Kathleen B. Daly. THE EFFECTS OF MICROSCALE AND TRADITIONAL CHEMISTRY EXPERIMENTS ON THE DEVELOPMENT OF INTEGRATED SCIENCE PROCESS SKILLS. (Under the direction of Moses M. Sheppard) Department of Science Education, April 1991.

Two accelerated Chemistry classes were used to compare the development of the integrated science process skills. The students in each class were pretested using the Test of Integrated Process Skills (TIPS I) and posttested using the Test of Integrated Process Skills II (TIPS II). One class performed eight traditional macroscale laboratory experiments and the other class performed eight microscale laboratory experiments over a five month period.

The results showed a significant gain in scores between the pretest and the posttest. There was not a significant difference between the macroscale group and the microscale group in terms of scores on the posttest. Therefore, one treatment was not shown to be significantly different from the other in terms of the development of the integrated science process skills.

THE EFFECTS OF MICROSCALE AND TRADITIONAL CHEMISTRY EXPERIMENTS ON THE DEVELOPMENT OF INTEGRATED SCIENCE PROCESS SKILLS

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Kathleen B. Daly

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CHAPTER ONE

INTRODUCTION

Statement of the Problem

Two of the most prominent themes in recent reform movements in education have been the demand for increasing student performance in math and science, and the demand to improve the critical thinking skills of students. Numerous studies and reports have indicated that the concerns are valid (American Association for the Advancement of Science, 1989; The National Commission on Excellence in Education, 1983). Indeed, it appears that the public and many educators have come to believe that the two reforms are correlated and that by increasing one there will be an increase in the other.

The concern with thinking skills and the association between reasoning ability and the disciplines of math and science is not a recent development. Mann (1979) points to Plato's argument that "Arithmetic stirs up him who is by nature sleepy and dull and makes him quick to learn, retentive and shrewd. He makes progress well beyond his normal power" (Mann, 1979, p. 128). This concept was later echoed by Sir Francis Bacon who also thought that the study of mathematics and science was a remedy for students' lack of attention (Mann, 1979). Although it has been indicated that most students beyond the age of twelve should be able to reason at the formal operational level (Piaget, 1972), Day (1981) indicates that only about 50% of students over twelve are able to demonstrate higher level thinking abilities. At present it is uncommon to go a week without seeing a newspaper or magazine editorial or article calling for increased emphasis on thinking skills and increased achievement in math and science. Finding appropriate teaching methodologies to achieve what has been requested is not an easy task. It must be recognized that the teaching of thinking skills takes time. This use of time must be justified to parents, teachers, students and administrators in the current educational atmosphere of criterion referenced tests, end-of-course tests, and promotion-retention testing. Determining if the time is well spent and if the educational strategy is appropriate are questions that must be addressed. Evaluation is a critical component of any new program or methodology.

Laboratory work is considered an essential part of the science curriculum. Laboratory work provides concrete experience, and helps develop process skills and higher level thinking skills. However, there have been increasing concerns by teachers and school administrators about possible injuries during laboratory activities and potential legal action. Cost is also becoming an important factor due to the necessity for maintaining chemical supplies and providing space with proper safety equipment for storage. To improve laboratory safety, reduce costs, decrease space requirements both for storage and laboratory activities, and improve student skills in the lab, teachers have begun to substitute microscale experiments in inorganic chemistry much as the universities have done in organic chemistry. Microscaling has also been incorporated into general chemistry at the university level, but not to the extent that it has been incorporated in organic chemistry (Zipp, 1989).

The purpose of this study is to determine the relative effectiveness of traditional macroscale chemistry experiments and microscale chemistry experiments on students' reasoning abilities as measured by the Test of Integrated Process Skills (referred to here as TIPS I) and the Test of Integrated Process Skills II (TIPS II). Evaluation of the development of the desired students' process skills may be important to teachers who are considering adding microscale experiments to their laboratory curriculum.

Null Hypotheses

1) There are no initial significant differences between the two groups of students who performed macroscale chemistry experiments and the students who performed microscale chemistry experiments in terms of:

1. percent scores on the mathematics section of the Preliminary Scholastic Aptitude Test (PSAT);
2. grade point average on the previous math course, geometry;
3. intelligence quotient (IQ) scores;
4. grade point average (GPA) when entering the tenth grade; and
5. the total score on the pretest, TIPS I.

2) There are no significant differences in scores between TIPS I and TIPS II among the students who performed either the macroscale chemistry experiments or the microscale chemistry experiments.

3) There are no significant differences in the development of the integrated science process skills between students who performed microscale experiments and students who performed macroscale experiments as measured by differences in scores on TIPS II.

Definitions

For the purposes of this study, the following definitions are submitted:

MACROSCALE GROUP or COMPARISON GROUP is the group of tenth grade chemistry students who performed the traditional macroscale laboratory experiments.

MICROSCALE GROUP is the group of tenth grade chemistry students who performed the microscale laboratory experiments.

MACROSCALE LABORATORY EXPERIMENTS are the traditional laboratory experiments using large quantities (several milliliters or grams) of chemicals and traditional laboratory equipment.

MICROSCALE LABORATORY EXPERIMENTS are experiments for which chemical quantities are substantially reduced, by a factor of 0.01 to 0.001 the amount used in macroscale laboratory experiments (Mayo, Butcher, Pike, Fobte, Holtum, & Page, 1985). (They sometimes require the use of different laboratory equipment.)

THE TEST OF INTEGRATED PROCESS SKILLS (Dillashaw, & Okey, 1980) is a thirty six question multiple-choice test designed to measure science process skills of seventh to twelfth grade students. The test is not curriculum specific but is designed to measure the science process skills of identifying variables, operationally defining, identifying and stating hypotheses, designing investigations, and graphing and interpreting data. (Referred to here as TIPS I to avoid confusion with TIPS II.)

THE TEST OF INTEGRATED PROCESS SKILLS (II) (Burns, Okey, & Wise, 1985) is a thirty six question multiple choice test designed to measure the same science process skills as TIPS I. The test is noncurriculum specific and designed to be used with middle and secondary students (grades 6 through 12). (Referred to here as TIPS II.)

SUBGROUP SCIENCE PROCESS SKILLS IN TIPS I AND TIPS II:

Identifying Variables

Operationally Defining

Stating Hypotheses

Graphing and Interpreting Data

Designing Investigations

INTEGRATED SCIENCE PROCESS SKILLS (Padilla, 1986, July)

IDENTIFYING VARIABLES is the ability to identify variables and keep most constant while controlling the independent variable.

OPERATIONALLY DEFINING is stating how to measure a variable.

STATING HYPOTHESES is determining the expected outcome of an experiment.

GRAPHING AND INTERPRETING DATA is organizing and drawing conclusions from data.

DESIGNING INVESTIGATIONS OR EXPERIMENTING includes determining an appropriate problem, stating the hypothesis, controlling and defining variables, designing and conducting an experiment, and interpreting the results.

FORMULATING MODELS is creating a picture of a process or event.

These integrated process skills were developed from the basic science skills which are defined in Chapter Two.

CHAPTER TWO

REVIEW OF THE LITERATURE

The review of the literature will consist of sections describing:

a) thinking skills and science process skills;

b) the Tests of Integrated Process Skills, TIPS I and TIPS II;

c) the use of microscale laboratory experiments in chemistry.

THINKING SKILLS AND SCIENCE PROCESS SKILLS

The North Carolina Standard Course of Study commonly referred to as the Basic Education Program (BEP, 1985) states that "In order to become productive, responsible citizens and to achieve a sense of personal fulfillment, students must develop the ability to think... (and that) thinking skills should be developed and reinforced throughout the curriculum and during every activity of the school day". (BEP, p. 9) In defining its intent the BEP states that "the most basic thinking skills are memory and translation...(but that)... remembering isolated bits of information or even restating that information in one's own words does not necessarily require reasoning on the part of the student." (BEP, p. 9) To differentiate rote learning from higher level thinking, the BEP states "Higher level thinking skills are defined as those processes which require thinking or reasoning above the levels of memory or translation--interpretation, application, analysis, synthesis and evaluation." (BEP, p. 9)

In reviewing the literature on thinking skills it is obvious that the definitions of thinking and thinking skills vary greatly. Beyer (1985) concluded that the definitions existing in the literature were imprecise, vague and confusing. He stated that "defining critical thinking as virtually all forms of thinking fails to distinguish its unique features and functions, and is about as useful as no definition at all" (p. 270). Marzano et al. (1988) support Beyer's contention and conclude that although there has been progress in understanding the dimensions of thinking skills, that the multitude of definitions and programs causes confusion. Drawing heavily on the works of Perkins, Sternberg, Gardner, Anderson, and Jonson-Lair, Marzano et al. (1988) identified five dimensions of thinking that include: metacognition, critical and creative thinking, thinking processes, core thinking skills and the relationship of content area knowledge to thinking. The authors contend that this framework reflects the "various domains of thinking as they are understood in terms of current research...(and that)...educators can use this framework as a resource to match the demands of the curriculum to the needs of the students" (Marzano et al., 1988, p.4). Quellmalz (1985) indicated that the perspective of philosophers, psychologists and curriculum theorists have resulted in different frameworks and terminologies of thinking skills. In analyzing the works of researchers in these fields, Quellmalz concluded that to teach higher order thinking, students must be taught to extend their lines of thought. They should be able to identify and analyze a problem, relate information necessary to solve the problem, and evaluate solutions and conclusions. Students should be critical of their techniques and use the cognitive processes of analysis, comparison, inference, and evaluation in reasoning through problems.

Nickerson (1984) asserts that thinking should be integrated into the curriculum because it is totally dependent on knowledge. Effective thinking is not guaranteed by having much knowledge, but without knowledge, effective thinking is prohibited. Chambers (1988) affirms Nickerson's conclusion and indicates that learning to think and thinking correctly must occur in contexts. Science provides a general context for thinking and the particular disciplines such as Biology, Chemistry, etc., also provide useful contexts for thinking.

According to Yeany, Yap, & Padilla (1986) there are two sets of reasoning abilities; formal operational reasoning abilities and the integrated science process skills. Each comes from a different theoretical perspective. Formal operational reasoning abilities stem from developmental psychology and include such skills as the ability to identify and control variables and the ability to use correlational, combinational, probabilistic, and proportional logic. The integrated science process skills stem from science education and include the abilities necessary to identify variables, hypothesize, operationally define, design experiments, and graph and interpret data. There have been several studies finding a high correlation between the two sets of abilities (Padilla, Okey, & Dillashaw, 1983; Tobin, & Capie, 1981; Walkosz, & Yeany, 1984) and studies which have sought to identify the specific relationship between the two sets of abilities (Yap, & Yeany, 1988; Yeany, Yap, & Padilla, 1986). Several authors have indicated that within the realm of science, the context for thinking has been defined as a set of skills commonly termed integrated science process skills (Boyer, & Linn, 1978; Linn, & Thier, 1975; Renner, & Webber, 1972; Tobin, & Capie, 1981). The integrated process skills were developed as an extension of the basic science skills discussed by Livermore (1964), and Esler (1973, 1989) and summarized as follows:

Observing - Identifying objects or events and their properties. Observing includes the identifying of changes in various physical systems, the making of controlled observations, and the ordering of a series of observations.

Classifying - Development begins with simple classifications of various chemical and biological systems, and progresses through multi-stage classifications, and then categorizing according to a predetermined set of properties.

Measuring - Development of appropriate units of measurements progressing to more accurate measurements, by averaging.

Communicating - Displaying information in appropriate graphic or pictorial designs to describe the information in detail.

Predicting - From previous events, being able to predict future events. The developmental sequence progresses from interpolation and extrapolation in graphically presented data to the formulations of methods for testing predictions.

Inferring - From observations, being able to suggest more about a set of conditions. Initially, the idea is developed that inferences differ from observation. As development proceeds, inferences are constructed for observation of physical and biological phenomena, and situations are constructed to test inferences drawn from hypotheses.

Esler (1989) indicates that these basic skills are first taught and then used together to form the integrated process skills. Tannenbaum (1972) indicates that these science processes are the means by which scientists are able to accomplish their work. Padilla, Okey, and Dillshaw (1983) classified these processes as: hypothesizing, identifying variables, operationally defining, designing investigations, and graphing and interpreting data. They also demonstrated a direct correlation between these processes and the formal operational thinking abilities of proportional logic, controlling variables, probabilistic logic, correlational logic and combinational logic. Burns, Okey, and Wise (1985) state that the integrated science process skills are vital aspects of meaningful laboratory activities and that competence in these skills enables students to act on information and produce solutions to problems. Burns et al. (1985) point out that assessing a student's abilities in using these processes can be difficult and time consuming through observation in laboratory situations. They go on to state that although an instructor can get an intuitive feel for a student's abilities through observation, quality tests should be used to accurately measure student performance in the use of the integrated process skills.

THE TESTS OF INTEGRATED PROCESS SKILLS (TIPS I AND TIPS II)

As the science process skills were defined and accepted, several specific inquiry and activity oriented curricula were introduced. Such programs as Biological Sciences Curriculum Study (BSCS), Science Curriculum Improvement Study (SCIS), and Introductory Physical Science (IPS) were intended to teach students to use the science processes. Dillshaw and Okey (1980) provide an overview of process skills test development during the 1960's and 70's as these programs were introduced. Initially the tests were program specific and aimed at specific curricular goals of the programs. Molitor and George (1976) and Tannenbaum (1968) developed non-specific curricular tests, but the tests were geared to the upper elementary and middle school students. Dillshaw and Okey (1980) developed the Test of Integrated Process Skills (referred to here as TIPS I) which was designed originally for students in the middle schools through high school but could be used for college students. Tobin and Capie (1982) developed the Test of Integrated Science Processes, which was also intended for use in middle school through college. In a response to a perceived need for additional evaluation instruments for upper level students, Burns et al. (1985) developed the Test of Integrated Process Skills II (TIPS II), which was intended to serve as either an alternate or equivalent process skill assessment instrument to provide diagnostic or summative testing in research studies.

TIPS I has a reliability (using Cronbach's alpha) of 0.89, a mean item discrimination index of 0.40, and an average item difficulty index of 53 %. The readability index is estimated to be 9.2, due to the necessity of using multiple syllable words in describing investigative procedures (Dillashaw, & Okey, 1980). TIPS II has a total test reliability (using Cronbach's alpha) of 0.86 with a mean item discrimination index of 0.35. The mean item difficulty index is 53 % with a test readability of 9.5 (Burns, Okey, & Wise, 1985).

Using a split half method, Burns et al. indicated that TIPS I and TIPS II are highly correlated tests. To avoid students having to take both tests with 72 questions, two new tests were formed. Half of the items were from TIPS I and half were from TIPS II. The second form of the test contained the other half from each TIPS test. The two forms were administered to 359 students in grades 8 through 12. Findings indicated that TIPS I and TIPS II are related to the same objectives, and they produce highly similar mean scores (25.76 and 25.94, respectively, out of 36 items). The average difficulty index of each test is the same (0.53 when used with comparable groups of students), and the scores on the tests are highly correlated. Specific test and subtest reliabilities for TIPS and TIPS II are indicated in Table I.

THE USE OF MICROSCALE LABORATORY EXPERIMENTS IN CHEMISTRY

Laboratory work is considered an essential part of the science curriculum to provide hands-on experience and to develop process skills and higher order thinking skills. All labs pose some types of hazards whether to the inexperienced students performing the lab or to the environment from the waste produced by the lab. Armour (1988) states that almost any chemistry experiment generates a diversity of wastes that must be properly disposed of. These wastes include products generated by the laboratory activity as well as any unused chemicals that need to be discarded. Although some wastes are considered nonhazardous and can be disposed of easily, many waste products require special handling because of legal and environmental consequences. According to a 1984 study by the Science Division of the North Carolina Department of Public Instruction (SDPI), over half of the approximately 500 chemicals normally associated with science instructional laboratories are considered too hazardous to be used and inadvertently disposed of. In addition, the study indicates that many other chemicals used or produced in laboratory experiments are in some way hazardous to health or the

TABLE 1

SUBTEST RELIABILITIES OF TIPS I AND TIPS II

Subtest	TIPS I	TIPS II	Total Number of Items	Projected Reliability (All Items)
Identifying Variables	.65	.57	24	.76
Designing Investigations	.22	.49	6	.52
Stating Hypotheses	.57	.65	18	.76
Operationally Defining	.42	.62	12	.68
Graphing and Interpreting Data	.45	.64	12	.71
Total Test Reliability	.82	.86	72	.91

Note. From "Development of an Integrated Process Skill Test: TIPS II" by J. C. Burns, J. R. Okey, and K. C. Wise, 1985, _Journal of Research in Science Teaching_, _22_ (2), p. 174. Copyright 1985 by the National Association for Research in Science Teaching.

environment. As would be expected, the largest use of these chemicals is in chemistry laboratory experiments (Safety First, 1988). As teachers become more aware of the importance of protecting health and the environment from chemical pollution, disposal of chemicals becomes an increasing problem. Since most wastes can no longer be disposed of easily, alternate means of reducing and handling chemical wastes must be sought. Microscale chemical experiments offer a practical and cost-effective means of minimizing the problem of waste disposal. The concept of microscaling is not new. Microscaling has been used by the pharmaceutical industry and clinical chemists for many years. The techniques have only become popular in instructional areas in the past several years (Flinn Scientific, 1989).

Macro or large scale is used to refer to classical laboratory techniques which have been used for decades in high schools (Flinn Scientific, 1989). Miniscale refers to procedures which reduce chemical quantities by 50% and traditional laboratory equipment can be used (Wahl, 1989). Microscaling involves an even greater reduction of chemicals used in the laboratory and therefore a large reduction in the waste produced. For microscaling, chemical quantities are reduced from 0.01 to 0.001 of the original quantities specified for traditional laboratory experiments (Mayo et al., 1985).

Merrimack College appears to be the first to develop microscale inorganic chemistry in 1986 and offered it to sophomore chemistry majors. The first inorganic laboratory to be totally microscaled was offered in 1987 (Szafran, Singh, & Pike, 1989). Microscaling usually requires different equipment from macroscale or miniscale laboratory experiments. For general experiments, very inexpensive equipment can be used. Drops of chemicals are used instead of milliliters. Milligrams are used instead of grams. Microscale experiments employ the same chemical reactions and use reagents of the same concentrations as macroscale experiments, but the quantities of chemicals used are substantially reduced (Mills, & Hampton, 1988).

In addition to the benefit of the reduction of chemical waste, Mayo et al. (1985) indicate that microscaling facilitates the development of laboratory skills to a greater extent than traditional experiments. Hammond and Tremelling (1987) support this contention and state that "microscale work required a higher level of concentration and attention to detail than macroscale experiments" (p. 440). In reviewing the effect of microscaling on a college level organic chemistry program, they reported that microscale experiments gave similar results to those obtained with traditional macroscale experiments and asserted that the addition of the microscale experiments increased the student's laboratory experience and performance in qualitative organic analysis.

At the high school level, the primary difference between microscale and macroscale experiments is that microscale experiments tend to be more qualitative than quantitative. This is due to the fact that balances with the degree of precision necessary to measure the reduced quantities are not available in the typical high school. Thermometers necessary to measure the small changes in temperature are extremely expensive. According to Zipp (1989) however, quantitative needs can be met. He suggests that due to the ease and speed of carrying out the microscale experiments and the reduced quantities used, students can carry out more trials under more varied conditions in the same amount of laboratory time. Students measure heights of precipitates in millimeters with a ruler instead of using a balance for grams. They count drops instead of measuring milliliters of a liquid.

Summary

The underlying premise of this study is the belief that laboratory experiments are an essential component of a high school chemistry course. Frequently, teachers are not conducting as many laboratory experiments as would be pedagogically desirable due to cost, time, and concerns about safety for students and the environment. Microscale experiments can greatly reduce these concerns and therefore increase the amount of laboratory experience for students. According to a study done by Lehman (1989), high school chemistry students as well as their teachers more frequently listed cognitive outcomes as an advantage of laboratory experiments. Lehman's study did not specify the type of laboratory experiments used by the students or teachers. This study will attempt to verify that microscale experiments achieve the same cognitive outcomes as general laboratory experiments.

No research was found which compared microscale experiments with macroscale experiments in terms of the development of the integrated science process skills by students. It is the intent of this study to make such a comparison. The statistical evidence generated can assist teachers in evaluating the use of microscale experiments in their chemistry classes.

CHAPTER THREE

METHODOLOGY

This chapter includes:

a) an overview of the study;

b) the research design;

c) the implementation of the research design;

d) a description of the instrumentation.

OVERVIEW OF THE STUDY

The benefits of using microscale experiments for safety, the environment, and other physical laboratory concerns have been well documented in the literature. No actual experimental studies have been done on the effects of microscale experiments on the outcomes of students performing these experiments. In this study, two accelerated chemistry classes were selected for statistical comparison. For the purpose of this study, reasoning ability in science was defined as the student's ability to identify variables, define operationally, state hypotheses, graph and interpret data, and to design experiments (Yeany et al., 1986). These processes are commonly referred to as integrated science process skills and have been directly correlated to the formal operational thinking abilities of proportional logic, controlling variables, probabilistic logic, correlational logic and combinational logic (Padilla, 1983). Each of these processes is measured by the Test of Integrated Process Skills (TIPS I) and the Test of Integrated Process Skills II (TIPS II).

Both classes were taught the same chemistry content as prescribed in the Standard Course of Study developed by the North Carolina State Department of Public Instruction (1985). The instruction was presented to both classes in the same manner by the same teacher. One class performed the traditional macroscale laboratory experiments and the other class performed microscale experiments. The development of the integrated science process skills was measured by TIPS I and TIPS II for both classes.

Design of the Comparison of Chemistry Students Performing Microscale Laboratory Experiments with Chemistry Students Performing Macroscale Laboratory Experiments

Design: A non-equivalent control-group design was used for this study as described by Campbell and Stanley (1963) and Borg and Gall (1989). This design effectively controls for internal sources of invalidity. Both classes received the same pretest, TIPS I, administered on the same day by the same teacher. The macroscale group performed eight traditional macroscale chemistry laboratory experiments pertaining to the chemistry topics covered in class. The microscale group performed eight microscale chemistry laboratory experiments pertaining to the same chemistry topics covered in class. Traditional laboratory experiments and microscale laboratory experiments were found which covered the same topics. (See Appendixes A & B for a list of the experiments used for both groups) After both groups completed the laboratory experiments, the two groups were given the same posttest, TIPS II, administered on the same day by the same teacher.

Subjects: Students in two tenth grade accelerated chemistry classes were assigned to their respective classes by the school guidance counselors the previous year according to their past school performance and available test scores. Due to the need to ease conflicts in scheduling, these assignments may not have been done in an entirely random manner. Therefore, initial evaluations of group similarities were conducted by comparing the total and subscores for the two classes on the pretest (TIPS I), total grade point average (GPA) upon entering the tenth grade, intelligence quotient (IQ), Preliminary Scholastic Aptitude Test (PSAT) scores in math, and grade point averages in their last math course, geometry.

The tenth grade accelerated chemistry class used as the macroscale laboratory group for this study, consisted of sixteen students. Six of the students were female, and ten were male. The class met third period from 10:30 AM to 11:25 AM every day of the week. TIPS I was administered to this class on October 22, 1990, and the class then performed eight traditional macroscale chemistry experiments over the course of five months. This class was arbitrarily selected to perform the macroscale experiments.

The microscale laboratory group was also a tenth grade accelerated chemistry class which consisted of eighteen students. Five of these students were female and thirteen were male. This class met fourth period from 11:30 AM to 12:25 PM every day of the week. This class was administered TIPS I on the same day as the macroscale group. The microscale group performed eight microscale chemistry experiments on the same topics as the macroscale experiments performed by the comparison group. These laboratory experiments were done on the same days as the macroscale experiments over the same five month period of time.

Both classes were taught by the same teacher, using the same textbook, given the same lectures covering the same topics, and all laboratory experiments were carried out under the supervision of this same teacher. TIPS II was administered to both classes on March 20, 1991 by the same teacher. (TIPS I was administered for the pretest and TIPS II was administered as the posttest to avoid the effects of familiarization with specific test items.)

Implementation of the Research Design

Data for the Comparison of Students in Two Accelerated Chemistry Classes: Information for each student in the two classes used in this study was obtained from the school's guidance department. Grade point averages cumulative through the ninth grade and the most recent IQ scores were used. PSAT scores in math and grade point averages in geometry were deemed important because of the amount of mathematics in chemistry. (Geometry was the most recent math course taken by these students.) TIPS I was administered to all subjects and used for comparison of students in the two classes.

Each group was given a pre-laboratory discussion and a post-laboratory discussion. All students were required to turn in a laboratory report on each laboratory experiment for a grade. Any student absent on the day of the laboratory experiment was required to complete the experiment upon returning to school. After grading, reports were returned to students and discussed in class. The only significant difference in the laboratory experiments for the two groups was that one group used a traditional macroscale procedure and the other group used a microscale procedure. For a list of the laboratory experiments for each group, see Appendixes A and B. At the end of the treatment period for each group, TIPS II was administered.

A DESCRIPTION OF THE INSTRUMENTATION

The Test of Integrated Process Skills (TIPS, referred to as TIPS I) was administered to both classes and used for comparison of the two classes before treatment began. TIPS I was developed by F. Gerald Dillashaw and James R. Okey (Dillashaw, 1980) to measure five integrated science process skills. The test consisted of thirty six multiple choice questions with varying numbers of questions for each of the integrated science process skills. Comparisons of each class were made on the total number of right answers on the test.

After the treatment of of the eight macroscale experiments and the eight microscale experiments performed by each group, the Test of Integrated Process Skills II (TIPS II) was administered to each group. TIPS II was developed by Joseph C. Burns, James R. Okey, and Kevin C. Wise to serve as an alternate and equivalent process skills test for TIPS I (Burns et al., 1985). TIPS II also contains thirty six multiple choice questions with varying numbers of questions for each of the integrated science process skills.

TIPS I and TIPS II were chosen as the pretest and posttest instruments, respectively, due to their high equivalency, their same index of average difficulty, and the high correlation of scores. Both tests are non-curriculum-specific and are designed for middle and high school grades (Burns et al., 1985). TIPS I was given as the pretest to prevent any familiarity with the questions due to the short period (five months) between pretest and posttest.

CHAPTER FOUR

FINDINGS

This chapter includes:

a) the initial comparison of students who performed macroscale laboratory experiments with students who performed microscale experiments (hypothesis 1);

b) the effects of the treatment on each group (hypothesis 2);

c) whether any changes were due to the treatment effect (hypothesis 3).

The Comparison of Students Who Performed Macroscale Laboratory Experiments With Students Who Performed Microscale Experiments

Hypothesis 1: There are no initial significant differences between the two groups of students who performed macroscale chemistry experiments and the students who performed microscale chemistry experiments in terms of:

1. percent scores on the mathematics section of the Preliminary Scholastic Aptitude Test (PSAT);
2. grade point average on the previous math course, geometry;
3. intelligence quotient (IQ) scores;

4. grade point average (GPA) when entering the tenth grade; and

5. the total score on the pretest, TIPS I.

To determine the statistical equality of the macroscale class and the microscale class before treatment began, a multianalysis of variance (MANOVA) was run using Statistical Analysis Software (SAS). The mean scores and sources are listed in Table 2. The summary of the MANOVA test using the four criteria listed is given in Table 3.

TABLE 2

MEANS FOR INITIAL COMPARISON

OF THE MACROSCALE GROUP AND THE MICROSCALE GROUP

Status	N	% PSAT M	Geometry	IQ	GPA	TIPS I
Macroscale	16	47.0	86.2	113	87.3	24.3
Microscale	18	59.6	89.4	117	90.7	26.7

% PSAT M is the percent score in math on the Preliminary Scholastic Aptitude Test

Geometry is the percent grade for the most recent math course

IQ is Intelligence Quotient

GPA is grade point average when entering the 10th grade

TIPS I is the total score on the pretest

TABLE 3

MULTIVARIATE ANALYSIS OF VARIANCE TEST SUMMARY

Statistic	Value	F	Num DF	Den DF	PR > F
Wilks' Criterion	0.845	1.03	5	28	0.420
Pillai's Trace	0.155	1.03	5	28	0.420
Hotelling-Lawley Trace	0.184	1.03	5	28	0.420
Roy's Maximum Root Criterion	0.184	1.03	5	28	0.420

The microscale class had slightly higher average scores for the data collected. A probability greater than 0.420 in Table 3, indicates that both groups are from the same population. Before treatment, these two groups are considered equal within the 95 % confidence interval.

Hypothesis 2: There are no significant differences in scores between TIPS I and TIPS II among the students who performed either the macroscale chemistry experiments or the microscale chemistry experiments.

This hypothesis was to determine if the two groups made a gain in the development of the integrated science process skills after performing eight laboratory experiments. The scores between TIPS I and TIPS II for both groups were compared using a multianalysis of variance with SAS. The mean scores and standard deviations are listed in Table 4 for the macroscale group and Table 5 for the microscale group. Table 6 gives the summary of the multivariate tests for the within subject effects for the pretest and the posttest tests.

TABLE 4

DESCRIPTIVE STATISTICS FOR COMPARISON

OF THE MACROSCALE LABORATORY TREATMENT

Science Process Skill Measure	TIPS I Mean	TIPS I SD	TIPS II Mean	TIPS II SD
Identifying Variables	7.13	2.19	8.13	2.63
Designing Investigations	2.00	0.89	2.56	0.73
Stating Hypotheses	6.56	1.26	6.50	1.71
Operationally Defining	4.69	1.20	5.25	1.13
Graphing and Interpreting Data	3.94	0.85	4.75	0.93
Total Score	24.31	3.61	27.19	4.51

N = 16

TABLE 5

DESCRIPTIVE STATISTICS FOR COMPARISON OF THE MICROSCALE LABORATORY TREATMENT

Science Process	TIPS I		TIPS II	
Skill Measure	Mean	SD	Mean	SD
Identifying Variables	8.22	2.86	8.83	2.64
Designing Investigations	2.39	0.70	2.83	0.51
Stating Hypotheses	7.00	1.53	7.33	1.37
Operationally Defining	5.22	0.73	5.00	1.37
Graphing and Interpreting Data	3.89	1.13	4.94	1.26
Total Score	26.72	4.93	28.94	5.36

N = 18

TABLE 6

SUMMARY OF MULTIVARIATE TESTS FOR NO GAINS BETWEEN THE PRETEST AND POSTTEST

DF	Type III SS	Mean Square	F Value	PR>F
9	27028	3003.1	611.24	0.0001

The null hypothesis was rejected. The probability of 0.0001 indicates that there was a gain in scores between the pretest and the posttest used to measure the development of the integrated science process skills for both groups.

Hypothesis 3: There are no significant differences in the development of the integrated science process skills between students who performed microscale experiments and students who performed macroscale experiments as measured by differences in scores on TIPS II.

Since both groups are shown to be from the same population, a MANOVA run on SAS was used to test hypothesis 3. The mean scores for the microscale and the macroscale groups for TIPS II including the subtests are given in Table 7. A summary of the multivariate test for the hypothesis of a treatment effect is given in Table 8.

TABLE 7

MEAN SCORES ON TIPS II

FOR THE MACROSCALE GROUP AND THE MICROSCALE GROUP

	TIPS II	
Measure	Macro	Micro
Identifying Variables	8.13	8.83
Designing Investigations	2.56	2.83
Stating Hypotheses	6.50	7.33
Operationally Defining	5.25	5.00
Graphing and Interpreting Data	4.75	4.94
Total Score	27.19	28.94

TABLE 8

SUMMARY OF THE MULTIVARIATE TESTS

FOR THE MACROSCALE AND MICROSCALE TREATMENT EFFECTS

DF	Type III SS	Mean Square	F Value	PR>F
9	52.73	5.858	1.19	0.2995

The results listed in Tables 7 and 8 indicate that there was no significant difference in the scores for the two groups due to the different treatments. The null hypothesis was accepted.

CHAPTER FIVE

SUMMARY AND DISCUSSION

This chapter includes:

a) a general summary;

b) an interpretation of the results;

c) limitations of the study;

d) implications of the findings.

General Summary

The purpose of this study was to determine the effects of microscale laboratory experiments on the development of the integrated science process skills. The benefits of microscale laboratory experiments, such as laboratory safety and less environmental wastes, have been well documented in the literature (Mayo et al., 1985; Wahl, 1989; Zipp, 1989). Several researchers have found a significant link between the development of the integrated science process skills and formal reasoning abilities (Yap, & Yeany, 1988; Yeany, Yap, & Padilla, 1986). This study compares the development of the integrated science process skills between microscale laboratory experiments and the traditional macroscale laboratory experiments. A non-equivalent control-group design was used for this quasi-experimental study. Two classes were chosen for comparison and pretested using

TIPS I. Both classes received eight laboratory treatments and were posttested using TIPS II. Statistical comparisons of two groups to test the hypotheses were done using a MANOVA analysis.

Interpretation of the Results

Hypothesis 1 sought to determine the equivalency of the microscale and macroscale group. Both groups were compared on their performance on the mathematic section of the PSAT, average grade in geometry, IQ, overall GPA and total score on TIPS I (Table 2), to determine if they were equivalent groups. The test of the hypothesis indicates they were from the same general population (Table 3).

One of the purposes for having students participate in laboratory experiments is to develop science process skills that will aid students in their future laboratory experience. Hypothesis 2 sought to determine if both groups made a gain in the development of the integrated science process skills as measured by the difference in scores between TIPS I, before treatment and TIPS II, after receiving their respective treatments. Both groups were shown to have made a statistically significant gain in test scores between the pretest and the posttest (Table 6). The study indicates that chemistry, as presented (i.e. combination of lecture and laboratory experience), aids in the development of the integrated science process skills.

Hypothesis 3 sought to determine if performing microscale chemistry experiments caused a more significant development in the integrated science process skills as measured by the difference in scores on TIPS II. There was no significant difference in performance on TIPS II between the group that received the macroscale treatment and the group that received the microscale treatment. The findings, therefore, indicate that there was no significant difference between performance of the two groups on TIPS II (Table 8).

The findings of this study indicate that both the microscale group and the macroscale group were from the same general population and made significant gains in the development of the integrated science process skills as measured by TIPS I and TIPS II. From these results, the microscale laboratory experiments cannot be shown by this study to be significantly better than the macroscale laboratory experiments.

Limitations of the Study

The sample size and time for this study were limited due to the school's environment. There were only sixteen students in one class and eighteen students in the other class. A larger population from different types of school populations might warrant further investigations between the two types of laboratory experiments. This study was limited to one teacher and the students assigned by the Guidance

Department to two classes. Five months was used for this study. A longer period of time should increase the gains in the development of the science process skills measured. With larger gains, a difference between the two treatments might be found.

This study could not separate laboratory experience from knowledge acquired through lecture. Further study on completely laboratory oriented courses might be warranted.

Implications of the Findings

This study indicates that the use of microscale laboratory experiments will not deter the development of the integrated science process skills. For a teacher, the most important consideration for using a technique is the attainment of the desired student outcomes. Teachers may use microscale experiments for safety or environmental reasons without undesirable effects on the development of science process skills. A combination of the traditional macroscale laboratory experiments with microscale experiments may further enhance student skills. This combination might overcome the quantitative limitations of some microscale laboratory experiments. This study did not investigate combining the two laboratory techniques. Since neither technique was found to be substantially better, further study of combinations might be warranted.

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Appendix A

Macroscale Laboratory Experiments

The following laboratory experiments were used with the macroscale group:

Introduction to Quantitative Measurement: Density Determination (Carmichael, Hines, & Smoot, 1983)

Melting Point - Developed from Heating and Cooling Curves (Wagner, 1983)

Boiling Point - Developed from Heating and Cooling Curves (Wagner, 1983)

Types of Chemical Reactions (Wilbraham, Staley, Simpson, & Matta, 1990)

Charles' Law: The Effect of Temperature on Volume (Carmichael, Hines, & Smoot, 1983)

Determining and Graphing the Effect of Temperature on Solubility (Carmichael, Hines, & Smoot, 1983)

Chemical Equilibrium and Le Chatelier's Principle (Wagner, 1983)

Hydronium Concentration Indicators (Carmichael, Hines, & Smoot, 1983)

Appendix B

Microscale Laboratory Experiments

The following laboratory experiments were used with the microscale group:

Density and Specific Gravity (Russo, 1986)

Micro-Melting Point (Russo, 1986)

Micro-Boiling Point (Russo, 1986)

A Study of the Types of Reactions (Russo, 1986)

Charles' Law (Miller, unpublished)

Temperature and Solubility (Emry, & Allgood, unpublished)

Equilibrium (Russo, 1986)

pH Indicators in Micro Plate (Dryfus Workshop, 1988)