extent fixed by the discipline itself. Approaches used to learn those concepts, however, could well be broadened to include methods matching different learning styles if such were found to be helpful. Knowledge of learning style differences could also be used to counsel students as they begin laboratory study. Knowledge of one's learning style helps focus attention on the learning process, and could help students pick strategies which have worked for previous students with a similar style.

Definition of Terms

Integrated Science Process Skills: science skills such as drawing and interpreting graphs, identifying dependent and independent variables, and inferring relationships from tables of data. The integrated process skills are contrasted with the basic skills such as observing and measuring (Dillashaw & Okey, 1980, pp. 601-602).

Interface: (noun) the electronic circuitry which connects measurement sensors to a computer.

Interface: (verb) to connect measurement sensors to a computer, so the computer can record the readings.

Learning Style: "the individual's preferred ways of grasping and transforming information" (Dixon, 1985, p. 16).

Learning Style Inventory: an instrument (test) designed to measure learning style. The term "Learning Style(s) Inventory" and the abbreviation "LSI" are applied to separate instruments by Canfield, Dunn, Kolb, and sometimes others. There are also similar titles like "Learning Styles Scales," "Learning Modalities Inventory," "Learning Preference Inventory," and "Cognitive Style Inventory," all referring to separate instruments.

Microcomputer-Based Laboratory (MBL): an integrated package which consists of a computer, measurement sensors, circuitry to connect the sensors to the computer, and software to control the measurements and analyze the results.

MSU Laboratory Interface: the microcomputer-based lab equipment developed by the Chemistry Department at Montana State University. The term is also used more narrowly to refer to the circuitry which connects the sensors to the computer.

Technology: when used with respect to education, instructional media which fit in the category of "hardware," such as radio, television, and computers.

Limitations

Several institutions have small numbers of Laboratory Interfaces, but MSU is the only university which has

equipped all freshman labs with Interfaces. In addition, it is only the freshman labs at MSU which are fully computerized. Therefore, this project studied only students in freshman chemistry laboratories at MSU.

Delimitations

Students selected for this study were those enrolled in the winter quarter freshman chemistry labs. This quarter was selected because there are many more students enrolled in lab classes winter quarter than spring quarter.

Assumptions

Freshman chemistry laboratories at MSU are taught autumn, winter, and spring quarters. It is assumed that students in the labs during winter quarter are essentially similar to students enrolled other quarters.

To avoid any appearance of coercion, students invited to participate in focus groups were given the option to decline. Students were also assured that their identities would be shielded on questionnaire results and in statements made in focus groups. Therefore, it is assumed that students have answered questionnaires and focus group questions candidly and openly.

CHAPTER 2

BACKGROUND AND REVIEW OF LITERATURE

The Use of Technology in Education

Some educational specialists reserve the term "educational technology" to refer to "a systematic way of designing, implementing, and evaluating the total process of learning and teaching in terms of specific objectives" (Percival & Ellington, 1988, p. 20), but this usage is by no means universal (Stakenas & Kaufman, 1981, pp. 41, 42). In this paper "educational technology" means instructional media which fit in the category of "hardware," such as radio, television, and computers.

Historical Use of Technology in Education

American education has a long history of infatuation with technology, but many of the uses of technology have been inappropriate or ineffective. The first technological innovation in this century to impact the field of education was the motion picture. Thomas Edison, who was hardly a disinterested observer, confidently predicted in 1913 that "books will soon be obsolete in the schools" (quoted in Cuban, 1986, p. 11). A decade later he said,

I believe that the motion picture is destined to revolutionize our educational system and that in a few years it will supplant largely, if not

entirely, the use of textbooks. . . . The education of the future, as I see it, will be conducted through the medium of the motion picture, . . . where it should be possible to obtain one hundred percent efficiency. (quoted in Cuban, 1986, p. 9)

Educational radio rode the next wave of enthusiasm in the 1930s and 1940s (Stakenas & Kaufman, 1981, p. 15), but the impact was small. Among other problems, the appropriateness of some radio programs to the general educational endeavor must be questioned. Broadcast programs for the use of educational radio ranged from appropriate programs such as "Exploring the News" and "Music Enjoyment" to "Let's Draw" (Cuban, 1986, p. 22).

Educational television followed radio and today enjoys modest success (Stakenas & Kaufman, 1981, p. 18). One must ask, however, why none of these innovations have fulfilled early predictions. Most uses of hardware in the classroom have followed a similar pattern (Cuban, 1986, pp. 4, 5). Reformers, who were often wholesalers or administrators, would espouse the new technology as a solution to educational problems. Enthusiastic adoption would be followed by studies which demonstrated the effectiveness of the new technology. Some time later, surveys would show infrequent use by classroom teachers. Three key points in this pattern were that (a) teachers seldom initiated these innovations, (b) the question of whether the new technology should be introduced was seldom asked, and (c) the new

technologies were often used inappropriately and were too limiting in the "complicated realities of classroom instruction" (1986, p. 59).

The last point deserves further elaboration. Those who view what happens in a classroom as a technical process seek technological solutions. They "believe that student learning is mechanical; that is, what teachers do skillfully will cause predictable student outcomes. No persuasive body of evidence exists yet to confirm that belief" (1986, p. 88). That some held this view can be seen in book titles such as Automatic Teaching: The State of the Art, which contains "The Ideal Teacher" as a chapter (Galanter, 1959). The "ideal teacher," of course, is a machine.

Currently the computer is the new wunderkind. The echo of Edison's prediction is voiced today by Alfred Bork (1981), one of the leading proponents of the use of computers in schools--"it appears likely that computers will soon be more important in our educational process than books, and, indeed, may entirely replace the book medium for many purposes" (p. 2). Will the use of computers in education follow Bork's prediction, or will it go the way of radio? Before parallels are drawn too quickly, three differences should be noted between the technologies mentioned above and the use of computers in education.

First, the adoption of computers has both bottom-up and top-down forces (Cuban, 1986, p. 77; Moursund, 1987, pp. 4, 63). That is, parents and individual teachers are urging adoption at the classroom level, and so are administrators and state educational supervisors at the system level (Becker, 1984, pp. 24-25).

Second, computers have come to be useful to people in their everyday lives (Moursund, 1988, pp. 4, 5). For example, it is difficult to find anyone who has returned to using a typewriter after becoming comfortable with a word processor. People assume, rightfully so, that students would find computers to be equally useful to them.

Finally, the potential exists to use computers appropriately in education. In the laboratory, computers can help the student focus on the physical phenomena under study by relieving the tedium of manual data manipulations (Amend, Tucker, Larsen, & Furstenau, 1990, p. 111; Rutherford & Ahlgren, 1990, p. 113).

Computers in Chemical Education

Computers have been used for instruction in chemical education since the early 1970s (Castleberry & Lagowski, 1970, p. 91). They were first used in "individualized instruction" applications as simple tutorials on a terminal connected to a mainframe computer. Consequently, they did not see widespread use. Earlier uses for data reduction

and analysis did not have "instruction" as a primary component (Bard & King, 1965, p. 127; Emery, 1965, p. 131; Swinnerton & Miller, 1959, p. 485).

The availability of personal computers in the last decade has made a dramatic difference in the quantity and quality of tutorial software in chemistry. The Journal of Chemical Education contains at least 50 articles featuring computer-assisted instruction during that time (Furstenau, 1990, p. 4). Drill-and-practice is still the most common use of computers in science classes (Baird, 1989, p. 19), but new products like KC²Discover and Project SERAPHIM allow students to explore rather than to just receive information (Feng & Moore, 1986, p. 327). Commercial products like those developed at Western Washington University contain help screens, a periodic table, and a "pop-up" calculator to augment the tutorial (Weyh, 1989), thus going far beyond traditional "drill-and-practice." From the standpoint of adult education principles, however, there is still an objection to this use of computers because the computer rather than the student is the director of the learning (Knowles, 1980, p. 48).

Computers can also be used to simulate laboratory experiences which would otherwise be too dangerous or too costly (for example, Clariana, 1989, pp. 14-19; Heckenlively, 1987, pp. 123-127; Raw, 1987, pp. 135-138). However, this use is an area where questions of

"appropriateness" come into play--computer simulations should be used as replacements for direct contact with nature only when necessary (Marks, 1982, p. 19; Winders & Yates, 1990, p. 11). Chemistry is very abstract by its nature (e.g., who has seen an atom?). One should therefore be very cautious about removing chemistry still further from everyday reality by using simulated experiments. The whole purpose of the laboratory is to bring students into contact with nature and not to insulate them from it.

Computer Interfacing

In addition to tutorial and simulation software, there has been a growing use of computers as measurement instruments in the laboratory. Figure 3 shows the scientific process as it is practiced in the chemistry laboratory. The power of the computer can be utilized in this process, especially in Steps 3 and 4. With a suitable interface, the computer can accurately acquire large amounts of data much more quickly than a person is capable of or over longer periods of time than a person cares to. For example, the Laboratory Interface can take several thousand measurements per second or can acquire data over periods of days or weeks. After the data are acquired, the computer can be used to manipulate it and quickly draw graphs. This allows the operator to concentrate on

relationships between the variables which are made visible on the graphs.

Figure 3. The Scientific Process in the Laboratory (adapted from Furstenau, 1990, p. 97)

1. Choose experimental problem
2. Design experiment
3. Acquire data
4. Perform data analysis
 - 4.1 Calculate
 - 4.2 Graph
 - 4.3 Search for relationships
5. If no generalization is apparent, repeat from Step 4.1, or even from Step 3 or 2.
6. Once a generalization is apparent, write conclusions or report

There are many examples of the use of computers as measurement instruments. Most of these applications use the game port on Apple II series computers (for example, Kelly, 1990, pp. A254, A257; Wainwright, 1986, p. 53). A few use computers made by Atari (Meyer, 1990), Commodore (Rutledge & Hooks, 1987), and IBM (Snyder, 1987). As a rule, these applications are unsophisticated, using slow BASIC-language commands to control the computer and low-precision 8-bit converters to change sensor measurements to digital numbers. This limits the speed and usefulness of the resulting measurements. The primary focus has been on the programming and electronic circuitry required for data acquisition (Step 3). Often the resulting data is analyzed (Step 4) using separate commercial packages such as Appleworks, Lotus 1-2-3, or Microsoft Works. These

analysis programs are powerful but complicated, and they are not particularly suited to student use with laboratory data.

Interfacing of this type has become so popular that courses and workshops are offered on how to construct and program the interfaces (Henry, 1987; Walton, 1986). The hidden message of these courses is that this piecemeal approach to computer interfacing in the laboratory is not simple. "Programming and constructing interfaces is both a formidable task and a learning experience. Create a team of teachers and students. Learn and work together" (Westling & Bahe, 1986, p. 47). At this point the focus has become computer interfacing rather than chemistry.

Microcomputer-Based Laboratories

The "piece-at-a-time" approach to laboratory interfacing described above directs the attention towards computer programming and circuit design and away from chemistry. To prevent this shift in focus a new type of laboratory environment has been developed--the microcomputer-based laboratory (MBL). An MBL is an integrated hardware/software package which combines a computer, measurement probes, circuitry to connect the computer with the probes, and software to run the computer. The software is complete enough to allow the student to set up an experiment, collect data, and analyze the data by

manipulating it in various ways (Furstenau, 1990, p. 97). In other words, Steps 2, 3, and 4 of Figure 3 should be done using one integrated package.

There are several benefits to this approach. The most obvious is that the student is relieved of the tedium of manual data measurement and recording, "allowing the student to focus on the physical phenomena under study" (Balkovich, Lerman, & Parmelee, 1985, p. 1215). Another advantage is the redistribution of time (Amend, Tucker, Larsen, & Furstenau, 1990, p. 102). In a traditional chemistry lab, collecting a usable amount of data can easily take the major portion of a lab period, leaving little time for experiment design and data analysis. With the MBL data can be collected quickly, so more time is available for design, analysis, and drawing conclusions. Ironically, one study found that laboratory set-up time was also quicker for students using an MBL, compared to those using traditional equipment (Stein, Nachmias & Friedler, 1990, p. 190). A third advantage is the quick feedback of results to students, thus giving them time to repeat steps when necessary (Cordes, 1990, p. 62).

Perhaps the most important advantage is the assistance the software can give in analyzing the data. "Computers . . . play a role in helping people think by running programs that amass, analyze, summarize, and display data" (Rutherford & Ahlgren, 1990, p. 113). By speeding up some

of the slower steps, a microcomputer-based lab allows students "to actually think about their data" (Amend, Tucker, Larsen, & Furstenau, 1990, p. 111). However, this advantage seems to vary by age--a group of eighth grade students considered the MBL to be "a procedural convenience, rather than . . . a cognitive advantage" (Stein, Nachmias & Friedler, 1990, p. 198). The same study found MBL students to pay less attention than traditional students during data collection in a temperature experiment, but this was an example of putting "new wine into old wineskins." The liquids used in the traditional experiment were chosen to allow slow-paced manual data collection over a 10- to 20-minute period. The experiment could have been modified for the MBL by using a different liquid and made the same educational points in 2 or 3 minutes.

A different study identified another potential drawback in the use of an MBL. It found that, while students in both traditional labs and microcomputer-based labs achieved the same skills in interpreting graphs, the traditional students outperformed the MBL students in the construction of graphs (Adams & Shrum, 1990). Care must be taken, therefore, to ensure that students in an MBL lab are not missing the opportunity to learn some of the skills they should.

The MSU Laboratory Interface

Microcomputer-based labs are becoming common enough in elementary and secondary schools that hardware and software are being offered commercially (Holte, 1989, p. 42; Seiger, 1990), but hardware with the capabilities required in the college setting has only recently been developed. A system developed in Australia has the precision and flexibility required (Cheesman, 1989). However, assembly-language software "drivers" are required to adapt the package to different computers, and it uses a computer language which is probably too slow for effective use on many microcomputers. Another example is the Laboratory Interface developed at Montana State University.

Criteria. The MSU Laboratory Interface was developed with several criteria in mind: It should make all common electronic measurements the freshman labs with research precision; it must be easy to program; it should be capable of using simulated as well as actual data; and it must be expandable (Amend, Furstenau, & Tucker, 1990, p. 593). By meeting these criteria, the Laboratory Interface fulfills two goals: It makes the overall process of science available within a laboratory period, and it acquaints students with the use of research-grade computerized equipment in the laboratory.

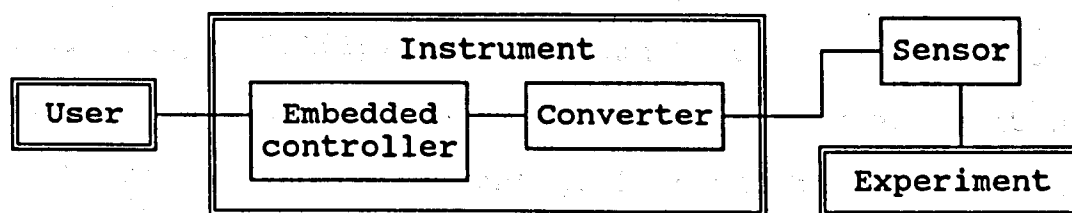
The first goal is reached through the redistribution of time. Students can design an experiment, collect data, analyze the data, and draw conclusions within a standard laboratory period (Amend, Tucker, Larsen, & Furstenau, 1990, pp. 102-103).

The second goal is reached because the laboratory interface utilizes high-precision 13-bit converters to change sensor measurements to digital numbers and because it uses IBM-compatible computers which are much faster than the older Apple II series. In addition, the student does all the actual computer operations. To start, the student sets up an experiment by entering the type, number, and frequency of measurements to make. This is done using simple menu-driven software so there is no complicated programming language to learn. Next the student instructs the computer to actually make the measurements, perhaps with a real-time graph of the results appearing as measurements are made. Finally, the student uses the data analysis portion of the software to manipulate and graph the data in various ways until relationships become apparent. Data and graphs can be printed or saved on disk for later analysis.

Description of the Interface. Figure 4 shows the typical configuration of a computerized laboratory instrument. The operator turns the instrument on and

connects the probe. The sensor responds to the physical quantity of interest such as temperature or pressure and produces an analog electrical signal. The converter then changes the analog signal to a digital number which the built-in computer presents to the user as the final result. In this case the computer is an "embedded controller," which is a microprocessor with a permanently-stored program which operates the instrument. The computer and its operation are hidden from view. This arrangement is convenient for the user but is inflexible; there is little or no control over the measurements. If repeated measurements are desired, they must be written down at the appropriate times.

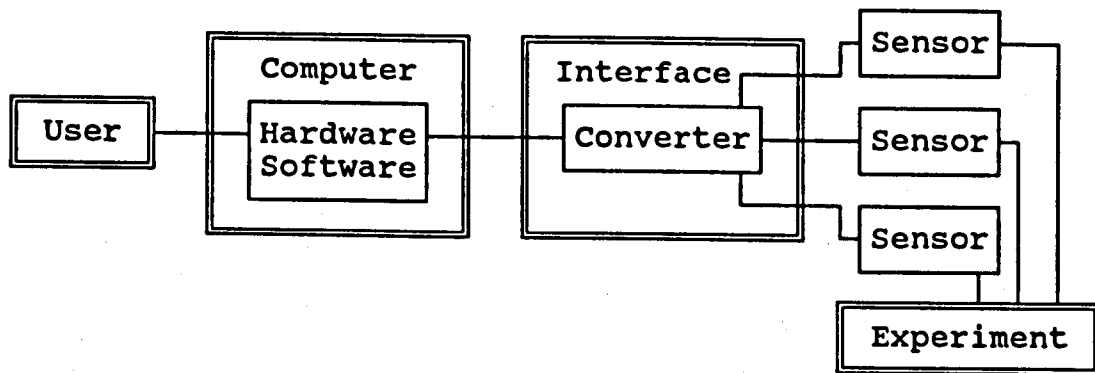
Figure 4. Diagram of a Typical Chemical Instrument with an Embedded Controller (Microprocessor).



The Laboratory Interface follows a similar scheme (see Figure 5), but the computer is a standard IBM-compatible PC. Sensors connect to the interface, which converts signals to numbers that are sent to the computer. The software converts these numbers to calibrated measurements

such as temperature, voltage, current, or light intensity and presents the results to the user. This may be a number on the screen, a graph on the screen, values stored in columns of the built-in spreadsheet for later manipulation, or perhaps all three.

Figure 5. Diagram of the MSU Laboratory Interface with Multiple Sensors.

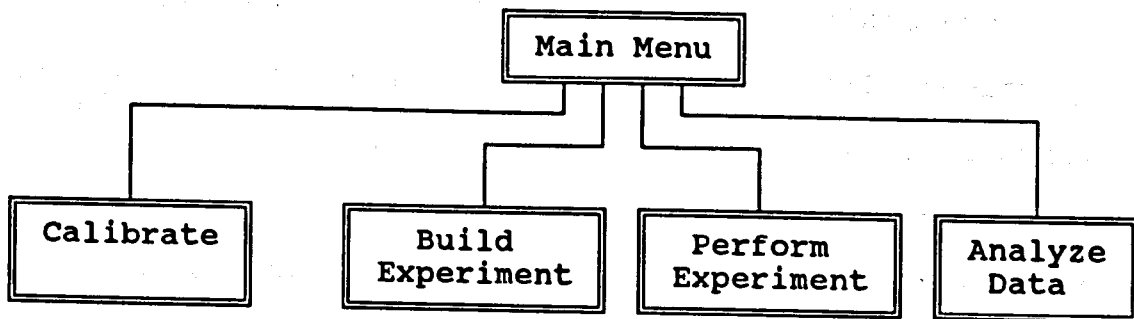


One advantage of the laboratory interface is its flexibility. Multiple sensors can be used (see Figure 5), and the frequency and number of measurements are controlled by the user. Another advantage is that the same computer and interface are used with many different kinds of sensors, so significant cost savings are possible compared to having many separate instruments.

Interface Software. The largest disadvantage of the computerized interface is that the user must "program" the measurements to be made. The type, number, and frequency

of measurements must be selected and stored before data acquisition can begin. This requires knowing which steps to select and how to select them. A certain amount of learning must occur before the student can make measurements and benefit from the power of the tool. The initial task for the student is to become comfortable using the software which controls the interface. Figure 6 shows the main parts of the software.

Figure 6. Parts of the Laboratory Interface Software



The main parts of the software, as far as the student is concerned, are the sections that build experiments, perform experiments (acquire data), and analyze the data. Calibration is only necessary when certain sensors are changed.

In the "build experiment" section the student programs the computer to make the desired measurements. The student uses a menu-driven editor to select the types of measurements which will be made, specify how many

measurements will be made, and direct the results to the screen or to columns in an electronic spreadsheet.

To perform the experiment, the student loads the appropriate program and starts the data acquisition. The computer will stop automatically when the preprogrammed number of measurements have been made. Alternately, the program could have specified that the measurements stop when a certain condition is met or when a certain key or switch is pressed.

The data analysis phase could happen at the same time the measurements are being taken if the values are displayed on the screen in the form of single numbers, columns of numbers, or a graph. However, it is usually desirable also to store the measurements in a file so later they can be retrieved into the columns of a spreadsheet. The data then can be manipulated using standard mathematical functions and the results can be shown graphically on the screen. Once the relationships between the variables becomes apparent the values and the graphs can be printed to form a permanent record of the experiment.

Learning Styles

As cognitive psychology took its place beside behaviorism in the study of human thinking, it become increasingly clear that the workings of the mind are more

complicated than previously believed. Former positions had to be modified or enlarged.

In fact, each one of the principles confidently enunciated by Skinner in The Science of Learning and the Art of Teaching now turns out to be untrue--at least in as general a sense as he believed at that time. (McKeachie, 1974, p. 186)

As it became apparent that individual human learning was more complex than the conditioning of laboratory animals a wide variety of conceptualizations of learning emerged. One explanation for this diversity is that just when the time was ripe for a unification of multiple theories of individual learning, the field of psychology shifted from studying individual differences to studying "between-group differences such as racial differences, sexual differences, and social class differences" (Curry, 1983, p. 2). This shift left the study of individual learning and learning styles incomplete.

A Hierarchy of Learning Styles

In an effort to organize the different theories and instruments, Curry reviewed 21 instruments for "psychometric acceptability." The only criteria for acceptance were that "there had to be some meaningful data collected, reported and described concerning [the] validity and reliability" of the instrument, but even these minimal requirements excluded 11 of the tests (p. 7). Based on a content analysis of the remaining instruments and

statements regarding their intended purpose, nine of the instruments could be put into a three-level hierarchy, like the concentric layers of an onion. At the center were descriptions of learning dealing with the cognitive personality. Examples are Witkin's Embedded Figures Test and the Myers-Briggs Type Indicator.

The Embedded Figures Test (Oltman, Raskin, & Witkin, 1971) purports to measure the amount of field dependence or independence of an individual through the task of identifying geometric figures within a distracting background. It actually only measures field independence and implies field dependence by a lack of independence, which is a questionable procedure (Bonham, 1988, p. 12). These traits characterize global versus analytical styles of cognition.

Another instrument in the innermost category is the Myers-Briggs Type Indicator (MBTI) (Myers, 1962). It yields scores for intuition versus sensing, introversion versus extraversion, thinking versus feeling, and judgement versus perception. It is based on Jung's theory of psychological types, and thus it tends to be accepted by those who subscribe to Jung's theory and ignored by those who do not (Wiggins, 1989, pp. 537-538).

The outermost layer of the hierarchy concerns instructional preferences; that is, the environment in which an individual prefers to learn. This is the level at

which the learner encounters the external world. Canfield's Learning Style Inventory (1983) fits this category, but Curry excluded it for failing to meet the validity and reliability requirements. This LSI is concerned with the conditions, content, and mode of learning and the expected degree of success. An instrument with an orientation somewhat similar to Canfield's is the Dunn LSI. It asks students for responses about their learning environment, their emotionality, their sociological needs, and their physical needs (Dunn & Dunn, 1978). This test also fits the outermost layer of the hierarchy because it examines conditions under which learning occurs but does not address the learning itself. A third example in this category is the Grasha-Riechmann (1974) Student Learning Style Scales (SLSS). It provides scales to indicate the extent to which students are independent, dependent, collaborative, competitive, participant, and avoidant.

At the middle level of Curry's hierarchy are theories dealing with the assimilation and processing of information. Examples of learning style descriptions in this category are those of Entwistle (1981, p. 105), who differentiates between "deep" and "surface" learning, and Pask (1976, p. 130), who found differences between "holist" and "serialist" learning. A third example is the Inventory of Learning Processes (ILP) (Schmeck, Ribich, & Ramaniah,

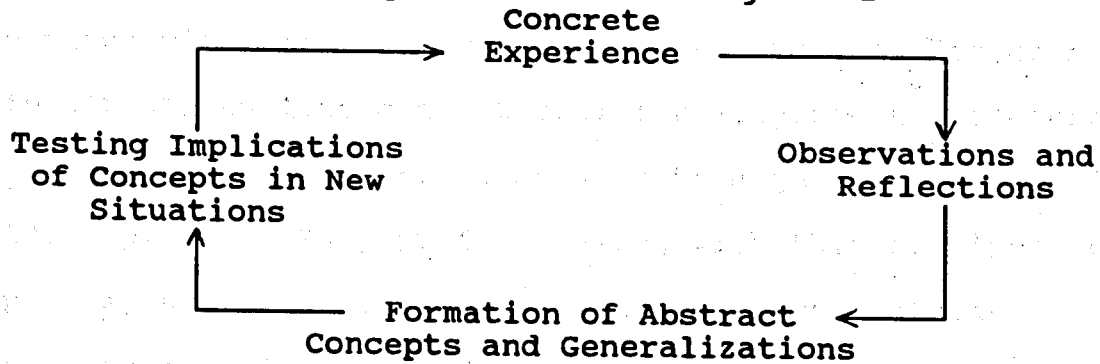
1977) which has scales for study methods, the retention of facts, the synthesis of study materials, and the ability to relate information to personal experience. Kolb's Experiential Learning Model and Learning Style Inventory also fall into this middle category.

Kolb's Learning Styles

Kolb defines learning as "the process whereby knowledge is created through the transformation of experience" (1984, p. 41). His explanation of learning is based upon what he calls the "Experiential Learning Model" (1974, pp. 27, 28). This four-stage cycle (see Figure 7) describes learning as starting with some concrete experience which one observes and reflects upon. This leads to the formation of generalizations which are tested in new situations, creating new concrete experiences. Learning is cyclic, and the different stages of the cycle require different cognitive skills. Some would extend Kolb's model to include learning situations that are not cyclic and to add other types of learning such as skills (Jarvis, 1987, pp. 7, 18).

One recent shift in learning theory has been from stimulus-response to an "information processing approach" (McKeachie, 1974, p. 187). Kolb exemplifies this in his description of learning styles. He placed the four cognitive tasks in the Experiential Learning Model into

Figure 7. Kolb's Experiential Learning Model



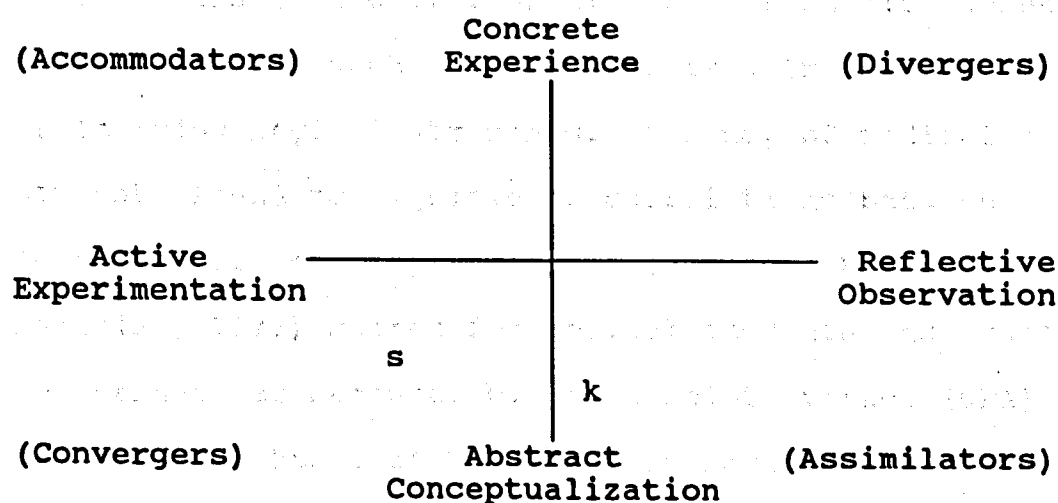
opposing pairs to arrive at two dimensions along which people vary in their learning (see Figure 8). The vertical dimension describes the way people perceive information; it varies from those who can gain new insights through abstract thinking to those who prefer concrete experiences. The horizontal dimension describes the way people process information once it is perceived; that is, how they internalize new information and make it part of their overall knowledge base. This dimension varies from those who can process information by observing and reflecting on it to those for whom actively working with new information is the best way to assimilate it. This framework

Includes various styles of learning and suggests that effective learners may be those who can call upon various approaches, depending on the purposes and circumstances of the learning.
(Simpson, 1980, p. 54)

Kolb uses the terms Convergers, Divergers, Accommodators, and Assimilators to label the four quadrants of the learning style plane. While Kolb (1981) stresses that the four learning styles should not become stereotypes

(p. 238), he does describe general characteristics of persons with the four traits. Convergers seem "to do best in situations like conventional intelligence tests where there is a single correct answer" to a question (Kolb, 1974, p. 30). They prefer dealing with things, rather than people, are relatively unemotional, are good at the practical application of ideas, and often prefer the physical sciences and engineering.

Figure 8. Kolb's Four Learning Styles



Divergers are the opposite of Convergers. They excel in the generation of ideas, as opposed to finding "correct" answers; are interested in people; are relatively emotional; and tend to specialize in the arts (p. 31).

Assimilators are adept at creating theoretical models. They prefer inductive reasoning, are more interested in abstract concepts than people, but are less interested in

practical applications than Convergers. Mathematicians and theoretical scientists often display this style (p. 31).

Accommodators are the opposite of Assimilators. They prefer doing things, are often more flexible than the others, use intuition and trial-and-error, tend to ignore theory, and are often in practical fields such as marketing, sales, or business (p. 31).

Learning Styles and Academic Performance

There is a recurrent wish that knowledge of learning styles would be a useful predictor of academic success, and failure to find such correlations is a frequent criticism of learning style instruments. A study of medical school students found no significant correlations between Inventory of Learning Processes (Schmeck, Ribich, & Ramaniah, 1977) scores for medical students and academic performance as measured by grade point average (GPA) and the National Board of Medical Examiners (NBME) Test (Leiden, Crosby, & Follmer, 1990). Unlike some other studies, this one correctly listed the possible reasons for the lack of expected results: (a) the reliability of the learning style instruments may have been too low, (b) the sample size may have been too small, (c) GPA and NBME scores may not accurately measure academic performance, (d) the learning style instruments used may not have been valid measures of learning style, or (e) "it may be that learning

styles, while related to academic performance, are not a major factor in explaining academic performance" (p. 400).

Another example of negative results was a study of college freshmen. It found no significant difference between the English grades of students whose Kolb LSI learning styles matched those of their instructors versus the grades of students whose learning styles did not match those of their instructors (Davis, Murrell, & Davis, 1988). One possible reason for the negative findings is that "it is unclear from the available literature whether [a] teacher's learning style will always be reflected in their teaching procedures" (p. 9).

In contrast to these two examples, the perception dimension of Kolb's learning style was found to be significantly related to overall skill in the processes of science (Nakayama, 1988). Students who prefer abstract conceptualization out-performed students who prefer concrete experience. In conclusion, it should be emphasized that "more is needed than a knowledge of a student's learning style in order to improve the quality of teaching and learning" (Conti & Welborn, 1986, p. 22).

Criticisms of Learning Style Instruments

Arguments against different learning style instruments are based on several grounds. Often instruments are not judged on their own merits but on what the critic wishes

the instrument were like. For example, Ferrell (1983) is a proponent of a conceptualization which describes learning style as being comprised of cognitive, affective, and physiological behaviors (Keefe, 1979). She reviewed four learning style instruments (Grasha and Riechmann SLSS, Kolb LSI, Johnson DMI, and Dunn LSI) and took each to task for not following Keefe's scheme. Other critics wish for a complete profile of each student, and lament the fact that "these models and inventories cannot faithfully describe the totality of a student's experience" (Karrer, 1988, p. 10).

Sometimes the methodology of a critic is as questionable as that of the target of the complaint. One "validity study" of Kolb's LSI used responses from 54 participants at a continuing education conference for medical professionals (Fox, 1984). To test the construct validity of the LSI, a second measure was needed against which LSI scores could be compared, so a questionnaire was developed using words from Kolb's descriptions of the four learning styles. For example, Kolb described Divergers as liking "brainstorming idea sessions." However, Fox's questionnaire item regarding this word was "The conference allowed me the opportunity to brainstorm" (p. 79). This item is asking for a description of the conference, not the learner's preferences. Other questionnaire items contained similar statements about the conference but not about

individual preferences. In discussing the reasons for the low validity of the LSI, Fox failed to even suggest the possibility that his questionnaire may not have been valid or reliable (pp. 83-84).

Another common criticism of instruments is the establishment of norms using either poorly-defined or inappropriate sample populations. The normative population for Canfield's LSI is criticized for not matching the intended audience (Low, 1985, p. 841). Sewall (1986, p. 25) criticizes Kolb for using normative groups which are biased toward the upper end of educational, intellectual, and socioeconomic spectrum and for failing to include any information regarding reported differences due to age or sex. While these criticisms of Kolb seem valid, Sewall's overall poor opinion of the LSI is not necessarily sound. His assessment is partly based on Fox's study and on a study by Whitney and Caplan (1978). Sewall reports that Whitney and Caplan found that "there were no significant differences between the two groups" (Sewall, p. 32). However, Whitney and Caplan actually reported that "the learning styles of these two groups of physicians did appear to differ" (p. 685).

Some criticize Kolb's LSI for its ranking format (Sewall, 1986, p. 21). Ranking one word highly automatically ranks other words lower, an effect which causes even simple correlations to be artificially high.

(Bonham, 1988, p. 15). Other researchers complain about inappropriate choices of statistical tests. Kolb reports a Spearman-Brown split half reliability coefficient, but Moore and Sellers (1982) maintain that a more appropriate choice for Kolb's ranking format would have been a Spearman rank order coefficient (p. 231).

Chemists and Learning Styles

Kolb surveyed 800 managers and graduate students in management and divided them by undergraduate major (1981, p. 240). Using norms of that group, college chemistry majors fell into the Assimilator category, but they were close to the line dividing Assimilators from Convergers (see the 'k' in Figure 8). However, only 27 of the 800 persons in the sample were chemistry majors, so placement on the graph is based on a small sample. Also, drawing conclusions about all chemists using data from persons who once studied chemistry but are now managers or studying to be managers is questionable.

In contrast with Kolb, Smedley surveyed a population of professional chemists--all 441 were members of the American Chemical Society (1987, p. 321). He found the average to fit Kolb's Converger category (see the 's' in Figure 8). Comparing Smedley's practicing chemists with Kolb's managers and management students with chemistry majors, the chemists were in roughly the same area on the

perception (vertical) scale but were more inclined towards active experimentation on the processing (horizontal) scale.

On average, then, "chemists are more inclined toward active experimentation and abstract conceptualization as modes of learning than is the normal adult population" (p. 321). No significant trends in learning style were found with respect to undergraduate major, sex, employment category, or education level (p. 322), but there was a movement toward reflective observation and abstract conceptualization with increasing age (p. 321). With respect to teaching non-chemistry majors in the chemistry lab, Smedley points out that "educators might also help students who are not Convergers by including activities that appeal to all four of the learning modes" (p. 323).

Integrated Science Process Skills

Since the 1960s there has been an emphasis among science educators on the processes of science along with the facts of science (Molitor & George, 1976, p. 405). The American Association for the Advancement of Science (AAAS) led the way with its elementary series titled Science--A Process Approach (AAAS, 1967; Livermore, 1964). It identified eight basic processes (observing, classifying, measuring, communicating, inferring, predicting, recognizing space/time relations, and recognizing number

relations) and six integrated processes (formulating hypotheses, making operational definitions, controlling and manipulating variables, experimenting, interpreting data, and formulating models). The descriptions were somewhat imprecise, but they served to focus attention on a neglected aspect of science education (Yeany, Yap, & Padilla, 1986, p. 279). Instructions for individualized measurement procedures were suggested by the AAAS, but these were largely ignored by researchers because they required too much time of a trained observer (McLeod, Berkheimer, Fyffe, & Robinson, 1975, p. 416).

The identity and measurement of the process skills has remained fluid. Tannenbaum (1971) identified only seven skills (observing, classifying, quantifying, measuring, experimenting, inferring, and predicting) which he measured with a 96-item instrument. This test was the first which attempted to separate the measurement of science processing skills from any specific field of science (Mattheis & Nakayama, 1988, p. 2). Other tests such as Ludeman's Science Processes Test (1975) remained close to the AAAS curriculum. However, Ludeman was the first to raise the question of exactly what a test of "science processes" measured. In his case, high correlations between the science processes test and the factual knowledge test which accompanied the curricular material led him to suspect that they measured the same construct.

Another 1975 instrument focused on only four of the integrated processes skills in an attempt to develop criterion-validated items (McLeod, Berkheimer, Fyffe, & Robinson). The 79-item test addressed controlling variables, interpreting data, formulating hypotheses, and operationally defining variables. High correlations between the test scores and direct student observations of the AAAS procedure and high intercorrelations of scores on the two tests led the authors to speculate that perhaps the integrated process skills themselves are not unique (p. 420). Reading level, IQ, and Piagetian level of development were suggested as correlates.

Another way to view the science process skills is to put them into a hierarchy. One study used Tannenbaum's instrument to measure science process skills before and after an Introductory Physical Science class (Butzow & Sewell, 1979). Differences in improvement among low-ability and high-ability groups led to the assumption that there might be a hierarchy in the process skills: observing, classifying, and predicting on Level 1; comparing, inferring, and experimenting on Level 2; measuring on Level 3; and quantifying on Level 4 (p. 270).

Perhaps the most limited example of a process skills test addressed only the skills of inference and verification (Molitor & George, 1976). It used mainly illustrations in an attempt to eliminate the confounding

effects of variations in verbal fluency among lower grade students.

Currently, the most widely used instruments for measuring integrated science processing skills are the Test of Integrated Process Skills (TIPS) and its alternate form TIPS II (Dillashaw & Okey, 1980; Burns, Okey, & Wise, 1985). These are 36-item multiple choice tests which address the integrated skills of "formulating hypotheses, operationally defining, controlling, and manipulating variables, planning investigations, and interpreting data" (Dillashaw & Okey, p. 602).

Even among researchers using TIPS there is dialog about the relationship between process skills and other cognitive constructs. For example, a study using elementary-education majors could not establish the independence of processing skills and formal reasoning ability (Baird & Borich, 1987, p. 267). The researchers concluded that the two might not be orthogonal traits. That is, they might be different names for the same thing. However, the small sample size of 54 may have contributed to the negative finding. A similar study of 492 students in grades 7-12 found high correlations between science processing skills and logical thinking, and a factor analysis identified only a single factor (Padilla, Okey, & Dillashaw, 1983, pp. 243-245). In this case the researchers stated that there was "strong evidence for a

common underlying construct" but then concluded that the search should continue for the causal relationship between the two separate traits (p. 245).

Another study specifically searched for hierarchical relationships between the integrated process skills and cognitive skills (Yeany, Yap, & Padilla, 1986). It was found that the most basic cognitive skills are conservation reasoning, combinatorial reasoning, and designing experiments. Above these are the integrated process skills of controlling variables, operationally defining variables, and graphing and interpreting data and the cognitive skill of proportional reasoning. The next level has the process skill of identifying hypotheses and the cognitive skill of probability reasoning. In the top level, which requires competence in all the lower levels, are the process skill of identifying variables and the cognitive skill of correlational reasoning. The conclusion was that "some of the skills . . . cannot be acquired until others are in place" (p. 289).

A follow-up study approached the question of a hierarchy more directly by testing process skills before and after review of supposed subordinate skills (Yap & Yeany, 1988). The data showed that "some form of hierarchical link between the Piagetian cognitive modes and integrated science process skills is highly evident" (p. 278). However, the data supported some of the supposed

relationships but not others (pp. 259-278). Possible reasons for the failures were given as (a) the hierarchies are incorrect (unlikely); (b) the hierarchies are correct but incomplete (more likely); and (c) instruction in the subordinate skills was ineffective (quite likely). A fourth explanation might be that there are two types of hierarchies, static and dynamic. The first refers to the intellectual development of the individual and the second refers to the specific skills learned by the individual (p. 278).

The laboratory setting of active participation and the adult learning principle of "participatory experiential techniques" (Knowles, 1980, p. 50) make it worthwhile to focus on science process skills. Whatever the details of the science process skills, there is an ongoing need to emphasize the processes of science along with facts and theories. Even innovative curriculum approaches such as those of the Physical Sciences Study Committee (PSSC) and the Biological Sciences Curriculum Study (BSCS) asked students to independently design procedures in less than 10% of lab activities, and current "back to basics" movements are forcing a more traditional approach to science (Padilla, Okey, & Garrard, 1984, p. 278).

Learning Styles and the
Integrated Process Skills

Dillashaw and Okey developed the Test of Integrated Process Skills (TIPS) to fill "the need for a test geared to secondary students and not associated with any particular science curriculum" (1980, p. 602). It was developed for the high school level, but it has also been found useful with college elementary education majors. Using Kolb's 1976 edition of the Learning-Style Inventory and TIPS II, Nakayama (1988) investigated the relationship between learning styles and success in science processing skills among 107 college students. A weak correlation ($r = 0.20$, $p < 0.05$) was found between the perception score (vertical axis) and the skills of graphing and interpreting data (p. 19). In the processing (horizontal) dimension, a similarly weak correlation ($r = 0.20$, $p < 0.05$) was found with operationally defining variables (p. 20). For the total TIPS score a correlation ($r = 0.23$, $p < 0.01$) was found with the perception score. The authors interpreted these weak correlations to mean "the more students prefer abstract conceptualization to concrete experience, the better they perform on the overall test of integrated science process skills" (p. 19). With these exceptions, no significant correlations were found between learning style scores and TIPS total scores or subscale scores. The final conclusion was that the

Overall performance of integrated science process skills might be influenced by the cognitive-style preferences in the ways of perceiving information (concreteness or abstractness), rather than in the ways of processing information (reflection or action). (pp. 23-24)

However, the low correlation values indicate that the relationships are not strong.

CHAPTER 3

METHODOLOGY

The design for this research was a naturalistic case study which employed both qualitative and quantitative methods. Interview data was collected through a series of focus groups using the students in the freshman chemistry laboratories. Other measures were Kolb's Learning-Style Inventory, Okey and Dillashaw's Test of Integrated Process Skills, and a questionnaire. The last three were used to guide the focus group inquiry and to illuminate its results.

Case Studies

"The qualitative case study can be defined as an intensive, holistic description and analysis of a single entity, phenomenon, or social unit" (Merriam, 1988, p. 16). By definition, a case study deals with a bounded system or single case (Stake, 1988, p. 255). Case studies are particularistic in that they "focus on a particular situation" (Merriam, p. 11). Qualitative case studies are descriptive; they use a wide variety of data collection and analysis techniques to build a "thick" description and tend to report results using narration and quotations rather than numerical data (p. 10). An important objective

is to "illuminate the reader's understanding of the phenomenon under study" (p. 13). The results reported by a case study tend to be concrete and contextual and to lead to generalizations by the reader to populations he or she has in mind (p. 15). "What the researcher looks for are the systematic connections among the observable behaviors, speculations, causes, and treatments" (Smith, quoted in Stake, 1988, p. 255) within the specific bounded system being analyzed.

A case-study approach was chosen for this study because the complete computerization of freshman chemistry laboratories at MSU is unique; no other complete college-level implementation is known. These labs are the bounded system. The particular situation is the interaction of students with the computerized Laboratory Interface. The goal was to understand the experiences of students as they use the MBL.

Naturalistic Inquiry

Naturalistic inquiry (N/I) "has not had a very long or prominent history in educational research" (Lincoln, 1989, 237) but is "an approach which has considerable promise for social and behavioral inquiry" (Guba, 1978, p. 1). Descriptions of N/I usually contrast it with rationalistic inquiry, which is "characterized by its major intent: to investigate cause-and-effect relationships" (Merriam, 1988,

p. 6). The goal of naturalistic inquiry, on the other hand, is insight and understanding, and qualitative researchers "are interested in insight, discovery, and interpretation rather than hypothesis testing" (p. 10). Therefore, one of the key uses of N/I in educational settings is to "explore what happens in schools from the point of view of the participants" (Atkinson, Delamont, & Hammersley, 1988, p. 234).

The contrasts between these two research paradigms can be demonstrated by examining the study of a new method of teaching mathematics. In an experimental design, the researcher might randomly assign students to two groups and test the mathematics proficiency of both groups. Then for a period of time the treatment group, Group A, would be taught using the new method while the control group, Group B, would receive traditional instruction. At the end of a specific period of time both groups would be tested again, and the results would be compared statistically to measure for "significant" results. The goal would be to test the hypothesized presence or absence of expected differences.

In contrast, the researcher using naturalistic methods might visit classrooms where the different methods were being used. He or she might watch the teachers and students, noting things which could provide insight into what was happening the situation; these might include such things as teacher enthusiasm, student attention, apparent

understanding or misunderstanding by students, and total time spent. There could also be an examination of papers returned to students to look for patterns of success or misunderstanding and interviews with students and teachers to elicit personal reactions to the method. The investigator would note preliminary findings or suspicions and would shift the emphasis of questions and observations to clarify emerging patterns. The researcher would employ "triangulation," which is gathering data from several different types of sources to shed light upon a single phenomenon. The inquiry would continue until "saturation" was reached; that is, until the several lines of inquiry all pointed to the same set of conclusions. Here the goal is insight into the dynamics of the situation and an understanding of how the methods promote or inhibit learning.

The two methods of inquiry differ mainly in the amount of manipulation by the investigator in two dimensions. The first is the manipulation of conditions and stimuli both before and during the research. The second is the predetermination of possible outcomes (Guba, 1978, p. 6).

For the rationalistic researcher the world consists of variables to be isolated and manipulated in an effort to clarify their relationships. The experimental tactics "are those of laboratory control when possible and statistical manipulation when not" (Guba, 1978, p. 13). Preconditions

are manipulated or controlled as much as possible. The stance is reductionist: that is, control as many variables as possible, leaving only one or a few to vary. Borrowing from chemistry, the term "molecular" is used for this focused view. To achieve tight control over the variables often calls for extensive manipulation of the experimental conditions by the investigator. The laboratory is seen as the best environment for research because extraneous effects will be minimized and controlled.

For the naturalistic researcher, however, the context in which the research occurs is an important part of the overall picture, and the influence of the environment is purposely examined. Phenomena are studied in their natural environment which is as close to the real world as possible. Intrusions into the natural setting are avoided whenever feasible.

As for the predetermination of possible outcomes, rationalistic research designs tend to be fixed in advance with clearly stated "null hypotheses" defining what will be tested. The range of expected outcomes is carefully delineated, and statistical tests are used to determine the degree to which the outcomes occurred. The purpose is to verify the presence or absence of the suspected relationships.

In contrast, the naturalistic researcher is seeking broad descriptions and an overall understanding of complex

phenomena. Therefore, it is desirable to retain as many viewpoints as possible. The purpose is the discovery and description of phenomena. This may lead to uncovering phenomena whose existence was not even suspected. The goal is insight and understanding rather than measurement (Conti & Fellenz, 1987). The stance is expansionist with an overall "molar" view of the experimental field rather than a focused view of selected variables.

Naturalistic research designs are tentative in the beginning, and there is always the possibility that the design will shift to pursue emerging patterns.

Most researchers only gradually come to realize which issues are best to build the story around. One cannot deal with the totality of anything. (Stake, 1988, p. 258)

The issue is not lack of initial planning. Rather, it is the realization of the impossibility of foreseeing all eventualities and the desire to go where the research is leading. This

Openness does not mean that the researcher lacks assumptions. It means that, instead of starting with specific hypotheses to test, a researcher starts with . . . an orienting theory. (Jacob, 1989, p. 232)

This guiding theory indicates which phenomena rate close attention and which are of less importance. In place of the intervention and management used in rationalistic research, the naturalistic inquirer uses selection to focus the research along manageable lines.

The philosophical base of rationalistic inquiry is positivistic while that of naturalistic inquiry is phenomenological. That is, the rationalistic inquirer accepts a single reality with social facts and phenomena external to persons. The naturalistic inquirer, on the other hand, believes in multiple realities with the individual's own frame of reference being important.

In both research and reporting, the conventional rationalistic researcher tries to be as value-free as possible with personal opinions excluded. As far as is feasible, the value context of the research is kept neutral to prevent it from interfering with the results. In contrast, the naturalistic researcher believes that personal values are impossible to suppress and instead aims to state them as clearly as possible so the readers can judge value issues for themselves.

Both forms of research strive for "objectivity" but view the term differently. To the conventional researcher, "objective" research would produce very similar results when done under similar circumstances by separate persons. In other words, the results would be repeatable. To the naturalistic researcher, "objective" conclusions are those which are confirmed by multiple sources (triangulation) and arrived at without bias or prejudice (Guba, 1978, pp. 17, 73-78). Given a set of data, the naturalistic researcher would not necessarily expect separate persons to arrive at

identical conclusions but would expect that all the conclusions would be judged by others to be reasonable and supported by the data (Lodge-Peters, personal communication, 1989). Confidence in the conclusions rests on the confirmability of the data (Lincoln & Guba, 1985, p. 300).

The use of the computer interface in MSU's chemistry laboratories has created a dynamic learning environment. With an approach as novel as the complete computerization of a student laboratory, there needs to be an open examination of the dynamics of the system. The predefined outcomes of rationalistic inquiry might easily lead to overlooking important new information. Therefore, because the goal is to understand the learning dynamics rather than measuring specific outcomes, a naturalistic approach was chosen. However, several quantitative measures were included to aid in triangulation and to help focus the qualitative research. Through this design multiple sources of data were collected. Although some of the data was analyzed in traditional ways, each was used as one piece of information to help explain the multiple reality which constitutes learning in the chemistry laboratories with the Interface.

Focus Groups

One source of data collection for this study was through focus groups. "At present, the two principal means of collecting qualitative data in the social sciences are individual interviews and participant observation in groups" (Morgan, 1988, p. 15). A third option is the focus group, a form of group interview in which the researcher acts as a moderator rather than a "questioner" (pp. 8-9).

Focus groups had their origin in the social sciences in the 1940s but have not been used extensively. Most recent uses of this technique have been in the area of advertising research and political research, where focus groups are often used to gather preliminary data before launching more expensive surveys (p. 13). In those settings focus group results are deliberately viewed as preliminary findings for further research, but there is no reason not to view the results as the principal data of the research.

In a focus group, the moderator supplies topics for discussion with the intent that interaction within the group will bring forth opinions, ideas, and insights from participants which might be left untapped in an individual interview (p. 12). "The strength of this approach appears to lie in the fact that many individuals are more willing to talk about problems in the security and interaction of a

group than when alone" (Troeger & Fellenz, p. 1). This is especially important with students of traditional college age, who tend to be less contemplative and insightful than older respondents (G. Conti, personal communication, December, 1990). In this study, the main incentive for using focus groups is not the interaction itself, but the improved quality of observations which might be made by students under the stimulus of the interaction.

The Instruments

Kolb's Learning-Style Inventory

Description. The "Learning-Style Inventory" (LSI) was developed by Kolb as a simple means of measuring an individual's learning-style preferences (1974, p. 30). The original 9-item questionnaire was expanded to 12 items in 1985 (Gregg, 1989, p. 441). Each item has four choices which are to be ranked in order of preference. For example, Question 9 in the 1985 version is:

I learn best when:

- ___ I rely on my feelings.
 - ___ I rely on my observations.
 - ___ I rely on my ideas.
 - ___ I can try things out for myself.
- (Kolb, 1985, p. 2).

In each item the four choices deal with (a) concrete experience, (b) reflective observation, (c) abstract conceptualization, and (d) active experimentation in that order. Because the order of the four categories of

responses is consistent for all questions, adding rating values for corresponding responses yields four primary scores: CE for concrete experience, RO for reflective observation, AC for abstract conceptualization, and AE for active experimentation. The instrument is easy to administer and takes only 10 to 15 minutes to complete, an important consideration if it is being used within a standard laboratory period which already has every minute planned.

Scores for abstract conceptualization and concrete experience are at opposite ends of the perception learning scale, so a composite score is calculated by subtracting (AC-CE). A composite score for the processing dimension is calculated in a similar manner (AE-RO). These composite scores are used to place individuals along the two axes of Figure 8 (see p. 43), thus assigning them to one of the four learning styles. The ranking format yields ipsative scores; scores which compare people to themselves rather than against others (Bonham, 1988, p. 15). However, group norms are used to adjust the positions of scores on the axes (Kolb, 1985, p. 5).

Normative Sample. When reporting on studies of the LSI it is important to distinguish between those dealing with the original version versus the 1985 version. The first had only 9 items, and 3 of these were distractors

(Sewall, 1986, pp. 20-21). The new version, on the other hand, has 12 items, all of which are used.

The 1985 version of the LSI was normed using a sample of 1446 adults consisting of 638 men and 801 women (Learning-Style Inventory 1985, p. 5). The technical reference manual shows the demographic analysis of the sample with respect to sex, age, and educational level (p. 7). On the average, members of the sample had two years of college. Mean scores for the sample were 26.0 for CE, 29.94 for RO, 30.28 for AC, 35.37 for AE, 4.28 for AC-CE, and 5.42 for AE-RO.

Validity. Kolb (1984) emphasizes that the two dimensions of his learning model are not unitary, but rather are dialectically opposed. That is, there is not a perfect mathematical relationship between LSI scores for AC and CE and between AE and RO but there are general relationships. Thus,

We would predict a moderate (but not perfect) negative relation between abstract conceptualization [AC] and concrete experience [CE] and a similar negative relation between active experimentation [AE] and reflective observation [RO]. Other correlations should be near zero. (p. 74)

These expectations were born out in a sample of 807 people. The correlations between AC and CE ($r = -.57$, $p < .001$) and between AE and RO ($r = -.50$, $p < .001$) were

moderately negative. The other correlations were much lower, ranging from .13 to -.19 (p. 74).

To support the validity of the idea that the two dimensions of the learning model are independent, Kolb relates studies which show that the concrete/abstract dimension correlates with measures of cognitive development according to Kohlberg, Piaget, and others while the active/reflective dimension does not. The same pattern holds for correlations between LSI scores and age at entrance to college (Mentkowski & Strait, 1983).

Certo and Lamb (1979) examined the LSI using randomly-generated scores and concluded that apparent learning style scores could be explained as well by chance as by the supposed presence of some underlying learning construct. Kolb, however, admits "the built-in negative correlations in the LSI caused by the forced-ranking procedure," and cites the Certo and Lamb results as evidence of the validity of the LSI. Random-score correlations between AC and CE ($r = -.26$) and between AE and RO ($r = -.35$) are both significantly ($p < .001$) lower than those of actual scores (Kolb, 1984, p. 75). Furthermore, Kolb suggests using the Certo and Lamb data as a way to factor out the bias of the instrument.

For further evidence for the external validation of the LSI Kolb cites a study which compared LSI scores with an independent questionnaire measuring learning modes in

the workplace (Gypen, 1980). The correlation between corresponding primary scores on the two instruments was only .33, but Kolb interprets that as "empirical support for the bipolar nature of the experiential learning model that is independent of the forced-ranking method used in the LSI" (Kolb, 1984, p. 76).

In the earlier version of the manual Kolb cited the high correlations between words comprising the item responses as evidence of construct validity. However, that should be viewed as an indication of internal consistency, not validity (Sewall, 1986, p. 29).

Overall, the information provided by Kolb concerning the validity of the LSI is relatively weak. The 1985 technical reference manual shows a graph titled "Validity Relationship between Learning Styles and Career Field of Study" (Learning-Style Inventory 1985, p. 8), but there is no indication of how the graph supports the validity of the LSI. Kolb (1984) admits that the "data do not prove the validity of the structural learning model," but suggests using the LSI as an "analytic heuristic" for exploring the characteristics of learning (p. 76). That is the type of use proposed in this study.

Reliability. The estimates of internal consistency of the original version were low but fairly consistent across studies (Sewall, 1983, p. 26). Spearman-Brown split-half

coefficients reported by Kolb (1976) for the primary scales range from .54 for concrete experience (CE) to .73 for abstract conceptualization (AC). Derived scores had split-half coefficients of .79 for AC-CE and .83 for AE-RO.

Alpha coefficients reported by Freedman and Stumpf (1978, 1980) and Merritt and Marshall (1984) were lower but followed the same pattern; CE was the lowest at .34, and AC was the highest at .70.

Test-retest reliabilities were also fairly low. In six studies, average reliability scores for the primary scales ranged from .37 to .66 (Sewall, 1986, p. 32). As expected, the lower reliabilities were for longer time intervals than the higher scores--7 months versus 1 month. However, some of that shift may be due to the finding that students seem "to move in the direction of diversity of learning style" (Lassan, 1984, p. 20) over time.

The expanded 1985 version of the LSI shows improved reliabilities. Both the primary and composite scores "show good internal reliability as measured by Cronbach's Standardized Scale Alpha" (Gregg, 1989, p. 442), with values ranging from .73 to .88 (Learning-Style Inventory 1985).

In a factor-analytic study of four learning style instruments, Kolb's LSI was "the only instrument for which a match between factors and learning styles existed" (Ferrell, 1983, p. 36). Items loaded on four factors which

generally matched Kolb's four learning styles. On the other hand, some maintain that the ranking format of the LSI makes factor analysis inappropriate (Bonham, 1988, p. 15).

Drawbacks of LSI. Most of the instruments developed to measure learning style have detractors (Bonham, 1988; Sewall, 1986). The LSI is no exception. Presenting all options in the same order makes the scores vulnerable to response set; the small number of items degrades reliability; terse wording in item responses makes the test vulnerable to individual variations in interpreting the meanings of words; the ranking format forces the two dimensions to be dependent when they should be independent; although the instrument yields ipsative scores, these are normed before placing individuals in one of the four quadrants. The validity of the LSI has yet to be carefully established (Gregg, 1989, p. 442).

These objections would be serious if the LSI results were used directly for individual placement or counselling. However, in this study LSI scores were not used in this way. Rather, learning style information was used to select students whose overall LSI scores were similar to be in focus groups. Learning style information also formed a basis for exploring differences between groups in such

areas as interest in chemistry as a field of study and performance on a test of science processing skills.

Kolb's description of learning styles was chosen for this study because it distinguishes between experience and abstraction. The role of experience on learning is a major theme of adult learning. The LSI also measures the component of active experimentation. This matches the laboratory orientation of active learning versus the passive orientation of lectures.

The Test of Integrated Process Skills

The Test of Integrated Process Skills (TIPS) is composed of 36 multiple-choice items, each of which has four responses (Dillashaw & Okey, 1980). The content of the items was selected from a wide range of science areas so knowledge of a specific field is not required.

Content validity was established through the testimony of experts in the field of science education. A panel of four experienced science educators was given the test and the list of processing skills. Panel members matched test items with skills and answered the test questions. The matching of items with skills by the panel agreed with the matching by the test authors 95% of the time, which was interpreted as establishing the content validity of the test. Answers to test questions by panel members agreed with the authors' answers 97% of the time, which was

interpreted as establishing the correctness and objectivity of the scoring. The issue of construct validity was not mentioned by the test authors.

The final field trial of the test was with 709 students in grades 7, 9, and 11. The overall mean score was 18.99 with a standard deviation of 7.60. The mean scores increased with grade level, with values of 15.4, 19.8, and 22.3 for grades 7, 9, and 11, respectively. The mean item difficulty was 53%. That is, on the average, each item was answered correctly by 53% of the students. The reliability (Cronbach's alpha) was .89.

The discrimination index was also calculated for each item. This number varies from -1 to 1 and is a measure of how well an individual item discriminates between poor students and good students. Using overall test scores, students are divided into upper (U), middle, and lower (L) thirds, each of size N . For each item, the index is calculated using the formula $I = (U - L) / N$. An index of 1 means that students with high overall scores correctly answered this item and students with low overall scores did not answer correctly. That is, the item discriminated between good and poor students. An index of -1 means that all of the poor students correctly answered the item and none of the good students did--certainly not the desired result. An index of 0 means that the same number of good students and poor students answered the item correctly. In

other words, the item did not discriminate between good and poor students. Obviously, the closer the mean index is to 1 the better the average item is at discriminating between good and poor students. In the field trial scores there were 2 items with discrimination indices of 0 to .20, 12 with indices of .21 to .40, and 22 with indices of .41 to .60. Indices for individual items are not given. The mean item discrimination index for TIPS was .40, which is in the range considered to be "very good" (Ebel & Frisbie, 1986, p. 234). Thus, TIPS is "a valid and reliable measure of process skill achievement for students in the 7th to 12th grade range" (Dillashaw & Okey, 1980, p. 607).

One study using TIPS gave an indication of its predictive validity. The test was administered to 462 high school students attending a Science Olympiad competition, and the data indicated that TIPS "has predictive validity for student performance in selected events of the Science Olympiad" (Baird, Perry, & Simon, 1989, p. 8). The most significant correlations were in events which used at least two of the process skills. Interestingly, there was no significant correlation between TIPS scores and the Chemistry Lab event, perhaps because the event emphasized actual physical manipulation of measuring devices.

Research Population

Participants for this research project were students enrolled in the laboratory courses Chem 125 and Chem 135 and their teaching assistants. Students in Chem 125 are in the first quarter of the "chemistry for non-science majors" laboratory while Chem 135 students are in the first quarter of "chemistry for science majors." There were about 300 students, but this number varies slightly depending on the number of students in attendance on a given class day. Ages ranged from 17 to 62, with about 36% in the ages 17 through 19, 32% in the ages 20 through 22, and 32% in the ages 23 through 62 (see Table 1). The mean age was 22.7 and the median was 20. Of the 85% who reported their gender, males accounted for 54% and females 46%.

Table 1. Ages of Students

Age	Number of Students	Age	Number of Students
17	1	31	2
18	33	32	3
19	65	33	4
20	41	34	2
21	30	35	2
22	16	36	3
23	11	37	4
24	11	38	2
25	12	39	1
26	5	40	1
27	5	42	1
28	6	44	2
29	1	48	1
30	5	62	1

Procedures

Students in the chemistry labs were given several instruments and some were involved in focus group discussions. During the first full week of the quarter, Kolb's LSI was administered to all students in the labs, and the results were used to select focus group participants. The Test of Integrated Process Skills was administered the second week of the quarter and again the last week of the quarter. Comparisons were made between beginning and ending TIPS scores and between TIPS scores for the two different classes. Comparisons were also made between students grouped by learning style, and the relationships between LSI scores and TIPS scores were examined. The test form for TIPS also contained a question about interest in chemistry as a field of study. The questionnaire was given during the last laboratory session of the quarter.

Focus Groups

The central part of the research was focus group discussions. Focus groups were conducted with groups of students selected to accentuate differences in learning styles. Students whose LSI scores were at least one-half standard deviation away from the means of both the perception score (AC-CE) and the processing score (AE-RO) were asked to participate. Thus, only students who had a

distinct learning style were interviewed. Appendix A contains the question guide used by the moderator for the focus group discussions. Focus group sessions were audio taped to provide a record of statements made, and students were advised that the tapes would not be available to chemistry instructors or professors. Student names were not disclosed.

After a groundbreaking question about students' majors and the reasons they were in a chemistry laboratory, students were asked (a) what aspect of using the Laboratory Interface they found the most helpful and (b) why it was helpful. They were also asked to discuss aspects of using the Laboratory Interface which were the least helpful. The next question shifted to individual learning and asked what aspects of using the interface were easy to learn and why were they easy to learn. Subordinate questions asked about student experiences while learning to use the interface: What steps did students go through while learning?; what sources of information were used?; were these the best sources of information, or only the most accessible?; did they read about the use of the interface before coming to the laboratory?; if so, did the reading help?; did it seem like other students had about the same experiences, or were there noticeable differences?.

Students were also asked about aspects of learning to use the Laboratory Interface which were difficult, and why.

They were asked about initial phobias they had regarding the use of computers in the laboratory and whether these early fears turned out to be justified. Another question asked students how they viewed the benefits of using the interface compared to the effort it took to learn to use it. The summary question asked what one or two things they would recommend to improve the laboratory program, specifically with respect to the interface, and why those choices were picked.

The focus group interviews obtained feedback and insights about learning to use this computerized equipment from those who have actually been through the learning experience. This information, combined with results from the other tests and questionnaires, gives an overall picture of how students learn in this setting. The findings will help students and instructors in the laboratories and will advance the understanding of learning in a technological society.

CHAPTER 4

RESEARCH FINDINGS

Data were gathered from several sources. Kolb's Learning-Style Inventory was administered during the first laboratory session. During the next week, the TIPS science skills pretest was given. The TIPS posttest and the questionnaire were given during the final laboratory sessions, and focus groups were conducted after the final lab.

Learning-Style Inventory

Kolb's Learning-Style Inventory was administered to students near the start of the quarter (see Table 2). The mean values for Concrete Experience, Abstract Conceptualization, Active Experimentation, and Reflective Observation are all about the same for students. The graphical results of student scores in Figure 9 shows how evenly-mixed the students were in their learning styles; the number of participants and the pattern of distribution in each of the four quadrants is approximately the same. This can be expected in general courses like Chem 125 and 135, which draw students from all academic disciplines.

Kolb's Learning-Style Inventory was also administered to teaching assistants to see how teachers and students compared (see Table 2). The mean value for Concrete

Table 2. Learning-Style Inventory Results for Students and Teaching Assistants

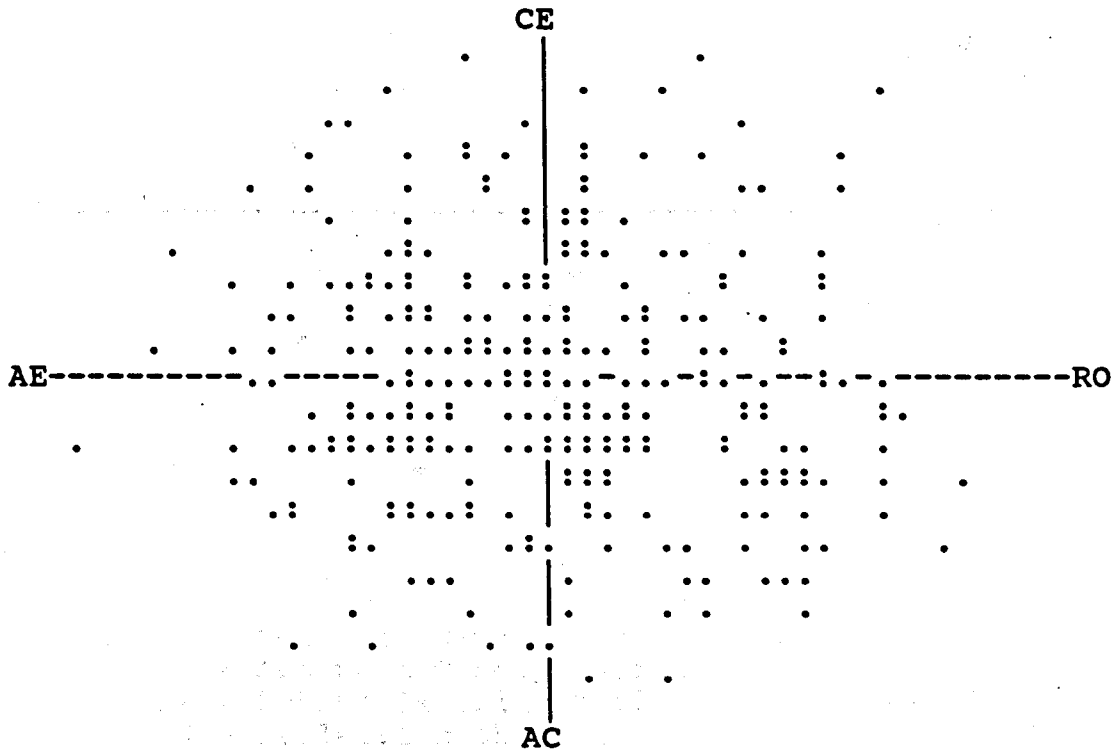
Category	Mean	Std Dev	Min	Max
<u>Students (N = 302)</u>				
CE ¹	27.4	9.0	12	48
RO ²	30.3	7.2	12	48
AC ³	30.4	7.1	12	48
AE ⁴	32.5	7.7	13	48
AE-RO	2.3	11.5	-26	36
AC-CE	3.0	13.1	-30	36
<u>Teaching Assistants (N = 10)</u>				
CE	22.2	5.0	14	30
RO	29.4	6.5	22	40
AC	35.9	7.7	24	47
AE	32.7	10.0	13	44
AE-RO	3.3	13.9	-19	19
AC-CE	13.7	9.0	-3	29

- ¹CE = Concrete Experience
²RO = Reflective Observation
³AC = Abstract Conceptualization
⁴AE = Active Experimentation

Experience was much lower for teaching assistants than for students (22.2 compared to 27.4), and the mean value for Abstract Conceptualization was much higher for teaching assistants than for students (35.9 compared to 30.2). This indicates that the teaching assistants had a definite tendency toward abstract learning. Contrasting Figure 10 with Figure 9 graphically illustrates the learning style differences between teaching assistants and students. This finding for the learning styles of teaching assistants supports Kolb's assertion that different methods of inquiry and communication in the various academic disciplines

produce homogeneity within the disciplines (Kolb, 1981, pp. 233-234).

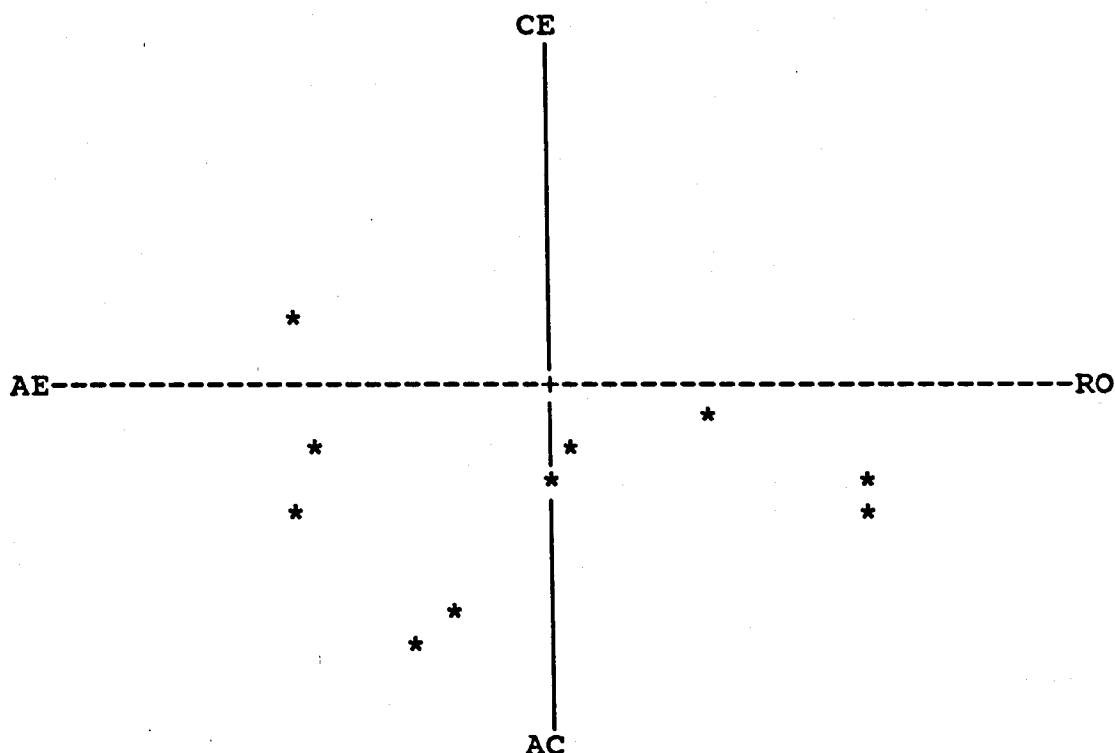
Figure 9. Plot of Student Learning-Style Inventory Scores



Note. CE = Concrete Experience
 AC = Abstract Conceptualization
 AE = Active Experimentation
 RO = Reflective Observation

Kolb considers Abstract Conceptualization and Concrete Experience to be at the two ends of a continuum, so he calculates a composite score by subtracting the two: AC-CE. The AC-CE score for students was 3.0 and for teaching assistants was 13.7 (see Table 2), again indicating that teaching assistants were much more abstract in their approach to learning.

Figure 10. Plot of Teaching Assistant Learning-Style Inventory Scores

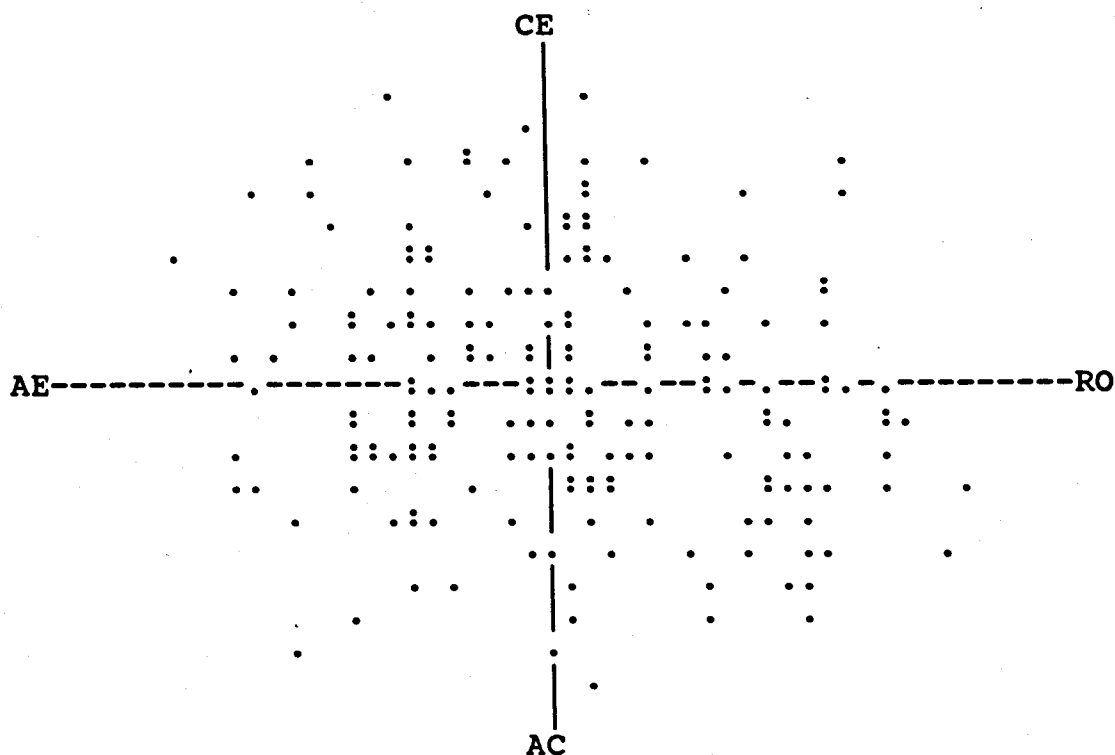


Note. CE = Concrete Experience
 AC = Abstract Conceptualization
 AE = Active Experimentation
 RO = Reflective Observation

A t-test is used to compare two means statistically. When comparisons were made between the learning styles of students taking Chem 125 (chemistry for non-science majors) and those taking Chem 135 (chemistry for science majors), t-tests showed that there were no significant differences. On the horizontal axis of the learning style graph the mean scores for the two groups differed by 1.8 ($t(300) = 1.3$, $p = .20$), and on the vertical axis the mean scores for the two groups differed by only .8 ($t(300) = .51$, $p = .61$). The similarity of learning styles for the two groups can be

seen graphically by comparing Figure 11 with Figure 12. Thus, the tendency toward abstract learning which is displayed by the teaching assistants is not apparent in these introductory students.

Figure 11. Plot of Chem 125 Learning-Style Inventory Scores



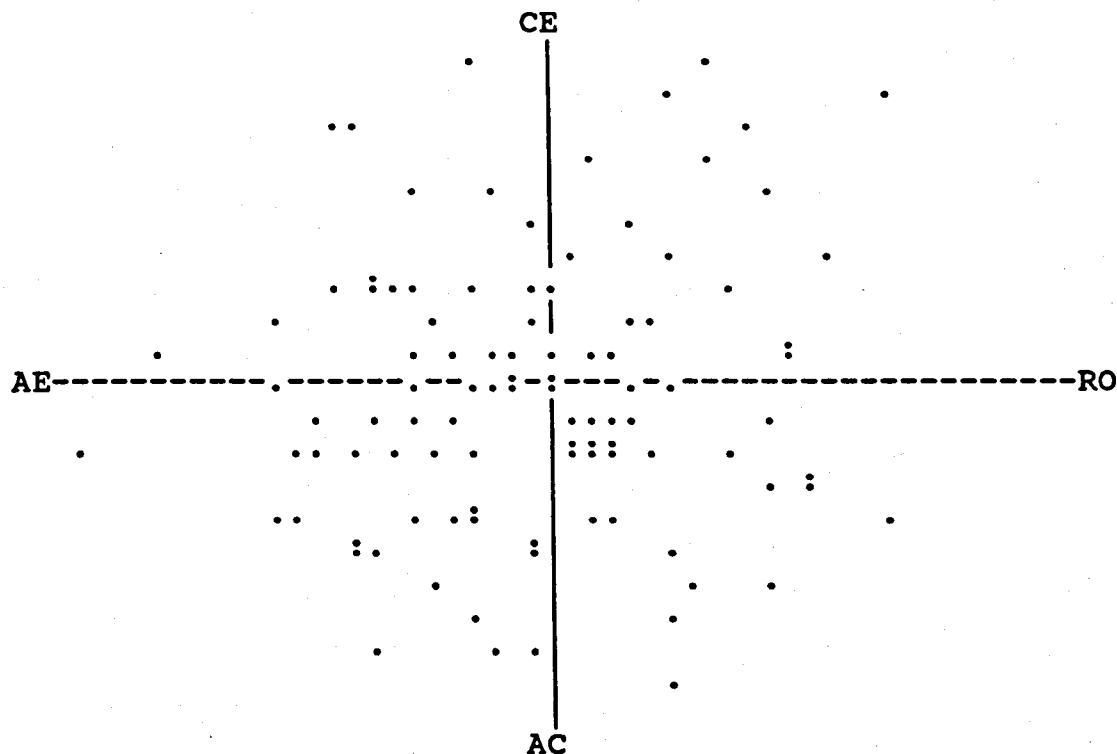
Note. CE = Concrete Experience
 AC = Abstract Conceptualization
 AE = Active Experimentation
 RO = Reflective Observation

The Test of Integrated Process Skills

The Test of Integrated Process Skills (TIPS) was administered near the start of the quarter and again during the final lab session. Items on the test are paired by

category, making it suitable to calculate a split-half reliability coefficient for this group. The equal-length Spearman-Brown reliability coefficient was .788 ($N = 277$), using the posttest scores for this sample.

Figure 12. Plot of Chem 135 Learning-Style Inventory Scores



Note. CE = Concrete Experience
 AC = Abstract Conceptualization
 AE = Active Experimentation
 RO = Reflective Observation

In this case, a t -test comparing the pretest and posttest means for the overall population found no significant difference in science skills ($t(271) = .03$, $p = .97$). However, there were significant differences between the mean scores of the Chem 135 and Chem 125 students. The

pretest mean of 75.4% for Chem 135 students was significantly higher than the pretest mean of 72.1% for Chem 125 students ($t(312) = 2.07, p = .039$). The posttest mean of 79.3% for Chem 135 students was also significantly higher than the posttest mean of 70.3% for Chem 125 students ($t(275) = 4.52, p = .001$). Chem 135 is intended for science majors while Chem 125 is for non-science majors. Thus, students in the class designated for science majors entered the study with a higher level of basic science skills than the non-science majors, and this gap widened by the end of the course.

To test whether this gain was statistically significant, an analysis of covariance (ANCOVA) was performed on posttest scores versus class, using the pretest scores as the covariate. By using an analysis of covariance, differences in pretest scores can be used to statistically equate all students so their posttest scores will reflect their gain during the quarter. Using ANCOVA, Chem 135 posttest scores were found to be significantly higher than those of Chem 125 students (see Table 3). The adjusted mean for Chem 135 students was 18.75 and that of Chem 125 students was 17.05.

Another analysis of covariance was conducted to investigate possible differences in TIPS scores due to learning style differences. TIPS pretest scores were used as the covariate, and the analysis compared TIPS posttest

scores grouped by Kolb learning style categories. No significant differences were found (see Table 4). Thus, students with all learning styles performed equally well on the TIPS posttest.

Table 3. Analysis of Covariance of TIPS Posttest by Class with Pretest as a Covariate

Source of Variation	<u>SS</u>	<u>df</u>	<u>MS</u>	<u>F</u>	<u>p</u>
Pretest	830.83	1	830.83	70.63	.001
Class	174.55	1	174.54	14.84	.001
Residual	3164.38	269	11.76		
Total	4169.75	271			

Table 4. Analysis of Covariance of TIPS Posttest by Learning Style with Pretest as a Covariate

Source of Variation	<u>SS</u>	<u>df</u>	<u>MS</u>	<u>F</u>	<u>p</u>
Pretest	786.85	1	786.85	62.85	.001
Kolb LSI	11.31	3	3.77	.30	.825
Residual	3104.72	248	12.52		
Total	3902.88	252			

Since the teaching style and skills of the instructor might have influenced student performance on the TIPS, an analysis was conducted to see if there were differences in TIPS scores when students were grouped by teaching assistant (TA). To do this it was necessary to consider Chem 125 and Chem 135 students separately. This was because various TAs taught either the Chem 125 or Chem 135 labs. However, they did not teach both. As shown in Table 5, there were significant differences on TIPS pretest

scores between students of different teaching assistants. This was presumably due to random variation in the assigning of students to different TAs since there was no known pattern to the way students were placed.

Table 5. Analysis of Variance of TIPS Pretest by TA for Chem 125

Source of Variation	<u>SS</u>	<u>df</u>	<u>MS</u>	<u>F</u>	<u>p</u>
TA	166.71	5	33.34	3.50	.005
Residual	1886.29	198	9.53		
Total	2053.00	203			

However, when Chem 125 posttest scores were adjusted for pretest scores using an analysis of covariance, there were no significant differences between students of different teaching assistants (see Table 6). Thus, the exposure to different teaching assistants was not a factor affecting student learning of science skills.

Table 6. Analysis of Covariance of TIPS Posttest by TA for Chem 125 with Pretest as a Covariate

Source of Variation	<u>SS</u>	<u>df</u>	<u>MS</u>	<u>F</u>	<u>p</u>
Pretest	582.99	1	582.99	40.87	.001
TA	94.28	5	18.86	1.32	.257
Residual	2453.27	172	14.26		
Total	3130.54	178			

A similar analysis was conducted for Chem 135. Here no significant differences were found in pretest scores (see Table 7). As in Chem 125, there were no significant

differences between TIPS posttest scores of students with different teaching assistants (see Table 8). Again, the exposure to different teaching assistants was not a factor affecting student learning of science skills.

Table 7. Analysis of Variance of TIPS Pretest by TA for Chem 135

Source of Variation	<u>SS</u>	<u>df</u>	<u>MS</u>	<u>F</u>	<u>p</u>
TA	28.42	3	9.47	.855	.467
Residual	974.57	88	11.08		
Total	1002.99	91			

Table 8. Analysis of Covariance of TIPS Posttest by TA for Chem 135 with Pretest as a Covariate

Source of Variation	<u>SS</u>	<u>df</u>	<u>MS</u>	<u>F</u>	<u>p</u>
Pretest	121.32	1	121.32	15.97	.001
TA	16.81	3	5.60	.74	.533
Residual	547.04	72	7.60		
Total	685.17	76			

End-of-Quarter Questionnaire

For the past 2 years, a questionnaire has been given to Chem 125 and 135 students at the end each quarter. The purpose was to get feedback from the students regarding their opinion of the use of computers in the chemistry laboratory. This practice was continued in this study with a modified questionnaire (see Appendix B). The first question asks about students' previous experience in chemistry. For questions 2 through 8 responses were on a

5-point Likert scale with these values: 1--Agree Strongly, 2--Agree, 3--Neutral, 4--Disagree, and 5--Disagree Strongly.

About 62% of the students in the study have had high school chemistry. When students were grouped into the age categories of 17-20, 21-22, and 23-62, an analysis of variance revealed significant differences between the three (see Tables 9 and 10). A post hoc test using the Scheffe procedure indicated that the oldest age category (ages 23 to 62) contained significantly fewer students with previous chemistry background. Only 29% of these older students had previous experience in chemistry while 82% and 74% of the first two categories had previous experience.

Table 9. Percent with Previous Experience in Chemistry by Age Category

Group Number	Group Ages	Question 1 Mean	Percent with High School Chemistry
1	17-20	1.18	82
2	21-22	1.26	74
3	23-62	1.71	29

Table 10. Analysis of Variance of Previous Experience in Chemistry by Age Category

Source of Variation	<u>SS</u>	<u>df</u>	<u>MS</u>	<u>F</u>	<u>p</u>
Age	13.79	2	6.90	37.82	.001
Residual	46.49	255	.18		
Total	60.28	257			

There were also significant differences in previous chemistry experience and the class in which students were enrolled ($t(260) = 2.53, p = .012$). In Chem 125, only 57% of the students had previous chemistry experience. In contrast, 73% of Chem 135 students had previous experience. Thus, one could expect older students and students in Chem 125 to have less general background in chemistry.

The relationship of previous experience in chemistry and learning styles was also investigated. Using analysis of variance, no significant differences were found between learning style groups (see Table 11).

Table 11. Analysis of Variance of Previous Experience in Chemistry by Learning Style

Source of Variation	<u>SS</u>	<u>df</u>	<u>MS</u>	<u>F</u>	<u>p</u>
Kolb LSI	1.60	3	.53	2.30	.078
Residual	56.24	242	.23		
Total	57.84	245			

Table 12 presents the results of Questionnaire Items 2-7 in numeric form. Students were the most positive about the Interface package in its role of acquiring and analyzing data. A large majority (88%) agreed that computers were useful in the role of acquiring data (Item 3), and almost as many (86%) agreed that computers were useful for analyzing data (Item 4). Over half (54%) agreed that learning to use the computers was easy (Item 6), but

many more (71%) agreed that using the system was easy once they had learned how (Item 7). Almost three-fourths (72%) agreed that the computers were useful as they designed experiments (Item 2). The strength of these positive opinions is displayed in graphical form in Figure 13.

Table 12. Attitudes Towards Computers in the Lab:
Responses to Questionnaire Items 2-7

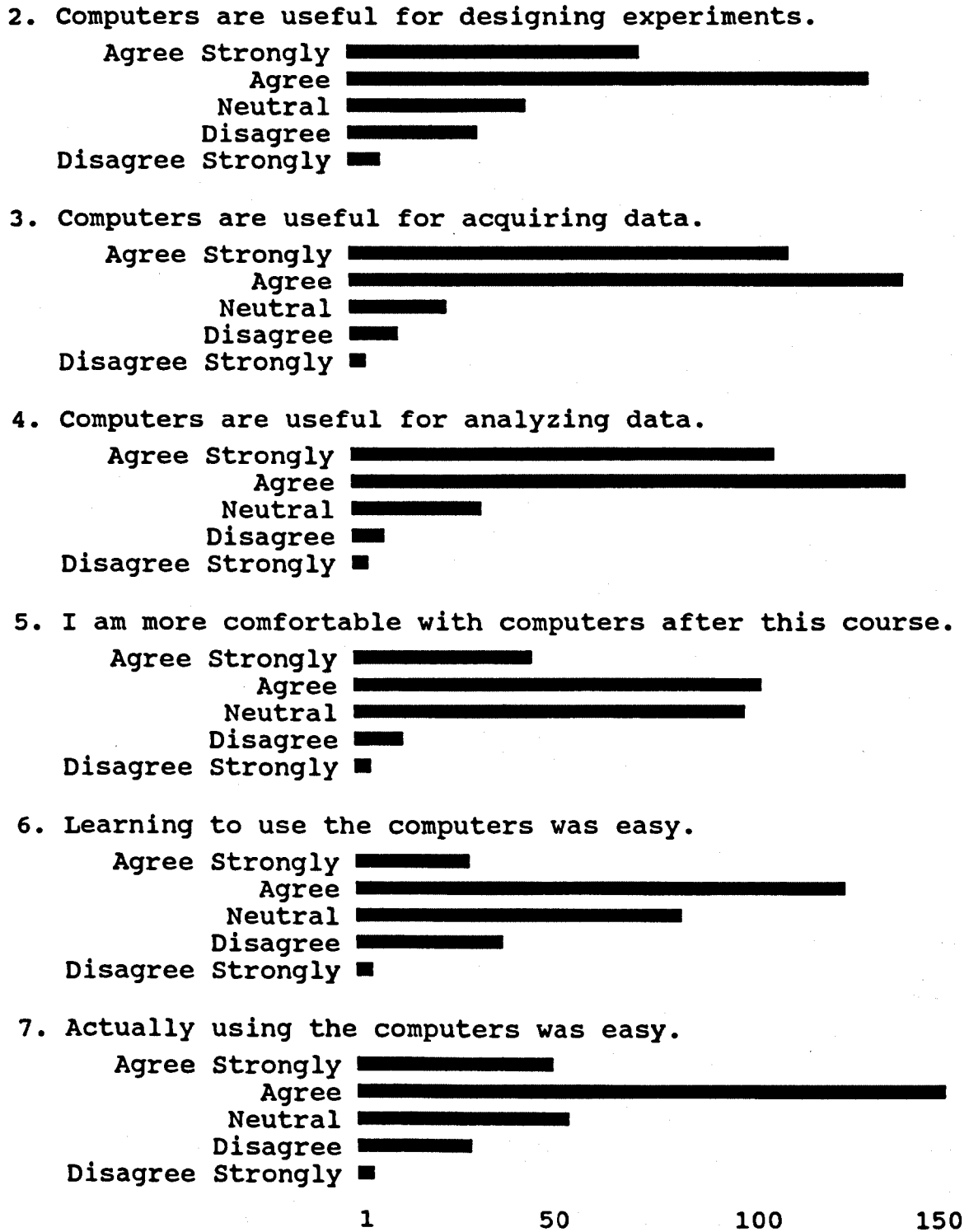
Item	Response					Mean
	1	2	3	4	5	
2. Useful for designing experiments	71	127	44	26	7	2.17
3. Useful for acquiring data	106	135	22	10	2	1.79
4. Useful for analyzing data	102	134	29	9	1	1.81
5. More comfortable with computers	42	100	94	29	10	2.51
6. Learning to use was easy	29	120	81	36	9	2.55
7. Actually using was easy	47	147	50	26	5	2.26
8. Improved attitude toward chemistry	17	72	132	33	20	2.89

Note: Response 1 = Agree Strongly, 2 = Agree, 3 = Neutral, 4 = Disagree, 5 = Disagree Strongly

N = 275

The question with the least agreement (52% agreement, 34% neutral, 14% disagreement) dealt with becoming more comfortable with computers as a result of taking this course (Item 5). Even here, however, the average response was on the positive side of neutral (2.51 compared to 3.00). The overall mean of the questions dealing with the Interface package was 2.18, and none of the questions had a negative average response (that is, greater than 3.00).

Figure 13. Attitudes Towards Computers in the Lab:
Responses to Questionnaire Items 2-7



Thus, the overall student opinion of the Laboratory Interface system was strongly positive. Despite this positive response, students do not think that their attitude toward chemistry as a field of study changed as a result of taking the course (Item 8; see Table 13).

Table 13. Attitudes Towards Chemistry as a Field of Study: Responses to Questionnaire Item 8

Item	Response					Mean
	1	2	3	4	5	
8. Improved attitude toward chemistry	17	72	132	33	20	2.89

Note: Response 1 = Agree Strongly, 2 = Agree, 3 = Neutral, 4 = Disagree, 5 = Disagree Strongly

Questions 2-8 on the survey were analyzed by the age groupings of 17-20, 21-22, and 23-62. The analysis of variance for these seven items found no significant differences between the responses of the different age categories (see Table 14).

Table 14. Analysis of Variance of Questionnaire by Age Category, Items 2-8

Item	F	df	p
2. Useful for designing experiments	.46	2	.63
3. Useful for acquiring data	.24	2	.79
4. Useful for analyzing data	.83	2	.44
5. More comfortable with computers	1.50	2	.23
6. Learning to use was easy	1.91	2	.15
7. Actually using was easy	2.50	2	.08
8. Improved attitude toward chemistry	.44	2	.64

The survey questions were also analyzed by learning style with learning style divided into Kolb's four categories of Assimilators, Divergers, Convergers, and Accommodators. With the exception of Item 3, no significant differences were found between the categories (see Table 15). On Item 3, students were asked to agree or disagree with the statement "I believe that computers are useful for learning chemistry in the lab in the role of acquiring data." The analysis of variance found significant differences between students with different learning styles (see Table 16). However, a post hoc test using the Scheffe procedure found no significant differences at the .05 level. When an analysis of variance reports significant differences among the overall collection of groups, post hoc tests, such as the Duncan and the Scheffe, are used to identify which group or groups

Table 15. Analysis of Variance of Questionnaire by Learning Style, Items 2-8

Item	F	df	p
2. Useful for designing experiments	1.67	3	.18
3. Useful for acquiring data	2.95	3	.03
4. Useful for analyzing data	.84	3	.47
5. More comfortable with computers	.70	3	.56
6. Learning to use was easy	1.30	3	.27
7. Actually using was easy	.79	3	.50
8. Improved attitude toward chemistry	.50	3	.69

are different from the rest. Paradoxically, it is mathematically possible for post hoc tests to fail to identify individual groups as accounting for differences found among the group as a whole.

Table 16. Analysis of Variance of Questionnaire Item 3 by Learning Style

Source of Variation	<u>SS</u>	<u>df</u>	<u>MS</u>	<u>F</u>	<u>p</u>
Kolb LSI	5.40	3	1.80	2.95	.034
Residual	147.85	242	.61		
Total	153.25	245			

The survey responses were also analyzed for differences between the Chem 125 and Chem 135 classes. Analysis using the t-test revealed significant differences between means for three items (see Table 17). For Items 3 and 4, which dealt with using computers to acquire and analyze data, Chem 135 students agreed more strongly than Chem 125 students that computers were useful. This higher rating may be due to the greater overall experience and interest in science which would be expected of students in "chemistry for science majors." In a similar vein, on Item 7 the Chem 135 students found that actually using the Interface was easier than did Chem 125 students. Thus, even though all students in the study had strongly positive attitudes toward using the Interface package to acquire and analyze data, those students who plan to major in a science

were even more emphatic than non-science majors in seeing its usefulness and ease of use.

Table 17. Questionnaire Items 2-8: t -Tests by Class

Question	Chem 125 Mean	Chem 135 Mean	t value	df	2-tail Prob.
2	2.24	2.02	1.75	273	.081
3	1.88	1.62	2.61	273	.010
4	1.90	1.65	2.51	273	.013
5	2.54	2.46	.62	273	.536
6	2.61	2.43	1.54	273	.124
7	2.36	2.04	2.81	273	.005
8	2.90	2.83	.51	272	.613

Six of the survey items (Items 2-7) measured student attitudes toward the use of the computer in the laboratory. When these items were averaged for each student, students in Chem 135 were significantly more favorable towards the use of computers in the chemistry lab than students in Chem 125 ($t = 2.62$, $df = 273$, $p = .009$). However, while the mean score for Chem 125 students (2.26) was less favorable towards computers than the mean for Chem 135 students (2.04), even the Chem 125 students were on the favorable side of "neutral" (3.00). Thus, while the overall attitude of all students toward the Interface was positive, science majors were even more positive than non-science majors.

Interest in Chemistry as a Field of Study

The answer sheet for the TIPS test that was given at the beginning and again at end of the quarter had an extra

item asking students to rate on a five-point Likert scale the statement that "I am interested in chemistry as a field of study." Using the entire population, the mean score for this item on the pretest was 3.01, and the mean on the posttest was 3.15. This was a non-significant difference ($t(267) = 1.91, p = .057$). However, when the Chem 135 students were compared to the Chem 125 students, the Chem 135 students had a significantly higher interest in chemistry as a field of study at the start of the quarter ($t(308) = 2.40, p = .017$). This difference had disappeared by the end of the quarter ($t(275) = 1.07, p = .286$).

An additional analysis was performed to see if the final interest ratings were different by class when the initial interest ratings were taken into account. The analysis of covariance found no significant differences (see Table 18).

Table 18. Analysis of Covariance of Final Interest in Chemistry by Class with Beginning Interest in Chemistry as a Covariate

Source of Variation	<u>SS</u>	<u>df</u>	<u>MS</u>	<u>F</u>	<u>p</u>
Beginning Interest	115.45	1	115.45	115.23	.001
Class	.37	1	.37	.37	.544
Residual	265.50	265	1.00		
Total	381.33	267			

Summary of Statistical Findings

The learning styles of students were quite evenly divided between Kolb's four categories, but their teaching assistants showed a definite tendency towards abstract learning. Students from all learning style categories appeared to do equally well on the test of science skills and to hold about the same opinions regarding the computerized lab. In contrast, there were significant differences between laboratory classes; Chem 135 students had more chemistry background, performed better in the initial science skills test, and were more favorable towards the Interface than Chem 125 students.

Focus Group Results

Focus groups were conducted at the end of the quarter with participants grouped according to Kolb learning style categories. Two groups of eight students from each of the four learning styles were selected. Attendance was voluntary. In some cases students who had promised to come did not; consequently, actual group sizes for the focus groups ranged from two to six. The moderator used a guide as a general outline for the sessions (see Appendix A), but, as expected in focus groups, students often led the discussion in different directions.

Student Learning Strategies

Many of the student comments shed light on strategies they used to learn. Some of these learning strategies are distinct with students of different learning styles while other learning strategies seem to be shared by all.

Active Participation. Statements by focus group participants tended to corroborate Kolb's idea that some learners mediate the transition from information to personal knowledge through reflective observation while others do this through active experimentation. Convergers (active, abstract learners) mentioned the contrast between reading about the system and actively experimenting with it as routes to understanding. "I didn't learn anything, really, until I tried to put it into the computer. The book didn't teach me much--doing it did. . . . When you really have to do it yourself, you still get confused even though you read it at home." Experimentation has a central place for Convergers because "anything you learn new, you just have to do it."

Several respondents, especially Convergers, mentioned frustration with the common classroom practice of having a quiz at the start of class to be sure students had read the material before coming. A common lament was that "we have a lecture, read it in the book, and have a quiz on it. But I'm not really doing it. The quiz is kind of ridiculous;

we were supposed to already know exactly what we were doing when we went in. . . . Before you get to try it and understand it, they're quizzing you on it."

Accommodators (active, concrete learners) also benefitted by personally experimenting with the system because "getting from not knowing anything about it to figuring it out took a lot of playing around." According to them, "the people that did mess around with the computer a little bit and played with it and got to understand it would do a lot better in the class." One student who found she had been relying too much on her partner reported that "I went into the Help Center and I redid some of our programs, and it forced me to work alone on it. I did much better, and it made a lot more sense to me." The general view of Accommodators was that they "learn better by doing than by reading it." This was tempered, however, with an appreciation of "having an idea of where you're supposed to go. I like to read it and do it and see it while I'm doing it."

Divergers (reflective, concrete learners) seemed to have the opposite experience from Convergers and Accommodators in the sense that doing the activities did not necessarily lead to understanding. "We had examples, but we did not have to understand them to do them. It was real easy to do because all the commands were right there, but at the same time you didn't have to think and

understand." Their recommendation was "for things that were covered [in the manual], I think you should have been required to think about them more and understand what's behind them rather than just having it given to you."

Divergers identified mental processing as an important result to learning: "The way the chem lab was taught was much more beneficial for my time. I came out with a lot more because I had to be able to process my thinking."

Assimilators (reflective, abstract learners) also felt that active experimentation was not the key to understanding. "Some things I like just to try, but when it's for something important to me, I don't like to be as free with it. Randomly trying things out confuses me more." Thus, active participation had different significance for different students: Convergers and Accommodators needed active involvement with examples to understand the system; along with active involvement, Divergers needed to think about and process the examples to achieve understanding; and Assimilators disliked "trying things out" as a means of learning.

Reading the Manual. As with active participation, the learning style groups differed in their learning patterns concerning the use of the computer manual. In contrast to Convergers and Accommodators, Assimilators found reading the manual helpful. "It ran right by the book," one said.

"All you had to do was look in the computer lab book, and it explained what the programs do and why and how you could use them. It was really straightforward, I thought." Others agreed that "it's right in the book" and that "everything you needed was in the book, and it's going to work."

This is in sharp contrast with the Accommodator who said that "before every lab I read over the manual and the lesson that we were going to be doing. But often until I was writing up the lab report, I didn't have the comprehension of what we were doing and what the purpose for that lab was." For others, "I did real well on my lab report. As I was writing it up, it came to me." Even Assimilators, however, found that "you really have to do it" before you completely understand it, and they would have preferred having the quizzes after working in the lab rather than before. Even for Assimilators, "once you have worked through it and you understand why you're doing what you're doing and you see it on the screen, it's so much easier to understand than having just read through it in a book." Convergents also mentioned trouble understanding the manual, and some "didn't find the computer book very clear or helpful" and felt that "the book doesn't explain very well."

The variety of student backgrounds was clearly illustrated when they were asked about their overall

impression of the manual. One student "got the idea when reading [the manual] that it was definitely written by a scientist. [I wish] they could collaborate with someone." In contrast, others thought the manual "wasn't very difficult to follow. It wasn't above our level." In general, students thought "the manual should have some more basic things for those folks who don't know them."

Using the Manual as a Reference. Learning style groups differed in their use of the strategy of reading the manual for overall understanding. In contrast, all learning style groups attempted to use the manual as a reference. The frequency with which students mentioned frustration over the lack of an index in the manual indicates that many of them tried unsuccessfully to use the manual as a quick reference. Some were looking for "just simple things--how to print, how to recall a program, how to restart the computer," and "how to print the screen." Others were looking for "common problems that people come across and solutions to the problems." In any case, many "didn't recall an index or anything. That might have helped. I spent a lot of time looking things up." All groups could "remember often times having to flip through the computer lab manual to find commands that you needed." This was because "there wasn't a quick reference. That would be helpful in the manual to have a page of quick

reference." Another pointed out that "some computers and programs will have these little cue cards that give you the moves--which keys to push. That would really be helpful, so you wouldn't have to memorize or look back in your manual." An aid such as this is important because "if you're stuck on a computer you're really stuck; there's nowhere to go." Simply put, students from all learning style groups strongly said, "Add an index."

Using Examples from the Manual. Opinions were mixed regarding the worth of the examples in the manual. Many thought "there weren't enough" while others, especially Assimilators, thought "there were a lot of examples." In keeping with their abstract thought and ability to make sense of the examples by just studying them, Assimilators were the most positive in their assessment. "In fact," one said, "when I wrote my program for the final project, I got the program directly out of the book. There were dozens of examples." When asked if he understood the sample exercises in the manual, another Assimilator said, "That was not really a problem. If you read it, you should know what was there." When asked if the series of examples helped in the final project, a third Assimilator said, "Setting up the programs for the final project was really easy because each week we got to learn a little about the computer system, and through experience you could cruise

right through it because it was right there in front of you."

One point mentioned by Accommodators was the practice of having multi-line examples in the manual but not having an explanation for each individual line. "They didn't actually write out a line [of an example program] and then tell you what it did," one complained. "In the book they would have four lines and then tell you what the four lines together would do." Similarly, "they would tell you exactly what the block [of program lines] did but how you got from the beginning of the block to the end of the block and got your answer, they never explained that." The problem is, "in order to write the program, you have to know what each line does" [as opposed to a block of lines]. For Accommodators, combining the examples in order to do the final project was not at all straightforward. "The little blocks [of example programs] were fine, but when we got to our final project, we couldn't use this block here and this other block there. We had to take different lines from each block and integrate them."

Another negative point was made by Divergers, who saw a lack of overall purpose in the examples. One explained this by saying that the examples "are good at presenting each command. I think what it lacks is showing you how to put them all together. You might understand what this does and that does, but you have never had any practice at

trying to put them in any kind of order." Another summarized her opinion of the examples by saying, "It is kind of like having to memorize vocabulary words without anyone showing you how to put a sentence together. That's what it reminded me of."

A problem mentioned by all groups except the Assimilators was the tendency to enter the examples without really understanding them. "Copying it out of the book and actually knowing what it does are two different things," an Accommodator said. "It doesn't show you the steps that the computer really takes when you put a programming message in [the program]." This was echoed by another Accommodator who said, "A lot of times when I was using it, my goal was just to get that thing written out and looking the same as it did in the book. I didn't care what each line did as long as it looked the same, and it did something at the end. By the time I got to the final project, I had no clue what to write."

A Converger shared the same sentiment. "We were having a computer lesson each week, and yet we weren't learning anything from it. At least I didn't. It seemed to me we were just typing things in to get it to work for the week, but we weren't really learning how to use the computer."

This view was also shared by Divergers. "All the computer programs were written out in the book. All you

had to do was copy them, and unfortunately that does not make you think." For Divergers, the problem could be helped "if they left one or two [command lines] blank and then said, 'What we're looking for in this program is something to tell the computer to do this.' If it even only took about 15 minutes to modify an example on your own, you would have to stop and think and try a few things. I think that would give you the security and confidence to try different things on your end project."

Some students described purposely modifying the examples just to learn more about what they did. One Accommodator reported that "when we did each example, I went in and changed it and inserted and deleted things. That helped me." In a similar vein, a Diverger did the same with larger experiment programs. "We tried rewriting programs several times, just trying to see how each thing is changing," she said. "If I change this line, how is the way it's running changing?"

The manual has both explanations and examples. When asked whether the manual should have explanations or examples, students of all four learning styles agreed that "both would help more than either one."

Working with Partners. All but one of the comments regarding working with partners were made by Accommodators and Convergengers--those with a tendency toward active

experimentation. Students' opinions of working with partners varied. Some saw having an experienced partner as a disadvantage. "You like it, but you don't learn very much. You learn more if you do it yourself and make mistakes and your instructor has to show you what you really have to do." Some also saw the reverse situation--being matched with a less experienced partner--as a disadvantage because of the extra time involved. "The TA said 'She doesn't know how to run it--let her run it,'" one student recounted. "She was scared to death of it, so by the time I told her how to run it we were the last people there every time, and that was frustrating. I said, 'I don't mind helping you, but we need to get out of here sometime today!'"

A few had problems with the general concept of working with any partner. One Accommodator said, "I like to work alone, and it was really hard working with two people on one computer. 'Who is going to push the button now?' If she was pushing the buttons then I didn't learn it; I didn't grasp it."

Most students thought working with partners of mixed experience was an advantage, however. For some an experienced partner was a morale booster. "My partner knew a whole lot more than I did. My attitude toward the Interface changed [for the better]." A partner can also help overcome initial confusion and provide needed

clarification. "The first week I had trouble understanding it. [My partner] picked up on it very quickly, and by watching her I picked up on it. I didn't understand what was going on at first, at all."

A few were rather passive when matched with a more experienced partner, but they still considered it valuable training. While some "gained a lot watching . . . and following through," others found that their "partner typed most of it in, so I just watched . . . and listened."

Others used the skill of partners to keep up with the class. "I was afraid I would be holding up the rest of the class, so if we were behind my partner would catch us up and then explain what was going on." Thus, "having [my experienced partner] next to me was a lot better. If I was on my own, the whole class would have been held up, and it just would have been a waste of time."

Many could see the overall benefits of matching less experienced with more experienced partners. "I think it's beneficial to split the people up," one student said. "My partner and I were very computer oriented, and we were the first ones out every time. Now that I look back at it, I wouldn't have liked it, but [they should have] switched us with some of the people that were having problems. Put one person there who understands it." Some who were not matched with experienced partners wished they had been: "I think it might not be a bad idea to rotate people around."

It is so frustrating to just sit there and not know where to go." Another student thought that rotation would be good if "the partner you originally chose was your partner for the final lab. You want to be thinking about your final lab because there will be a lot of work involved in that."

It appears that the most satisfactory situation for many students was an experienced partner and purposeful self-involvement. For example, one student said, "I don't know if [my partner] was willing, but I made her help me. I would say 'Let me try this on my own,' and she stepped aside. I tried it, and I pretty much figured it out, which was nice. I felt like I accomplished something."

Asking Questions. There seemed to be little reluctance for students in any learning group to ask questions whenever the need arose. There was an active informal network of students advising other students. "Your partner might know something you had to do, or [you could] go to other people and ask them how to do it." While some students asked questions, others were on the receiving end of the questions. "There was one girl next to me who kept coming over and asking 'How do you do this? How do you do that? Why?'" Others learned through a less formal method: "You have to eavesdrop when somebody else asks questions."

Most students asked questions mainly of the teaching assistants, but this was not before first trying to do it on their own. Students used several approaches. "I experiment around with it, fool around with it, and if that doesn't work I try to get the TA's attention." A second method was to "try to see what I have in front of me, what it is I'm trying to do. If I can't figure it out then I ask the TA." A third method "was for me to play with it while my partner went and asked the TA. Sometimes I would figure it out before he got back. Sometimes the TA's suggestion helped."

Several students would ask questions of the teaching assistant rather than trying to find information in the manual. To some extent this was due to the lack of a good index. "It's just a lot easier to raise your hand than it is to page through the whole book looking for the certain spot." In other cases the information was lacking in the manual. For example, one student said, "I don't think I found [how to edit] in the book. I got it from the TA." In many cases the specific situation would dictate whether to ask the teaching assistant: "It depends on whether he was busy. If it was just a simple thing like what an abbreviation meant, I would look it up" because "you get tired of calling the TA over for little things."

There were a very few who seemed reluctant to ask questions. "You just sit there being frustrated," a

Converger said. "You don't know what to do. And you try this and try that, and you end up using Control-Alt Delete," [thus resetting the computer]. In general, however, the advice was to "ask lots of questions. Our TA was really good at letting us know or explaining why we were doing things." The common solution to most problems was to "go ask the TA."

Structured Thinking. Accommodators and Divergers, who tend toward concrete experience, noted the structure imposed on their thinking by entering the steps of an experiment into the computer. "I'm definitely in the group that thinks [the Interface] clarifies things by forcing me to think about what I'm doing," an Accommodator said. "It helps make it more clear to me." A Diverger expressed a similar thought. "I think the hardest part was when we had to start [designing] programs. We had to start looking ahead; we had to think how information would be processed to get a certain result. You had to really know what you wanted and know what you were doing." Another Diverger said, "The way the chem lab was taught was beneficial for my time. I came out with a lot more because I had to be able to process my thinking and was also able to visualize more things with the computer." Neither Convergences nor Assimilators noted this imposition of structure, perhaps

because their abstract thought patterns naturally tend towards structured thinking.

The Role of Understanding "Why". Many students of all learning styles expressed a desire to know more about why they were doing certain actions. "The manual tells you to press a certain button, but it doesn't tell you why." Students wished "they would explain themselves a little more, not just say 'Push this button, do this,' and then you're going to get it. If they would say why you are doing it, what will happen, give some idea how the computer works." A typical lament was, "I just like to know why I'm using both disks. I want to know why you have to do that. I get a little frustrated. I need to see a purpose for things. Why did we do this or why did we do that?"

Some students saw a lack of coordination between the computer exercises and the chemistry labs. "On the first couple of [lessons] I don't remember applying it to the experiments. We just did the computer program in the beginning for computer practice, but we didn't use it in the lab itself. I need to see a purpose for things."

The problem was summed up by the plea, "If it had been better explained in the beginning rather than, 'Punch this in'; if I had known what was happening with the computer, how it was working, rather than, 'Here, type this in and

you get this,' and you kind of learn on your own after watching it."

The students' desire for "understanding why" could apply, not just to the use of the Laboratory Interface, but to many laboratory exercises. "You found out what it did, but you didn't really understand why it was doing it, other than to get your answers to write up your lab report." This is exactly the type of "cookbook" approach to laboratory classes which the chemistry instructors at MSU are trying to avoid.

Seeing It. Students from all groups but Convergents mentioned the advantages of visualizing what was happening in the lab. "Chemistry is neat but for me, I have to see things go on," one Accommodator said. "I know you're not going [to see it] all the time. I mean, atoms are pretty invisible. You don't see the stuff. But for me to learn I have to see some things to help line things up." For some this meant actually seeing the equipment. "I had to see it," an Assimilator said. "You read about this equipment, and you've never used it before. You don't know what it looks like or anything."

Others consciously visualized what would happen as an aid to their thinking. One Accommodator recalled that "when I would read it before coming to class, I would visualize what was going to happen. Sometimes it was hard

to visualize what was going to come up on the screen, but I don't think the instructions were difficult to follow."

For still others the visual presentation of the measured results was important. One Diverger said, "I would say the spreadsheet and graphing [were the most helpful], so you could visualize what was going on. It helped me visualize it." Another Diverger said, "It's definitely worth [learning to use] it because it really helped you visualize and it helps you understand. You weren't just looking at numbers, and you weren't caught up doing detailed graph work."

Seeing It Done. For an activity like maneuvering through the menu structure, many students expressed an appreciation for seeing their teaching assistant work through the steps. Each laboratory had a large monitor, which could be used to show the instructor's computer screen to the whole class, but only some TAs used them. All the students who had seen demonstrations on the large screen found it helpful. "They helped a lot. It was like, 'Oh wow, there it is.' It was by someone who knew exactly what they were doing. It's helpful, I think, when everyone can see what's going on. It should have been done the first day of the lab."

Some students regretted not seeing demonstrations on the large screen. "We had large monitors in the labs that

the TA can type on, but we never used that. Had he had a couple of programs and said, 'This is what happens; let's type this program and watch what happens,' it would have helped." This opinion was reinforced by a student who "was disappointed that they didn't use the monitor and show examples because I need to see that happen. 'Put these [program steps] in this order. Watch the program. What's it doing? Change these lines around. Watch it. What's different?'" Clearly, students "definitely think more time needs to be used by the TAs teaching everyone as a group with their monitor." Unfortunately for some, their monitor "was never turned on once."

Students were in strong agreement that "if the TA had showed us on our computer and told us [how it was working], it would stick in the brain and we would know what to do next time." This is simply because "you see it and then you can know it."

Summary of Learning Strategies. As students learned to use the computerized Interface system they would: experiment with the system; read the manual; use the manual as a reference; study examples in the manual; modify examples in the manual; watch a partner or the TA use the system; ask questions of a partner, classmate, or the TA; ask partners to show them the steps; eavesdrop on explanations given to others; structure their thinking by

noting the steps of an experiment; get an overall picture of the learning situation; try to understand the "why" for each step; visually inspect the actual equipment; mentally visualize what would happen in lab; examine graphs of data to search for meaning; use previous computer experience to serve as a model for this new situation; and note the benefits of the system as a motivational aid.

Student Assessment of the Laboratory Interface

Student comments often expressed their opinion of the Laboratory Interface itself as opposed to learning to use it. Taken together, these remarks give a picture of the way the students view the Interface.

Computer Phobia. Some students expressed no initial fear about using the computers, but rather curiosity or excitement. For one, fear was "not a problem. I thought you guys were really progressive. I was curious about it anyway, knowing that computers are everywhere." Another "thought it was weird, but I was excited. When I walked in and saw the computers, I thought I was in the wrong room. It didn't look like a lab to me. But it didn't bother me." A third said, "I didn't realize we would be working with computers, but it was kind of fun. It didn't bother me, really."

Many people without extensive computer experience, however, have various fears about using computers, and

chemistry students are no exception. Numerous students expressed an initial fear regarding the computers. One theme common to all learning style groups was fear of accidentally losing data. "I used to think that if I hit the <Delete> key I would delete everything. Once you get used to it you know it will delete a certain part but at first you wonder, 'Does <Delete> mean delete everything?' A common fear was "hitting the wrong key and wiping out the whole world." Many expressed "an incredible fear of losing my data. Like hitting <Escape> too many times and the whole thing is going to go whoosh, or not being able to recall it. But I only had one problem the whole time." This fear of hitting the wrong button was a problem common to many students. "I know I'm not the only one who had that incredible fear of hitting the wrong button. It makes you more wary of trying something on your own."

Almost all the other statements about fear fit the category of initial apprehension which could have been largely avoided by a more careful introduction. One student complained that "the first day they tell us we will have to write a program! Don't tell us that! Wait a couple weeks." Another said, "Somebody hears that they have to program this, and they panic." Others feared an imagined complexity that turned out to be simple: "I thought it might be tougher because I didn't know it would be so straightforward. I figured we would have to design

programs all by ourselves without any help from the books. But then I saw it was straightforward."

Only one respondent told of fear that did not soon disappear. "It was kind of scary going in there and looking at the instructions," she said. "Aaaah! What do you do? I suppose I kept that fear all quarter. I kept having trouble with it. For me to learn it, it wasn't presented right." More typical, however, is the student who "just didn't like the idea of a computer. That just scares me. But now they don't at all. Now I'm actually writing papers on a computer. That was good that the class did have computers because it forced me to use them. That was a big help."

One other student attitude mirrors the anthropomorphic view of computers held by popular American culture. One student insisted, "Some computers are just like that. If your mood is just perfect for it, then it will do [what you want]. You have to have a very positive attitude."

Computer Background. A few respondents who themselves had computer experience saw no real need for any prior experience. "It wasn't really that hard," one said. "I think you could figure it out without computer experience." Most respondents, however, thought that prior computer experience helped them in the class or would have helped them if they had had some. Those with little computer

experience felt at some disadvantage compared to their classmates. "The manuals took a lot for granted," one said. "It assumes that we already have some knowledge, and we don't." A student requested that the instructors "understand that a lot of people in the class don't know anything about computers and maybe bring it down to a level of somebody who doesn't know anything about computers. Just assume that nobody knows anything about computers." Another said, "It was like assuming that you had known computers before. That was one of the biggest problems I had. I had no computer experience."

The plight of older students was summed up by one female, who asked, "When the course was written, did you assume that most high schools now have computers and people would be familiar with them? People like myself that graduated 10 years ago don't have that background."

Those with a stronger computer background appreciated the advantage this gave them. "My computer experience really benefitted," one male said. "I really didn't have to think about what I was doing. I knew what was going on." In the words of a female with a strong computer background, "I felt like I had an unfair advantage. It was nice for a change."

Any type of computer experience helped to some extent. "You can tell when somebody has had experience with computers because somebody who has gets up there and just

starts humming with it, and somebody who hasn't gets up there and says 'Where's the <Return> key?'" Several students thought "it would help to have CS 150 [Introduction to Computers] or something; anything before this class. Just to even put your fingers on it is a help."

Others, however, found little relationship between their prior computer work and the laboratory computers:

- Word Perfect has no relation with the Lab Interface, and having to do Word Perfect didn't help me with the lab.
- I was taking CS 150 [Introduction to Computers] at the same time as the chemistry lab. It seemed that it would be easier for you, but that didn't help. I was disappointed that there was nothing in CS 150 that helped you understand the Lab Interface better.
- There are some similarities [to CS 150]. In Lotus and dBASE you have to do things that are a bit similar to the chemistry lab, but it's not much of a help, at least in the beginning.

The type of experience that was seen as the most valuable was some type of actual computer programming. One female said, "I really was grateful that I've had computers because if I hadn't I think I would have had a really difficult time understanding the basic programming." A male agreed, saying, "Most high schools require that you go through some basic programming for situations like this, I think. So most of the people that go through this should have some kind of understanding of a little bit of programming." Several others thought students "should have

a basic course in computers, including a little programming. You should be able just to jump on the computer and get after it."

Contrary to some opinions, this type of background is not common. The few who have had that experience think many others also have it: "In Wyoming we have to go through a basic programming class to graduate. That's just showing most people do understand." Unfortunately, that is not the case. Many students, especially older ones, have not had a computer course in high school or college. In addition, most "Introduction to Computers" courses in both high school and college are moving away from any actual programming. For example, CS 150 at Montana State University has none.

The Menu System. For all learning style groups reaction to the menu-driven software was generally positive after an initial period of confusion:

- All in all I thought the little menus were really neat. It was very workable and easy. You could create a command really fast.
- The menu system was very helpful because it was right there in front of you.
- It told you everything you needed to do.
- It gave you all the options. You'd know what your next step would be.
- It was easy to follow with all the instructions there. You picked what you want to build the program. It was very easy. Very understandable and easy to follow.

- As a novice, the menu choices help quite a bit. You're not in there to learn how to run a computer; you're in there to learn chemistry.
- If you had to memorize all that, you'd never do it.

Many students of all learning styles, however, reported problems understanding the menu system in the beginning. Some found learning the meanings of the menu choices "pretty easy to understand," but others "just kind of guessed." Many used trial-and-error: "At the beginning it was a problem. We'd pick one, and it wouldn't work, and we'd go back and try again. But toward the end we knew what they meant." Some "didn't know what a lot of the abbreviations meant." For most students this period of confusion was short-lived, but a few reported problems "that continued until the end with the final project."

Programming. It is not the intention of the chemistry faculty to teach "computer programming" in the lab, but there is a strong similarity between entering a step-by-step procedure for measuring laboratory data and writing a computer program. Both involve a carefully thought-out series of commands to the computer, both must conform to detailed rules of syntax, and both are prone to "logic errors"--that is, obtaining unexpected results because of entering the wrong commands. Students tend to view the task of setting up an experiment on the Interface computer as "programming."

In general, those with any computer programming experience at all found the system very easy, and those with no experience suffered some initial confusion. "They explained to us way back in junior high what a loop was," said one student, and another said, "I felt like I was back in my basic computer programming class, in understanding the way a program functions and executes. That background helped a lot." Several students found they "were able to stand at the computer and pick what you wanted, and you were all set. Sometimes you didn't have to read the book, the choices were just right there--GOTO, PRINT, and so on."

The trouble with this approach was that some students did not have the background to know what the choices could do for them. For them, a short introduction to the rudiments of programming, such as sequential statements, loops, and GOTO statements might have helped:

- It was easy to write the programs in the sense that you didn't have to memorize the commands, such as GOTO, but it was never really taught "GOTO does this."
- I didn't have any trouble with the programming because I've had some experience in it, but some of the people who were with us were saying, "What is that? What are we supposed to be doing?"
- The people that were next to us, every time they would go to do anything, they'd have to write their program a couple times. It would be real wrong, whatever they were doing.
- For someone sitting in a chem class who is not used to dealing with loops and exits and things like that; it just kind of compounds the problem.

Most students, however, found that the problems disappeared "once you learned the language of it. That was my stumbling block, just learning the language. Inexperience. Once you learned it then it was a breeze; it was really fine." Others agreed, saying that once they "learned the language it was easy. It was just learning the language."

Many students could imagine the problems they might have had without the menu system. For them, having the possible choices presented to them at each step of the way was a big help:

- That is where the most efficient part of the system comes into play. Basically it eliminates any kind of programmer error. When you are typing in code you often don't see things that are there. Menus eliminate that possibility.
- It's minor programming. Coming in to a [menu] system is a lot more helpful. It makes things go quicker and you can understand quicker without being faced with other problems.
- One thing that I found extremely helpful was the fact that when you're writing programs everything is there [in menu choices]. As long as you understand what you want the computer to do, the choices are there.
- It let you program without having prior computer experience.
- The programming was easy to learn.

Data Acquisition. Many students appreciated the data acquisition phase of using the Interface. "It made the collection of the various types of data more efficient and

faster. It was quick; it measured things fast." The elimination of manual data recording was seen as a real plus. "You didn't have to write [the information] all down because it was stored on disk. You could just punch it up later and print it out instead of having to write it all down." The data "went straight to the spreadsheet. It was great."

When asked to comment on data acquisition, some students ignored the programming task and said "the computer did all of the work for you, [such as] keeping track of the currents for at least five minutes. The computer took all the measurements. That's helpful." Others acknowledged the part they had to play in getting the computers to do the work, but concluded that "it didn't take long to make the programs to run it." The clear consensus was that "without the computer, [data acquisition] would have been much more difficult." The end result was that "it made the work a lot easier."

Measurement Precision. Comments by Assimilators and Convergents reflected an appreciation for precise, error-free measurements:

- It eliminates error. There are a lot of things you can do to make manual measurements inaccurate.
- It helped make really precise measurements.
- My temperature readings were really precise. You didn't have to constantly try to figure out how to read a thermometer.

- It was always accurate. We didn't have to worry about reading a thermometer wrong.

In contrast to Assimilators and Convergengers, neither Accommodators nor Divergers mentioned accuracy as an advantage. Assimilators and Convergengers are on the abstract conceptualization end of the perception scale while Accommodators and Divergers tend toward concrete experience. Perhaps the act of precisely representing a physical quantity by a numeric value strikes a sympathetic chord in abstract learners whereas concrete learners feel no such connection.

Graphing. Convergengers, Divergers, and Assimilators mentioned the ease with which graphs could be produced using the system. "We got a graph from the spreadsheet," one Diverger said. "Instead of making our own graph, we could just cut that out and put it in our reports. It was much easier and more accurate than if we had to do it ourselves." Another Diverger said, "I just think it's easier for the machine to do it, and much faster too." Indeed, many students liked the system "because it would make the plots for you, rather than having to hand plot it and have the chance of human error. It was more concrete that you were right. By hand, you could make some stupid error and the whole reading could be off." As an Assimilator said, "I personally hate making graphs by hand. They don't turn out that well."

Gaining Computer Skills. Some students recognized the opportunity the Interface system gave them to employ computers in a useful setting. "The computers were right there where you were doing the experiment," one said. "The computer was involved in it all the time. That was the most useful part." Another student thought that "for people who don't have computer experience it's a great introduction, even though it's probably a little bit intimidating for somebody who doesn't understand what a GOTO or IF-THEN is. It really shows them what they can do with it."

One of the goals of the Interface designers was to enhance the general computer skills of chemistry students. Students saw this as a reasonable goal as indicated by the student who said, "I think anybody, if you're doing chemistry, should be able to follow a few directions and use a computer. Shouldn't you?"

Benefits Versus the Effort of Learning. When asked specifically how they viewed the trade-off between the effort needed to learn to use the Interface compared to the benefits it yielded, respondents were unanimous: "The benefits clearly outweigh any costs." There were differences, however, in the comparison between the ease of learning to use the computer Interface and the benefits gained from using it. Accommodators and Convergers

mentioned the problems they had learning to use the system, but they concluded that the effort was worth it. As one Accommodator described it, "It was worth the problems at the time. There were hassles and headaches, but a lot of the headaches and hassle could be avoided. Just a little explanation [would have helped]." A foreign student who is a Converger said, "I think the computer was helpful, but for me it was the most difficult part in the beginning. It was in the beginning confusing, and I didn't find the computer book very clear or helpful to understand completely." These two learning style categories contain students who use active experimentation to help them understand the system. The common routine in labs, however, is to expect students to gain much of their understanding through reading before coming to class.

In contrast, Assimilators stressed the ease of learning to use the system. This is the group that mentioned the manual as being the most helpful. "The benefits clearly outweigh any costs," said one. "I would think costs [of learning] should in most cases be minimal." When asked how long it took for the benefits of the system to outweigh the costs of learning, Assimilators indicated that it was with "the first lab" or that "I was comfortable the first few labs." In general, Assimilators thought there was "a minimal effort for use and maximization of the benefits--a very ideal situation." One Assimilator had a

suggestion to prove to doubters that learning to use the Interface was worth it: "The best way to illustrate that would be to actually have people take measurements without the Interface. It would quickly become clear that it's much easier with the Interface."

Divergers stressed the advantage that learning to use the system gave them in visualizing the results. "I'd say it's definitely worth it because it really helped you visualize and it helps you understand," said one. "You weren't just looking at numbers, and you weren't caught up doing detailed graph work." To emphasize the point, another said, "I can compare it to a physics lab where we had to take a little pen [to make graphs]." Other Divergers appreciated the fact that "the computer took that busywork that you shouldn't have to be bothered with, like printing numbers in columns. It would do it via the program, which was neat." They noted that "you weren't caught up in doing little detailed graph work. You could get slopes right away, which is something you can't do [manually]."

In the opinion of students from all learning style groups, one of the things which could ease the effort of learning would be a better introduction to the computer system. The first few weeks of confusion would have been reduced with more explanation at the beginning:

- You just kind of went in blind to it. You just start doing it. They didn't have any real introduction saying, "This is what is going to happen." There was nothing about the computer.
- In the beginning, they don't explain it clearly enough. Afterwards you see, and then you understand it.
- I just think with a few adjustments it could make the pros outweigh the cons a little more.

The Role of Teaching Assistants

As is common in many universities, chemistry labs at MSU are designed by faculty but actually taught by graduate teaching assistants (TAs). The key position TAs play in the minds of students is shown by the fact that there were more focus group comments dealing with teaching assistants than any other single topic.

Perhaps the most striking characteristic of the comments is their variability. A few students had a mid-quarter change of teaching assistants so they were in a good position to make comparisons. One student reported that "my first TA the first day said 'Let's do this together,' which was really helpful. My second TA would say 'This is our stupid little interface and our computers and sometimes they work and sometimes they don't,' and you think 'Is it really that important?' Maybe there should be more uniformity in the way they handle the classes."

Some negative comments about TAs reflect the fact that graduate students in chemistry do not necessarily have an interest in or training for teaching. One student reported

that "we would ask our lab instructor and he would just laugh and go, 'Ha, ha, ha' and then walk away. Like, oh, thanks!" Another student reported having "a problem with my TA. A lot of people in my lab did. It was tough. He was a little unapproachable at times. It was difficult to have him assist us with anything without him insulting us." A third student "asked what a precipitation [precipitate] was, and he goes 'You don't know what that is?' I wouldn't have asked if I knew what it was! I was just hoping this guy wasn't going into teaching."

Another problem is the fine line between giving too little help and too much. One student was frustrated by receiving too little help. "My instructor said, 'I will help you with that,' and then when it came time we said, 'Help,' and he said, 'Well, I can give you a hint.' We were almost ready to cry. I can't remember these words he was throwing out at us. I have no idea what a loop is." The same student later pointed out, however, that "there's only one TA, and that's too time consuming if they're going to go around and tell everybody how to do it. But it would help us learning and understanding it."

A different student received too much help. "One thing that frustrated me," she said, "when we were stuck and asked for help, often times our TA just did it for us, and I felt cheated because I didn't learn anything." Other students viewed the problem of receiving too much help

philosophically, noting "the frustration of TAs with 20 people asking you for help. Their tendency is to just go ahead and do it and get it done and say 'It's fixed.'"

Another problem is that few of the teaching assistants have themselves had much experience with an approach to teaching chemistry which utilizes advanced technology in the laboratory; their own undergraduate background would most likely have been in a traditional laboratory. All TAs participate in a training workshop before classes begin, and this exposure gives a measure of technical proficiency. However, the tendency to "teach as we were taught" is strong, and for many TAs the transition to a new way of thinking about labs may be difficult.

Several students recalled that their teaching assistants were negative towards the Interface system. The students themselves, however, had the opposite opinion regarding the value of the system:

- With a little encouragement from the TA I think [the Lab Interface] could really be useful for people. When they treat it like it's not worth anything, you have a tendency to think it's not very useful. But then you find an experiment and say, "Oh yes it is." You kind of forge [ahead] on your own.
- Our first TA didn't even want the Lab Interface mentioned in the report. I thought that was really weird because it was so much a part of it--the spreadsheet and so on. I mentioned it anyway because I thought it tied in.

It is interesting to note that none of the negative comments regarding TAs dealt with them not knowing how to

use the system. It is possible, however, that uncertainty on the part of the TA in the system's use led them to discount the importance of the Interface.

To balance the picture of teaching assistants, there were about twice as many positive comments about them as negative. Most TAs were portrayed as being very helpful. "Our TA went from group to group, explaining the same thing to everybody," one student said. "Everybody said our TA was wonderful because she was so patient. Exactly the same question from every group." Another student said, "Our TA was always hanging around telling us which way to go." When asked if that was helpful, he said, "Oh, yeah. He was right there telling us what we needed to select. Especially when we were first introduced to it."

"[Our TA] was always walking around," a third student said. "If you had a question she was always available to answer the question for you. That was really helpful. If you were falling way behind, she'd sit down and help you through the program and say 'That's what this does.'" When asked if getting help from the TA was effective, one student said, "It was in our class, yes." Another agreed, "Ours too." When students were stuck on a problem, "it didn't take long to fix because the lab instructor saw it and showed us."

Several students liked the positive attitude their teaching assistants had towards the Interface system. One

student who had two TAs during the quarter recalled that "our next TA was marvelous. It seemed like he felt [the Lab Interface] was a part of the whole unit. The TAs should treat it with more respect because it is definitely a good tool."

Some students who were apprehensive about the system found the encouragement of their TAs helpful. "The thing that helped us the most," one said, "was that our TA kept pushing the idea that it was easy and that you didn't have to worry if you hadn't had any experience with a computer." Another shared that view, saying,

The TA has to encourage it so you don't feel like 'Oh gosh, this is a brand new thing.' It's not as exciting to think you're going to use it when the person that is showing you doesn't make it apparent that it is real important to use it and know what you're doing. You don't come away with a good feeling to start with. If someone wants to show you what you're doing and what you have to do, then you come away feeling 'OK, that is neat.' You want to do it more.

Focus Group Summary

A major finding of the focus group interviews was that even though students from all learning style categories apparently learned the same amount during labs, they learned in different ways. Specifically, Convergents and Accommodators favored active experimentation as the means of understanding the system, Divergers preferred to think about the Interface and its operations to understand it, and Assimilators would concentrate on reading the manual

for understanding. In general, Divergers and Assimilators found it easier to learn to use the Interface than Convergers and Accommodators did.

Opinion regarding the role the Interface played as an aid to structured thinking also varied by learning style. Accommodators and Divergers, who tend toward concrete thinking, mentioned and appreciated the structure imposed on their thinking while Convergers and Assimilators did not--perhaps because they took such abstract thinking for granted. In contrast, Convergers and Assimilators appreciated the precise, error-free measurements the Interface made while Accommodators and Divergers ignored this aspect.

There were many other aspects of learning to use the Interface which were shared by all learning styles. Asking questions, the importance of "understanding why," visualization, lack of long-term fears, and the importance of sympathetic TAs were mentioned as being significant by a wide range of students. In addition, a positive attitude towards using the Interface system was shared by students in all learning style categories.

No significant differences between any of the learning style groups were found on measurements with the rationalistic instruments of TIPS and the questionnaire. Focus group discussions, however, identified distinct differences between the learning style groups with respect

to several learning strategies. Thus, students appear to be reaching equivalent learning goals in very different ways. In a similar vein, TIPS and questionnaire results found no significant differences between students of different TAs. Focus group discussions, however, identified strongly-held opinions, pro and con, regarding the effectiveness of different TAs.

The statistical measures used in this study compared the averages of groups. Since all learning style groups were able to learn, the averaging techniques eliminated any individual differences which might have existed and showed the groups as equal. However, the groups were not equal in the ways they learned; they approached the learning task differently. Thus, in this study, the naturalistic portions were more sensitive to how students were learning than were the rationalistic portions.

CHAPTER 5

SUMMARY, CONCLUSIONS, AND RECOMMENDATIONS

Summary

The Chemistry Department at Montana State University has designed and implemented a microcomputer-based laboratory (MBL) for freshman chemistry. The purpose of this study was to examine how students learned to use the computerized Laboratory Interface package and what they perceived its strengths and weaknesses to be. The design for this research was a naturalistic case study which employed both qualitative and quantitative methods. Interview data were collected through a series of focus groups; other measures were Kolb's Learning-Style Inventory (LSI), Okey and Dillashaw's Test of Integrated Process Skills (TIPS), and a questionnaire. The last three were used to guide the focus group inquiry and to illuminate its results. The participants were approximately 300 students enrolled in freshman chemistry labs. Research questions involved student learning strategies, students' assessment of the Interface package, improvement in the skills and processes of science, student interest in chemistry as a field of study, and the connection between student learning styles and student views of and uses of the Laboratory Interface.

During the first full week of the quarter, Kolb's LSI was administered to all students in the labs, and the results were used to select focus group participants. The Test of Integrated Process Skills (TIPS) was administered the second week of the quarter and again the last week of the quarter. The test form for TIPS also contained a question about interest in chemistry as a field of study. Data from a questionnaire was gathered during the final laboratory session, and focus groups were conducted after the final lab.

The main focus of the study was the learning strategies students used as they became familiar with the Lab Interface. A number of learning strategies were identified; some of these strategies were dependent on the learning style of the student while others were shared by all students. Results from the Learning-Style Inventory indicated that the population for this case study had an even mix of all four learning styles. Focus group comments revealed sharp contrasts between some of the learning strategies of students with different learning styles. Two groups relied on active experimentation to learn the Interface system. The third group learned by relying on the printed manual. The fourth group learned best by studying and modifying examples until they understood them. Students in the latter two groups specifically avoided experimentation as a method of learning to use the

Interface. Students who prefer concrete experiences noticed and appreciated the structure imposed on their thinking by entering the steps of an experiment into the computer. Those whose learning style emphasizes reflective observation found it easier to learn to use the Interface than those who prefer active experimentation, but students from all learning styles thought that "the benefits clearly outweigh any costs [of learning]."

Other learning strategies were shared by all students. Many wanted to know more about why they were doing certain steps. For them, a clear overall picture helped put the individual parts of learning into perspective. Students from all learning styles used the manual as a reference and found the examples in the manual helpful. However, some preferred to have exercises in which they had to modify the examples. Almost all students were willing to ask questions of their partners, other classmates, and their teaching assistants.

The visual aspects of the system played an important role for many students. The arrangement of experiment steps on the screen, watching the Interface acquire and display measurements, the drawing of real-time graphs of experimental data, and watching others perform certain tasks on the computer were all mentioned as things which aided understanding.

Numerous students mentioned some initial apprehension regarding the use of computers, but almost all soon overcame these fears. Many, in fact, appreciated their new-found ease with the use of computers. Those with some computer background were thankful for the advantage this gave them, and those without such experience wished for some kind of introduction to this kind of computer use.

All respondents were pleased with the speed, accuracy, and ease with which the Interface system acquired data. It was clear to them that making the same measurements manually would have been very tedious. Students from all learning styles found the menu system of the Interface to be a definite help in setting up their experiments. They generally found the Laboratory Interface system to be a powerful aid in the collection and analysis of laboratory data. While abstract learners found the system easier to learn than did concrete learners, the consensus of all groups was plainly in favor of using the system.

Conclusions and Recommendations

Science Skills and Questionnaire Responses.

Students from all learning styles can learn effectively in the lab. Specifically, the test of science skills (TIPS) found no significant differences between students with different learning styles. The only

significant difference found by TIPS between groups of students was that science majors performed better than non-science majors. TIPS is designed for lower level students than college freshmen. Since the average score for this group of students was quite high, little improvement could have been expected. Although this statistical result may have been due to the short time interval involved in a one-quarter lab, this points out the need to design a test specifically for this level of student and for the goals of this class.

Previous experience in chemistry cannot be assumed for introductory students, especially older students and non-science majors. The end-of-the-quarter questionnaire found that there were significantly fewer older students who had previous experience in chemistry as compared to the younger students. There were also significantly fewer non-science majors with such experience than science majors. Thus, extra consideration is needed when designing course material for older students and for non-science majors.

The Interface is a useful tool in the laboratory and is an appropriate use of computerized technology in education. Overwhelmingly, students see the value of the computers for acquiring and analyzing data. They strongly agree that the computers were useful in the role of designing experiments and were easy to use. While the agreement regarding the ease of learning to use the

computers was less strong, it was still very positive. Students from all learning styles are willing to put forth the effort to learn a new technology if they can use it. Opinions were positive regarding increased comfort with computers as a result of the course. Thus, the students have a high regard for the use of the Laboratory Interface system for learning chemistry.

Students of all ages and learning styles showed similar attitudes regarding the use of the Interface, but science majors were more favorable toward the system than were non-science majors. This points out the need for extra care in the course for non-science majors, to ensure that situations which could lead to negative attitudes are avoided.

Learning Styles and Learning Strategies

Learning Styles. A major finding of this study is that a variety of learning styles exists in the population of students taking introductory chemistry, as shown by the LSI results. Therefore, students should be aware of what their own style is. According to Dixon,

Learning style instruments are best used as tools to create awareness that learners differ and as a starting place for each individual's continued investigation of self as learner. (1985, p. 17)

Thus, it would be worthwhile to discuss learning styles with students and worth the time to administer a

learning style instrument as a means of increasing student self-awareness. Students should be aware of their own learning style as well as the variety of styles exhibited by class members.

Learning and Teaching Strategies. Another major finding of this study is that students in the different learning style groups approached many learning tasks differently, as shown by the focus group results. This supports recent work at the Center for Adult Learning Research which emphasizes learning strategies instead of learning styles.

Students should be made aware of the variety of learning strategies identified in this study. Instructors can then help students understand their own learning patterns and can encourage them to expand their learning strategies. That is, instructors should teach "learning-to-learn" (Weinstein, 1990, p. 25).

First, however, TAs should have basic instruction in teaching, should know their own learning styles and strategies, and should be aware of how these affect the teaching strategies they use. Teaching assistants should then spend time discussing learning styles and strategies with students. This would serve as a reminder to the TAs that they need to be aware of their own teaching styles, and should employ a wide variety of teaching strategies in

their classes. Using a variety of approaches in their instruction can help to create diversity in the laboratory and foster a collaborative environment (Dixon, 1985, p. 16).

Active Participation. Active participation is a major learning strategy used by many students to learn in computer-related situations. Roughly half the students in the labs (the Convergers and Accommodators) require the hands-on process of active experimentation before they can adequately understand the Interface system. They "didn't learn anything, really, until [they] tried to put it into the computer." This being the case, course designers should structure laboratory exercises in such a way that adequate provision is made for such experimentation to take place. In addition, the difficulty some students have learning to use the system without active participation should lead course planners to rethink the policy of quizzing students about the equipment before they have a chance to use it.

The Laboratory Manual. For many students, a well-written manual is crucial to efficient learning. Assimilators, especially, relied on information in the manual to understand the computer system. For them, the active experimentation of the Convergers and Accommodators would have just caused confusion; they learned to use the

system by reading about it. They appreciated what for them was a clear set of instructions and examples in the present manual.

Many other students used the manual as a reference and were frustrated by the lack of an index. The indexing feature of a good word processor should be used to add an index to the manual; it would be a straightforward task. A page or two should also be devoted to a quick reference guide to the menu system and common Interface operations.

Every feature of the Interface should have an explanation of its use in the manual, accompanied by one or more examples. Important aspects of the examples should be described in detail.

On the other hand, many students need the active involvement of working with and modifying the examples before they are completely understood. For these students, learning was enhanced when they "had to be able to process [their] thinking." Thus, the manual should also contain several series of incomplete examples which the students would modify and finish to achieve a desired result. This would encourage them to internalize the meanings of the operations rather than just copying from the book to the screen.

One cognitive advantage of the Interface system is the way it forces students to clearly specify the set of steps they (or the computer) will perform to achieve a desired

result. Students found they "had to start looking ahead; [they] had to think how information would be processed to get a certain result." This type of thinking is at the crux of experiment design; it should be stressed by the explanations which accompany examples and by TAs and course planners.

Partners and Asking Questions. The learning climate in a laboratory should be characterized by an open, collaborative exchange of ideas (Knowles, 1980, p. 48). This was found usually to be the case in the chemistry labs; asking questions, especially of the teaching assistant, was the second most-frequently mentioned technique for finding things out. In view of the importance of asking questions, teaching assistants should frequently be encouraged to be as approachable as possible. There may be times when students need to be weaned from over-reliance on the TA, but this should be done at a pace which students can manage.

Different schemes for choosing or assigning partners should be explored to see if improvements could be made in the overall learning climate. Having students work with partners should enhance the collaborative atmosphere in the lab, but this practice received mixed reviews. Having a more experienced partner was seen as good as long as the partner did not do too much. Having a less experienced

partner was viewed by some as undesirable because of the extra time involved, but the benefits for the class as a group were also recognized by students. Teaching assistants should receive instruction in peer learning and should encourage a collaborative atmosphere in the lab, both among partners and among the class in general.

Structured Thinking. Setting up the steps of an experiment on the computer requires a clear idea of the goal to be reached and the steps needed to reach that goal. Concrete learners definitely benefit from the experience of working with the Interface software as they design an experiment. For them, the structure imposed on their thinking by the menu software helps them process their knowledge and understand more clearly. Teaching assistants should keep in mind the differences between their abstract learning style and the concrete approach of Accommodators and Divergers and should help those students see the structure in their experiment designs.

Understand Why. Many students need to understand the reasons for what they are doing, rather than just blindly following instructions. For example, some students would "just like to know why [they were] using both disks." These learners "need to see a purpose for things." For them, a clearer overall picture would have helped their understanding of the system. This type of system overview

should be presented in the first few lab sessions. Some students suggested "a voluntary session one night. Have everybody come who didn't know what was going on."

Seeing It. The visual aspects of the Lab Interface are a benefit to students. Many students "have to see things" to understand, and the Interface provides a clear visual component. The steps of an experiment are clearly shown on the screen, measurements are (usually) displayed on the screen as they are being made, and graphs of data can be generated easily. Instructors should help students to utilize fully the visual components of the system, such as graphing, so students can more easily understand the chemical principles being illustrated.

Computer Background. Prior computer experience is a definite advantage to students in the microcomputer-based lab. Students with previous computer experience, especially simple programming experience, felt themselves at a distinct advantage in the use of the computerized Lab Interface. Instructors and course designers, however, need to keep in mind that computer experience is not a prerequisite for the course and should plan instruction and exercises accordingly. Indeed, one of the goals of the system designers was to improve student skills in the use of computerized technology. Until such a time as it is reasonable to expect all incoming students to be familiar

with computers, instruction should be provided which assumes no prior computers experience.

Teaching Assistants

The Role of Teaching Assistants. TAs play a key role for students learning to use the Interface. There were more focus group comments dealing with teaching assistants than any other single topic, and there were about twice as many positive comments as negative comments regarding TAs. Thus, the indications are that TAs are generally doing a good job of adapting to the new technology. There were, however, a number of negative comments regarding teaching assistants.

Training Workshops. TA training workshops play a crucial role in the success of the laboratory program. Teaching assistants need to become informed regarding the issues of student learning styles and learning strategies and need to discover their own teaching styles. Only then can they adequately assist students in becoming more aware of their learning styles and strategies. Thus, TA workshops should incorporate an introductory course on teaching which includes major topics related to adult learning. This introductory course could be provided by campus faculty who are familiar with the issues involved.

Most teaching assistants have no experience with the Laboratory Interface in their own undergraduate courses. This puts them at a disadvantage which can be overcome only by having them become proficient with the system. The current practice of requiring training workshops for TAs before the start of the school year is to be highly commended. The fact that none of the negative comments regarding TAs dealt with them not knowing how to use the Interface system indicates that they were generally knowledgeable about it. However, some of the negative attitudes TAs displayed toward the system might indicate that they were not familiar enough with the system to appreciate its worth or were covering their ignorance of the system by denigrating it. It is only through intensive exposure to the system that the TAs can master it and learn to see its worth.

Another possibility is that some instructors may be philosophically opposed to the Interface system. For example, some may think that the time taken to learn to use the computerized chemistry equipment should instead be spent learning chemistry itself. (This assumes that laboratory chemistry can be divorced from the tools of chemistry, which is a doubtful stance.) The purposes and goals of using the Interface in the chemistry labs should be thoroughly discussed in the training workshops. TAs should understand the advantages of the system and thus

become promoters of its use. Improvements have been made in TA training since data collection for this study, and these changes should help alleviate some of the problems noted here.

Introducing Students to the Interface. The most critical session for students in the laboratory is the first meeting. Statements made by the instructors during the first class set the tone for student opinion regarding the computers in the lab. Some students reported that their instructor "was right there telling us what we needed to select, especially when we were first introduced to it." Other students, however, "just kind of went in blind to it. You just start doing it. They didn't have any real introduction saying, 'This is what is going to happen.'"

Instructors need to be especially careful about early statements regarding "programming." Some students became very concerned because "the first day they tell us we will have to write a program! Don't tell us that! Wait a couple weeks." Much of the initial student apprehension was due to fear that they "would have to design programs all by ourselves without any help from the books. But then [we] saw it was straightforward." The TA training workshops should carefully address the way the system will first be introduced to the students in order to lessen student apprehension rather than to heighten it. For many

students, a short introduction to the rudiments of programming, such as sequential statements, loops, and GOTO statements, would help.

Several times near the start of the course, TAs should perform a step-by-step demonstration of a process, such as maneuvering the menu system or editing a program line. Students "definitely think more time needs to be used by the TAs teaching everyone as a group with their monitor." Especially at the beginning of the course, when some students are apprehensive and confused, a short start-to-finish demonstration on the large monitor could dispel much of the perplexity students are feeling.

Recommendations for Further Research

Furstenau's dissertation (1990) reported the development of the Laboratory Interface at Montana State University, and this study is the first to describe how students learn to use it. There are other aspects of the Interface system and its use in laboratories which could be examined. One could examine student learning as it relates to other descriptions of learning style, such as those of Canfield (1983), Riechmann and Grasha (1974), and Entwistle (1981). Another would be the effect that teaching style has on student learning in computerized laboratories (Conti & Welborn, 1986), and still another would be the role played by previous computer experience for student

learning. More could be learned about learning strategies students use in different situations and about whether explicit instruction in learning strategies is effective.

A different approach would be to compare the microcomputer-based laboratory to a traditional laboratory with respect to student learning of chemistry and the scientific process. Care would be needed in a study of this type to avoid biased results due to the specific questions asked and to the different philosophies of course designers. An instrument specifically for this level of student and for these class goals would have to be designed.

Amend, Tucker, Larsen, and Furstenau (1990) assert that the use of microcomputers in the laboratory should result in a re-allocation of time (p. 102). In a microcomputer-based lab, less time should be spent on data acquisition and more time should be spent on experiment design and data analysis. To confirm this, it would be useful to perform an analysis of time allocations in traditional and microcomputer-based laboratories.

The Future

The Laboratory Interface system at Montana State University is playing a leading role in the integration of computers into the study of chemistry. It is well-received by students, especially as they note its speed and accuracy

in data acquisition and the ease with which they can analyze and graph the data obtained. It is cost-effective in the labs and helps introduce students to the increasingly computerized technology of science. By learning more about how students approach the system, instructors can employ teaching strategies which will optimize learning and thus more fully exploit the system's potential.

The use of this or similar systems should be promoted in other institutions, but several obstacles need to be overcome. Since this is a new approach, there is no pool of experienced practitioners. Graduate students who act as teaching assistants in laboratories probably did not learn using this type of system. A century of refining and selection has gone into traditional laboratory exercises and instructions, but comparatively little time has gone into developing exercises suitable for the new-found power of the microcomputer-based lab. Publishers see no pool of ready customers, and consequently are unwilling to support texts. Administrators did not use such a system in their schooling and may see no need to switch now.

The solution to these problems is education: informing colleagues via conferences, workshops, and the literature; training teaching assistants in the new approach before they start teaching the labs; and informing administrators and financial officers of the advantages of the approach.

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APPENDICES

APPENDIX A

FOCUS GROUP GUIDE

BACKGROUND

Focus groups will consist of 6-7 students with Bruce Ivey as the moderator and will be held in the Chemistry Department conference room.

Participants for a given group will be selected from the 125 and 135 labs on the basis of their being in one of the four quadrants of Kolb's LSI. To highlight possible differences between groups, students selected for groups will be those whose AC-CE and AE-RO scores are at least one-half standard deviation from the means dividing the groups. Groups will meet at supper time or a little after and the main attraction for students will be pizza and pop.

OPENING STATEMENTS

Introduce myself:

Name, position, etc.

Overall purpose for the research:

"We are trying to learn about the effectiveness of the Laboratory Interface (LI) and how students learn to use it."

Purpose for focus groups:

"We are trying to learn what aspects of the LI students found helpful and unhelpful and how students learn to use the LI. We want to know about the experiences of the students as they learned to use the interface."

Selection of this group:

"You were selected because all of you have similar learning styles, as indicated by your Kolb LSI scores."

"The overall learning style of this group is ... "

Protection of privacy:

"The session is being audio taped so I will be able to produce a transcript of what was said. You will not be identified by name or section in any way in the final report. Only my advisor (in the Education Dept.) and I will have access to the original tapes"

and transcripts. Chemistry Department TAs and professors will not have access to the tapes."

How you can help us:

"Each of you has a unique and valuable story to tell about your use of the Lab Interface. Knowing about your experiences will help us make the lab more successful for other students."

The discussion topics:

"I will introduce several discussion topics, but feel free to bring in other perspectives and comments. If you feel there are important things that are being left out, please bring them up. Don't be bashful about jumping in with your observations."

"If someone says something which does not match with your experience, please tell us your experience too, so we get a balanced viewpoint. Even if what is said seems similar to what you would say, tell us your experience anyway. All experiences are different in some respect."

DISCUSSION TOPICS/QUESTIONS

1. "Please write your first name on a card and place on the table." Ask about Chem 125 or 135, major, why students are taking a chemistry lab.
2. "Let's begin on a positive note. What aspect of using the LI did you find the most helpful? Why was this helpful?"

"Help me understand what you just said."

"Can you give me an example of ... ?"

3. "What aspect of using the LI did you find the least helpful? Why was this not helpful?"
4. "Now let's shift and talk about learning to use the LI. First, what things about using the LI were easy for you to learn? Why were they easy for you to learn?"

"Tell us about your experience while learning to use the LI."

"What did you do to learn to use the LI?"

"What steps did you go through?"

"What sources of information did you use?"

"Were these the best sources of information, or merely the most accessible?"

"Did you study the use of the LI beforehand?"

"Did you keep track of how you were doing?"

"Did you make any changes in the way you were trying to learn to use the LI?"

"Do you think all students found the same things to be easy, or were these points easier for you than other students?"

5. "What things about using the LI were difficult for you to learn? Why were they difficult for you to learn?"

"Did you try different ways to learn this point?"

"Did some approaches work better than others?"

"Do you think all students had difficulty with this point, or did you have more trouble than most?"

6. "Almost everyone has some fear about trying to do something new with computers. When you first started this course, what fears did you have about learning to use the computerized LI? Looking back, were those early fears justified or not?"

7. "You have talked about the benefits of using the LI, for example, _____. You also talked about some of the difficulties of learning to use the LI (_____), and about problems you had during its use (_____). Looking back, do you think the benefits outweigh the disadvantages? Explain."

8. "To summarize, what one or two things would you like to tell us so we can have a more effective laboratory program? Why did you pick the choice you did?"

APPENDIX B

END-OF-QUARTER QUESTIONNAIRE

Chem 125/135 Survey

Winter 1991

We would like to improve this course as much as possible. You, as a student, are in the best position to give us feedback and ideas for improvement. The answers you give will IN NO WAY affect your grade. We ask you to give the following information only so we can improve the course and help future students. Please answer the questions honestly and fairly--your input does make a difference! Please write legibly.

Name _____ ID Number _____
 Major _____ Age _____ Sex _____

1. (A) I took chemistry in high school. (Circle A or B)
 (B) I did not take chemistry in high school.

For each item below please circle the choice which best describes whether you agree or disagree with the statement.

2. I believe that computers are useful for learning chemistry in the laboratory in the role of designing experiments.

Agree Strongly Agree Neutral Disagree Disagree Strongly

3. I believe that computers are useful for learning chemistry in the laboratory in the role of acquiring data.

Agree Strongly Agree Neutral Disagree Disagree Strongly

4. I believe that computers are useful for learning chemistry in the laboratory in the role of analyzing data.

Agree Strongly Agree Neutral Disagree Disagree Strongly

5. I am more comfortable with computers as a result of taking this lab.

Agree Strongly Agree Neutral Disagree Disagree Strongly

6. Learning to use the laboratory computers was easy.

Agree
Strongly

Agree

Neutral

Disagree

Disagree
Strongly

7. Once I learned how, actually using the laboratory computers was easy.

Agree
Strongly

Agree

Neutral

Disagree

Disagree
Strongly

8. My attitude toward chemistry has improved as a result of taking this course.

Agree
Strongly

Agree

Neutral

Disagree

Disagree
Strongly

Thank you for taking the time to complete this survey.
Please return this sheet to your instructor.

