Understanding of statistical data analysis among elementary education majors
by Cynthia Skillingberg Thomas

A dissertation submitted in partial fulfillment of the requirements for the degree of Doctor of Education
Montana State University

Abstract:
In the next 10 years, United States elementary, middle, and secondary schools will hire 2 million new teachers to meet rising enrollment demands and replace an aging teaching force. Half of United States teachers will retire during the same period. Given these projections and the fact that 21% of US teachers currently have less than a college minor in their principal teaching area, the education of preservice teachers must become a national priority. The purpose of this study was to determine to what degree elementary education majors acquire and retain the statistical data analysis content required for elementary and middle school as defined by the NCTM. A test instrument was developed and given to four groups of students (n=232) at Montana State University-Bozeman. Two-way ANOVAs and multiple regressions were done to determine if independent variables (age, gender, level of high school preparation, number of college math/stat classes taken and enrollment in the Math Option) influenced achievement in statistical data analysis. The overall conclusion was clear: Whatever gains are achieved in the content mathematics classes are lost by the end of student teaching. Consequently, students graduating from the elementary education program do not possess the content knowledge required to meet current professional standards. Neither age nor gender was determined to be statistically significant when trying to explain variability in total achievement or achievement in any of the five subtests. No significant difference in achievement between the students who were enrolled in the math option and those who were not was found, however discrepancies in the data presented by students led the researcher to doubt these results. Multiple regression analysis revealed that the set of independent variables did explain a significant proportion of the variability in achievement. However, even though the findings are statistically significant (R2=.123) they are of little practical significance. Recommendations are given for changes in math content and methods courses for elementary education majors. Test instrument is included.

UNDERSTANDING OF STATISTICAL DATA ANALYSIS

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of the requirements for the degree

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APPROVAL

Of a thesis submitted by

Cynthia Skillingberg Thomas

This dissertation has been read by each member of the dissertation 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 3 April 00

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CHAPTER 1

DEVELOPMENT OF THE PROBLEM

"School mathematics education bears increasing responsibilities in a data-rich era. Mathematics instructional programs should provide individuals access to mathematical ideas and should promote students' abilities to reason analytically. In a society saturated with quantitative information ranging from global climate change data to political polls and consumer reports, such skills will help students to understand, make informed decisions about, and affect their world." (National Council of Teachers of Mathematics, 1998 p.15)

Introduction

In the next 10 years, United States elementary, middle, and secondary schools will hire 2 million new teachers to meet rising enrollment demands and replace an aging teaching force. Half of United States teachers will retire during the same period (National Center for Educational Statistics, 1998). Given these projections and the fact that 21% of US teachers currently have less than a college minor in their principal teaching area (the National Commission on Teaching and America's Future (NCTAF), 1998), the education of preservice teachers must become a national priority. A number of professional associations concerned with teacher education are coordinating their efforts to define the qualities and qualifications essential for the next generation of teachers. These organizations include The National Council for Accreditation of Teacher Education (NCATE), National Council of Teachers of Mathematics (NCTM), American Mathematical Society (AMS), American Statistical Association (ASA), Mathematical

Association of America (MAA), and The International Society for Technology in Education (ISTE). For the first time, these and other stakeholders in teacher education are united in their efforts to raise the standards and expectations of teacher education programs. This research concentrated on an effort currently underway to improve the quality of teaching and learning in one aspect of K-8 mathematics education, statistical data analysis.

Problem

To what degree do students enrolled in the Elementary Education Program at Montana State University – Bozeman acquire and retain the statistical data analysis content required for elementary and middle school as defined by the National Council of Teachers of Mathematics?

Purpose

The purpose of this research was to compare and contrast student statistical data analysis knowledge at different stages of the Montana State University Teacher Education Program. In the mathematics content areas of the Third International Mathematics and Science Study (TIMSS), United States fourth graders slightly exceeded the international average in five of the six areas assessed, including sets of items designed to sample students' ability to do work in data representation, analysis, and probability (NCES, 1997). United States eighth-grade students scored just below the international average in the same areas (NCES, 1996). In a country with a national goal of having the best-educated children in the world, these results have prompted questions concerning the mathematical competence of United States teachers and the quality of the mathematics curricula in grades K-8. President Clinton's *Call to Action for American Education in the 21st Century* (1997) states that, as a nation, "Strong schools with clear and high standards of achievement and discipline are essential to our children and our society. The United States ranks below average internationally in 8th grade math. We must do better."

"A knowledge of statistics is clearly necessary for students to become informed citizens and intelligent consumers, and statistical reasoning needs to be learned" (NCTM, 1998 p. 70). The National Research Council recommends "Those who would teach mathematics need to learn contemporary mathematics appropriate to the grades they will teach, in a style consistent with the ways in which they will be expected to teach" (1989, p. 64). To be effective, teachers must know their subject matter so thoroughly that they can present it in a challenging, clear, and compelling way (NCATE, 1998).

Graduates of Montana State University's Elementary Education program are eligible to be certified to teach grades K-8. Therefore, it is imperative that as teachers they possess, as a minimum, the knowledge required of eighth grade elementary students. Today's candidate teachers who will become instructors in grades 5-8 often have the same mathematics background as those who will become teachers in grade K-4, yet they are expected to teach more complex content. The additional challenges inherent in the more ambitious curricular material often require them to be more like mathematics specialists than their original training may have prepared them to be. These teachers often have had little exposure to some of the mathematical ideas that ambitious curricula will require them to teach. Teaching mathematics and statistics in ways that make it understandable by students requires deep, flexible knowledge on the part of the teacher (Silver, 1998).

The National Council of Teachers of Mathematics (NCTM) offers detailed recommendations for teaching statistics in grades K-12 in both *Curriculum and Evaluation Standards for School Mathematics* (1989) and *Principles and Standards for School Mathematics: Discussion Draft* (1998). Mathematical science organizations such as the American Mathematical Association of Two-Year Colleges (AMATYC), the American Mathematical Society (AMS), the American Statistical Association (ASA), the Association for Women in Mathematics (AWM), the Association of State Supervisors of Mathematics (ASSM), the Council of Presidential Awardees in Mathematics (CPAM), the Mathematical Association of America (MAA), and the Society for Industrial and Applied Mathematics (SIAM) promote the vision of school mathematics curriculum as described by NCTM (NCTM, 1989)

The content must be consistent with national mathematics and science standards and convey disciplinary knowledge that relates to student environment and experiences (Friel & Bright, 1997). A growing number of reports and policy statements involving agencies of the federal (NCES, 1998) and state governments (Office of Public Instruction, State of Montana, 1998), professional organizations (NCTM, 1998), and other interested groups (ASA, 1998) call for specific reforms in the content and pedagogy of mathematics education. A National Science Report to the United States Senate (Teacher Retraining, 1997) stated that content must be consistent with national mathematics and science standards and convey disciplinary knowledge that relates to student environment and experiences. One of the content areas addressed in these reports is data representation, statistical analysis, and statistical graphs. The National Council of Teachers of Mathematics' *Principles and Standards of School Mathematics* (1998) is the most complete and influential presentation on the proposed reforms. With regard to the content focus of this research, the NCTM Standards for Statistics for PreK-8 were treated as the standard by which the statistical data analysis knowledge of elementary education majors at Montana State University was measured.

NCTM Standards for Data Analysis, Statistics and Probability

NCTM's *Principles and Standards for School Mathematics: Discussion Draft* includes 10 Standards. Five of those standards focus on content which address the mathematics that students should know and five standards focus on processes that address ways of acquiring and using that knowledge (See Figure 1).

Figure 1. NCTM Standards for School Mathematics

NCTM Standards for Grades Pre-K-12 (NCTM, 1998)

- Content Standards
  - Standard 1: Number and Operation
  - Standard 2: Patterns, Functions, and Algebra
  - Standard 3: Geometry and Spatial Sense
  - Standard 4: Measurement
  - Standard 5: Data Analysis, Statistics, and Probability
- Process Standards
  - Standard 6: Problem Solving
  - Standard 7: Reasoning and Proof
  - Standard 8: Communication
  - Standard 9: Connections
  - Standard 10: Representation

Standard Five, Data Analysis, Statistics, and Probability, for grades Pre-K-8, states that Mathematics instructional programs should include attention to data analysis, statistics, and probability so that all students –

- Pose questions and collect, organize, and represent data to answer those questions;
- Interpret data using methods of exploratory data analysis;
- Develop and evaluate inferences, predictions, and arguments that are based on data;
- Understand and apply basic notions of chance and probability (NCTM, 1998)

Specifically, this study dealt only with the following aspect of statistical data analysis knowledge within Standard 5.

- Interpret data using methods of exploratory data analysis;
    - Find, describe, and interpret mean, median, and mode as measures of the center of a data set; know which measure is best to use in particular situations; and understand how each does and does not represent the data;
    - Describe and interpret the spread of a set of data using tools such as range, interquartile range, and box-and-whisker graphs;
    - Interpret graphical representations of data, including descriptions and discussion of the meaning of the shape and features of the graph, such as symmetry, skewness, and outliers;
    - Analyze associations between variables by comparing the centers, spreads, and graphical representations of related data sets;
    - Examine and interpret relationships between two variables using tools such as scatter plots and approximate lines of best fit. (NCTM, 1998 p.238)

Research Questions

The data obtained in this study were used to characterize the statistical data analysis knowledge of pre-service elementary education majors and to answer the following questions:

1. Was there a difference in the statistical data analysis knowledge among elementary education majors in MATH 130 - Mathematics for Elementary Teachers I, MATH 131 - Mathematics for Elementary Teachers II, EDEL 333 - Teaching Mathematics, and EDEL 410 - Student Teaching?
2. Were demographic factors of gender, age when enrolled in MATH 130, high school mathematics preparation, number of college math and/or statistics classes taken, and/or enrollment in the Elementary Education Math Option related to statistical data analysis knowledge in MATH 130, MATH 131, EDEL 333, and EDEL 410?

Definition of General and Educational Terms

For the purpose of this research, the following definitions were used.

K-8 Certified	Persons with a Bachelor of Science degree in Elementary Education certified by the State of Montana to teach kindergarten through eighth grade in all content areas.
Age Range Sets	1) 25 and younger 2) 26 and older
Non-traditional age	Defined by Montana State University as those students who are older than 25 years old

Four groups to be researched	1) Students enrolled in MATH 130 fall semester 1999 2) Students enrolled in MATH 131 fall semester 1999 3) Students enrolled in EDEL 333 fall semester 1999 4) Students enrolled in EDEL 410 fall semester 1999
Math Option	Elementary Education students take 18 additional credits in Mathematics and/or Statistics in place of free electives to enhance their mathematics qualifications. (See Appendix E for specific details.)
Basic High School Mathematics Preparation	Classes up to and including Algebra One. This would include but not be limited to such classes as: Basic Math, General Math, Business Math, Pre-Algebra, Integrated Math I (SIMMS-IM), and Algebra One.
Average High School Mathematics Preparation	Classes including but not limited to Algebra II, Trigonometry, Integrated Math II (SIMMS-IM), Integrated Math III (SIMMS-IM), and Geometry.
Advanced High School Mathematics Preparation	Classes including but not be limited to Pre-Calculus, Calculus, Statistics, Integrated Math IV (SIMMS-IM), Integrated Math V (SIMMS-IM), and Discrete Math.

Definition of Statistical Terms

(Lappan, Fey, Fitzgerald, Friel, & Phillips 1998a, 1998b, 1998c, 1998d; Upshall, 1997; Nichols & Schwartz, 1998; Abelnoor, 1979).

Bar graph	A representation of discrete data in which the height of each rectangular bar indicates its value or frequency. Bars are separated from each other to highlight that the data are discrete or 'counted' data.
Box and whisker plot	A graph that shows the distribution of values in a data set. It is constructed from the five-number summary of the data that are minimum value, first quartile, median (second quartile), third quartile, and maximum.

Data analysis	Carefully examining collected data. Thinking about the reliability and validity of the data, conclusions that can be drawn, fairness and appropriateness of the data, and predictions that can be made using the data.
Interquartile range (IQR)	The numerical difference between the first and third quartiles of a distribution. This covers the middle half of the values in the frequency distribution.
Mean	The arithmetic average of the data. It is the center of gravity of the data. It is the value that a set of data would have if all the data were the same value.
Median	The middle of an ordered set of data.
Mode	The most frequently occurring datum.
Normal distribution	A theoretical graph that is continuous and perfectly symmetric on each side of the mean. Frequency values are highest in the middle. The mean, median, and mode represent the same value. Commonly referred to as a bell curve.
Outlier	A value in a data set that is 1.5 IQR less than the Q_1 or 1.5 IQR greater than Q_3.
Population	The entire collection of people or objects under study.
Probability	The branch of mathematics that focuses on determining the chance of something happening.
Quartile	A partition of an ordered array of data that is equal to one quarter of the data. Each partition is roughly equal in size.
Range	The range is computed by stating the lowest and highest values of the data set.
Sample	A subset of the population, chosen to represent it.
Scatter plot	A graph used to explore the relationship between two variables.

Skewed distribution	A distribution that does not model the normal curve but rather has the greatest frequency of occurrence on either the left or right side of the distribution.
Standard deviation	A measure of the distribution of the data. It measures how far data tend to be from the mean.
Statistics	The branch of mathematics that focuses on collecting and interpreting data.
Stem and leaf plot	A quick way to picture the distribution of values in a data set. The *stem* of the plot is a vertical number line that represents a range of data values in a specified interval. The *leaves* are the numbers attached to the particular stem values.
Symmetry	A description of the 'sameness' of portions of a figure.

Summary

This study focused on elementary education majors at Montana State University who were at various stages in their program, specifically students who were enrolled in MATH 130 - Math for Elementary Teachers I, MATH 131 - Math for Elementary Teachers II, EDEL 333 - Teaching Mathematics, or EDEL 410 - Student Teaching. It addressed the need for assessing the Standards-based statistical data analysis knowledge of these prospective elementary teachers. The researcher developed an instrument for assessing what pre-service elementary teachers know, master and retain at various levels of their university studies concerning aspects of the NCTM's statistical data analysis knowledge elementary and middle school children are expected to master.

CHAPTER 2

REVIEW OF THE LITERATURE

Introduction

The focus of this study was to determine if there was a difference in statistical data analysis knowledge among elementary education majors at Montana State University who are enrolled in MATH 130 - Math for Elementary Teachers I, MATH 131 - Math for Elementary Teachers II, EDEL 333 - Teaching Mathematics, or EDEL 410 - Student Teaching. The study assessed the NCTM Standards-based statistical data analysis knowledge of these prospective elementary teachers.

The data obtained in this study were used to answer questions about historical and demographic factors associated with statistical data analysis knowledge in MATH 130 - Mathematics for Elementary Teachers I, MATH 131 - Mathematics for Elementary Teachers II, EDEL 333 - Teaching Mathematics, and EDEL 410 - Student Teaching. It also determined to what extent interactions between age at the beginning of MATH 130, gender, level of high school math preparedness, and number of college math and/or statistics class taken were related to statistical data analysis knowledge of pre-service elementary education majors.

Content Knowledge for Teachers

Researchers recognize that teacher behaviors may not be the only factors influencing student achievement. The key questions of research are, "How much knowledge is required for teaching?" and "What kind of knowledge is required for teaching?" Shulman (1987) suggests several "categories of knowledge that underlie the teacher understanding needed to promote comprehension among students." (p. 8).

Shulman states that at a minimum, the categories should include:

- content knowledge;
- general pedagogical knowledge;
- curriculum knowledge;
- pedagogical content knowledge, that special amalgam of content and pedagogy that is uniquely the province of teachers, their own special form of professional understand;
- knowledge of learners and their characteristics;
- knowledge of educational contests;
- knowledge of educational ends, purposes, and values, and their philosophical and historical grounds (1987 p. 8)

This study investigated only content knowledge while it is understood that content knowledge alone does not insure good teaching. Leinhardt (1986) found that content knowledge was critical to good teaching. Parsons (1993) supports the theory that a deep subject matter knowledge aids in asking appropriate questions, responding to students, crafting lessons, and providing examples, explanations and demonstrations. While it is recognized that content knowledge is not the only indicator of good teaching, NCTM made a strong statement about the importance of content knowledge - "first and foremost, teaching candidates must have the mathematics content needed for their respective teaching grade levels." ("Start with math," 1999)

"A major goal of teacher education programs is to provide opportunities for prospective teacher to acquire subject matter knowledge" (Adams, 1998 p. 35). Several researchers (Ball, 1990; Even, 1990; Shulman, 1986, 1987; Simon, 1993; Loucks-Horsley, 1999; Steen, 1999a) agree that an individual who plans to teach subject matter to children should have content knowledge and understanding of the content in order to teach that content to school children. Prospective teachers are expected to meet the mathematical needs of children; teachers who have faulty knowledge or misunderstandings are likely to pass that false knowledge or misunderstanding on to the children that they teach (Babbitt & Van Vactor, 1993).

Today's candidate teachers who will become instructors in grades 5-8 often have the same mathematics background as those who will become teachers in grade K-4, yet they are expected to teach more complex content. The additional challenges inherent in the more ambitious curriculum material often require them to be more like mathematics specialists than their original training may have prepared them to be. These teachers often have had little exposure to some of the mathematical ideas that ambitious curricula will require them to teach their students. Teaching mathematics and statistics in ways that make it understandable by students requires deep, flexible knowledge on the part of the teacher (Silver, 1998).

A recent (1998) report published by the National Commission on Teaching and America's Future (NCTAF) reported that what teachers know and can do is the most important influence on what students learn. In this same report, NCTAF assembled research that clearly demonstrated what American parents already believe: Teacher quality is the factor that matters the most for student learning. The report further reported that the importance of teacher expertise is far outweighs the more modest but generally positive influences of small schools and classes. As a result, the commission recommended more rigorous preparation of teachers still in college. Smith, Peire, Alsalam, Mahoney, Bae and Young (1995) found that

> Proficiency in mathematics is an important outcome of education. In an increasingly technological world, the mathematical skills of the nation's workers may be crucial components of economic competitiveness. In addition, knowledge of mathematics is critical for success in science, computing and a number of other related fields of study" (p. 58).

This is supported by the National Council of Teachers of Mathematics in *Principles and Standards for School Mathematics: Discussion Draft* (1998) when they say that to make judgments about tasks, teachers need to know mathematics well beyond the mathematics they teach.

Importance of Statistical Data Analysis Knowledge

Consumers must know how to make critical and informed decisions. Knowledge of statistics will enhance those skills (NCTM, 1989 1998). Students must be able to interpret statistical predictions, (Drier, Dawson, & Garofalo, 1999). Our students will enter a global marketplace that uses quantitative data and graphs to communicate information and to influence decisions at an ever-increasing pace (Shaughnessy, 1992; Smith, Perie, Alsalam, Mahoney, Bae, & Young, 1995). The National Research Council recommends "Those who would teach mathematics need to learn contemporary mathematics appropriate to the grades they will teach, in a style consistent with the ways in which they will be expected to teach" (1989, p. 64). To be effective, teachers must know their subject matter so thoroughly that they can present it in a challenging, clear, and compelling way (NCATE, 1998). Steen (1999b) concurs when he said, "Nonmathematicians, especially students, harbor nonstandard ideas ("misconceptions") that, "like road accidents," could be avoided through better teaching." (p. 237). Certainly, it follows that student misconceptions could be alleviated or at least minimized if teachers were knowledgeable to begin with.

"A knowledge of statistics is clearly necessary for students to become informed citizens and intelligent consumers, and statistical reasoning needs to be learned" (NCTM, 1998 p. 70). Students must be taught to critically appraise statistics and to be familiar with statistical reasoning including collection, summarization, display and interpretation of data (Scheaffer, 1986). Scheaffer states, "They (students) should learn to become "professional noticers" of the many ways data is used and misused in their world. Students should begin to see statistical reasoning as a process for solving problems through data and quantitative reasoning, and should understand the basic principles involved in the design of a good survey or experiment." "It is important that we actually include probability and statistics in our schools, because people are going to use it and abuse it - perhaps more than any other branch of mathematics - whether or not we teach it." (Shaughnessy, 1992, p. 467).

The goal of statistics education in the elementary school is not that students become statisticians, but that they will be intelligent consumers of statistics as private citizens (Drier, Dawson, & Garofalo, 1999). "Teachers cannot expect children to pick up en passant the essential features of distributions or the effect of the 'role of large numbers'; these issues need to be discussed fully with the pupils." (Goodchild, 1984 p. 81). Real problems rarely work out as neatly as math problems from texts so students must be taught to interpret data from real world events (Kalman, 1997; Scheaffer, 1986). Students must have opportunities to speculate about when and why people choose to use certain graphs in publications and how pictorial and spatial representations help to communicate relationships (Drier, Dawson, & Garofalo, 1999; Kalman. 1997). Above all we must not assume that because statistical words such as average are in common usage it is properly understood (Goodchild, 1984).

In 1968 a joint commission of the American Statistical Association and the National Council of Teachers of Mathematics developed curricular materials and methods to promote teaching of statistics (Pereira-Mendoza & Dunkels, 1989). But it wasn't until the past ten years that statistics has increased in significance in K-12 education (Scheaffer, 1986). In 1989, the National Council of Teachers of Mathematics published *Curriculum and Evaluation Standards for School Mathematics*. The 'Standards' responded to the call for reform in teaching and learning mathematics. They represented an effort to ensure quality, indicate goals, and promote positive change in mathematics education in grades PreK-12 (NCTM, 1989). NCTM offers detailed recommendations for teaching statistics in grades K-12 in both *Curriculum and Evaluation Standards for School Mathematics* (1989) and *Principles and Standards for School Mathematics: Discussion Draft* (1998). Mathematical science organizations such as American Mathematical Association of Two-Year Colleges (AMATYC), American Mathematical Society (AMS), American Statistical Association (ASA), Association for Women in Mathematics (AWM), Association of State Supervisors of Mathematics (ASSM), Council of Presidential Awardees in Mathematics (CPAM), Mathematical Association of America (MAA), and Society for Industrial and Applied Mathematics (SIAM) promote the vision of school mathematics as described by NCTM (NCTM, 1989). While the NCTM is recognized as the definitive source for elementary mathematical standards, the National Council for Social Studies (1994), the Geography Education Standards Project (1994), the National Research Council (1996) and The National Council of Teachers of English, together with the International Reading Association (1996) have documented the need for statistical skills within their respective disciplines. The Secretary's Commission on Achieving Necessary Skills (1991) recommends that assessment of statistical skills that are needed for the workplace should take place at the 8th grade level.

NCTM Standards for Data Analysis, Statistics and Probability

NCTM's *Principles and Standards for School Mathematics: Discussion Draft* includes 10 Standards. Five of those standards focus on content which address the mathematics that students should know and five standards focus on process which address ways of acquiring and using that knowledge (See Figure 2).

Standard Five, Data Analysis, Statistics, and Probability, for grades Pre-K-8, states that Mathematics instructional programs should include attention to data analysis, statistics, and probability so that all students –

- Pose questions and collect, organize, and represent data to answer those questions;
- Interpret data using methods of exploratory data analysis;
- Develop and evaluate inferences, predictions, and arguments that are based on data;
- Understand and apply basic notions of chance and probability (NCTM, 1998)

Figure 2. NCTM Standards for School Mathematics

NCTM Standards for Grades Pre-K-12 (NCTM, 1998)
- Content Standards
  - Standard 1: Number and Operation
  - Standard 2: Patterns, Functions, and Algebra
  - Standard 3: Geometry and Spatial Sense
  - Standard 4: Measurement
  - Standard 5: Data Analysis, Statistics, and Probability
- Process Standards
  - Standard 6: Problem Solving
  - Standard 7: Reasoning and Proof
  - Standard 8: Communication
  - Standard 9: Connections
  - Standard 10: Representation

Grades Pre-K-12 are divided into four grade bands. These grade bands are Pre-K-2, 3-5, 6-8, and 9-12. Elaboration of the Data Analysis, Statistics, and Probability Standard for grade bands PreK-2, 3-5, and 6-8 are shown in Figure 3. Since the focus of this study was statistical data analysis knowledge, the notation and elaboration for the fourth component, which deals exclusively with probability, was not be included.

Figure 3. Standard 5: Data Analysis, Statistics and Probability

Standard 5: Data Analysis, Statistics, and Probability

Mathematics instructional programs should include attention to data analysis, statistics, and probability so that all students -

- **pose questions and collect, organize, and represent data to answer those questions;**

  In grades pre-K-2, all students should -
  - gather data about themselves and their surroundings to answer questions that involve multiple responses
  - sort and classify objects and organize data according to attributes of the objects;
  - represent data to convey results at a glance using concrete objects, pictures, and numbers. (NCTM, 1998 p 130-131)

  In grades 3-5, all students should -
  - formulate questions they want to investigate;
  - design data investigations to address a question;
  - collect data using observations, measurement, surveys, or experiments;
  - organize data using tables and graphs (e.g. bar graph, line plot, stem-and-leaf plot, circle graph, and line graph);
  - use graphs to analyze data and to present information to an audience;
  - compare data representations to determine which aspects of the data they highlight or obscure. (NCTM, 1998 p 181)

  In grades 6-8, all students should -
  - design experiments and surveys, and consider potential sources of bias in design and data collection;
  - recognize types of data (e.g., categorical, count, continuous or measurement) and organize collections of data;
  - choose, create and utilize various graphical representations of data (line plots, bar graphs, stem-and-leaf plots, histograms, scatter plots, circle graphs, and box-and-whisker plots) appropriately and effectively (NCTM, 1998 p 238).
- **interpret data using methods of exploratory data analysis;**

  In grades pre-K-2, all students should -
  - describe parts of the data and the data as a whole;
  - identify parts of the data with special characteristics, for example the category with the most frequent response. (NCTM, 1998 p 130-131)

In grades 3-5, all students should -

- describe the shape and important features of a set of numerical data, including its range, where the data are concentrated or sparse, and whether there are outliers;
- describe the center of sets of numerical data, first informally, then using the median;
- classify and describe categorical data (e.g., ways we travel to school) in different ways; analyze and compare the information highlighted by different classifications;
- compare related data sets, with emphasis on the range, center, and how the data are distributed;
- propose and justify conclusions based on data;
- formulate questions or hypothesis based on initial data collections, and design further studies to explore them. (NCTM, 1998 p 181)

In grades 6-8, all students should -

- find, describe, and interpret mean, median and mode as measures of the center of a data set; know which measure is best to use in particular situations; and understand how each does and does not represent the data;
- describe and interpret the spread of a set of data using tools such as range, interquartile range, and box-and-whisker graphs;
- interpret graphical representations of data, including descriptions and discussion of the meaning of the shape and features of the graph, such as symmetry, skewness, and outliers;
- analyze associations between variables by comparing the centers, spreads, and graphical representations of related data sets;
- examine and interpret relationships between two variables using tools such as scatter plots and approximate lines of best fit (NCTM, 1998 p 238).

❖ **develop and evaluate inferences, predictions, and arguments that are based on data;**

In grades 3-5, all students should -

- describe how data collection methods can impact the nature of the data set;
- discuss the concept of representativeness of a sample within the contest of a particular example (e.g., is the class representative of other fifth-grade classes in our town? In the U.S.? In Canada? Why or why not?);
- compare the data from one sample to other samples and consider why there is variability;
- in simple experiments, infer the structure of the population through drawing repeated samples (with replacement) (NCTM, 1998 p 182)

In grades 6-8, all students should -

- develop conclusions about a characteristic in a population from a well-constructed sample;
- through simulations, develop an understanding about when differences in data may indicate an actual difference in the populations from which the data were

collected and when the differences may result from natural variation in samples;

- use data to answer the questions that were posed, understand the limitations of these answers, and pose new questions that arise from the data (NCTM, 1998 p 238).

Methods Used in Other Studies

Friel and Bright (1996) developed a written test related to the use and interpretation of graphs. The written instrument was administered as a pre and posttest for seventy-six middle school students. The instrument was developed and scored based on levels of questions (Curcio, 1987) and ability to read graphs (Wainer, 1992). They found that students confuse axes of graphs, have problems with intervals of graphs, and seem to find the measures of center, mean, and median not readily identifiable from the graph. They concluded, "Fundamental to graphicacy are the broader issues of what kinds of questions graphs may be used to answer. By exploring learner's responses to different kinds of questions we gain some knowledge about learners' thinking." (Friel & Bright, 1996. p. 13).

Desmond (1997) developed a written instrument keyed to the NCTM Standards to test geometric content knowledge of eighty-three pre-service teachers during their last semester. She followed up with interviews of seventeen of the students. She found weak abilities on the part of the participants in Standards-based knowledge. There was a weak positive relationship between content and reasoning. In addition, communication skills as outlined by the National Council of Teachers of Mathematics seemed to be related to the geometric content being studied.

Ball (1990) reported on a study of 252 preservice elementary and secondary teachers in five different teacher education programs. This research explored participants' ideas, feelings and understanding about mathematics and about teaching and learning mathematics through the use of scenarios. Content knowledge of the scenarios was developed around different mathematical topics. Questionnaire responses were then followed by interviews. The mathematical understanding these students brought from their high school and college mathematics classes tended to be, "rule bound and thin" (Ball, 1990 p. 124).

Rusch (1997) studied 206 elementary education majors enrolled in a required mathematics education content course at five different post-secondary institutions. The focus of the research was to assess prospective teachers' understanding of place value concepts within a mathematics content course taught by either a constructivist method or a traditional, direct instruction method. A pretest/posttest strategy was used for the assessment instrument that was written specifically for the study. Results suggest that preservice teachers began the course with weak understanding of place value and improved only marginally. There was only a slight difference between the gains made by those students in the constructivist class and those in the traditional direct instruction class.

Professional Standards for Teaching Mathematics (NCTM, 1991) identified specific mathematics content and minimum high school and college mathematics course work requirements for elementary teachers. For teachers of grades K-4, nine semester hours of college coursework in content mathematics is required which would have as a prerequisite three years of mathematics for college-intending students or an equivalent preparation. For teachers of grades 5-8, NCTM recommends four years of mathematics for college-intending students followed by fifteen hours of college coursework in content mathematics. Dyas (1993) based her research on NCTM's recommendations to study the differences in groups that 1) met both the high school and college requirements, 2) met only the high school requirement, 3) met only the college requirement, or 4) met neither the high school or college requirements. She found that the groups that met high school and college requirements and those that met just high school requirement scored significantly higher than those who did not meet either requirement. This was supported in 1995 by Roberts who tested preservice teachers (n=103) on the van Hiele model and explored factors that may be related to their levels of geometric thinking. She found that the mathematics backgrounds of the preservice teachers showed a positive correlation between the number of high school mathematics courses completed by the preservice teachers and their total score on the Van Hiele Geometry Test. Roberts found no significant differences related to gender.

Hutchison (1992) studied the affect of prior subject matter knowledge on learning pedagogical content knowledge in a mathematic methods course. Participants understanding of fractions and pedagogical content knowledge were sampled using two task interviews, a mathematics education biography, three student teaching classroom observations in mathematics, and the classroom observations of the mathematics methods course. The findings suggest that mathematics teacher education programs should reconsider the type of subject matter knowledge required by preservice teachers, since those with weak prior mathematical content knowledge made few if any gains in pedagogical knowledge because of the need to simultaneously learn both subject matter and pedagogical knowledge.

Smith (1993) compared the conceptual understanding of computational estimation strategies of incoming preservice elementary teachers and those preservice elementary teachers near the completion of the teacher education program. The researcher developed a testing instrument to explore the quantitative mathematics ability as related to computational estimation strategies. The results indicated that for both operations, senior preservice elementary teachers had not acquired more conceptual understanding than those of freshmen. Computation estimation strategies tested were understood approximately the same.

Jones (1995) evaluated preservice middle grades teachers' subject matter knowledge (including beliefs) and pedagogical content knowledge of fractions, decimals, and percents as they progressed through the undergraduate middle grades teacher education program. Participants completed three interviews, two mathematics tests and a questionnaire. Analysis of results indicated that only a small number of participants, both mathematic concentration and non-mathematics concentration, learned contend knowledge of fractions, decimals and percents. The study recommended several changes in the teacher education program to include concepts courses for all students throughout their program.

Lott, (1998) conducted a study to examine prospective elementary teachers' knowledge of real numbers, the set of numbers that can be written as a decimal. Lott administered an open-ended assessment to ninety-three third-year preservice elementary teachers enrolled in three sections of an elementary mathematics methods course. They were asked to provide a drawing model to describe the relationship between given sets of numbers and to write a description of each set. Findings indicated that prospective elementary teachers demonstrated limited subject matter knowledge related to knowledge of real numbers.

Summary

A number of studies (Desmond, Ball, Rusch, Dyas, Roberts, Hutchison, Smith, Jones, and Lott) have found that undergraduates in mathematics related curricula fail to acquire and retain knowledge and skills essential to their disciplines and careers. These studies were conducted in content and methods courses addressing topics that include, geometry, fractions/decimals/percents, place value, estimation, and real numbers. In all cases the students were found to be characteristically below what was expected.

The National Council of Teachers of Mathematics standards are accepted as the basis for PreK-12 education. It is evident that statistical data analysis knowledge is an extremely important skill to function as an informed consumer in our society. Evidence has been presented that these skills are not innate and must be taught. Since we are preparing teachers, it is imperative that we educate them statistically and assess their achievement relative to national goals and standards.

CHAPTER 3

PROCEDURES AND METHODOLOGY

Introduction

This chapter discusses the population and sample, instrumentation, research design, data acquisition, data analysis, and procedures that were used in this study.

Elementary Education Program

The Teacher Education Program at Montana State University offers NCATE accredited Bachelor of Science degrees leading to Montana Teacher Certification for both elementary and secondary education majors. The elementary education component of this program enrolls over 500 students at any given time and graduates approximately 100 students per year. Formal admission to the Teacher Education Program occurs following completion of specified university core classes and other requirements specifically related to the teacher certification process. For most candidates, official admission occurs in their fifth or sixth semester at Montana State University.

The majority of elementary education majors are Montana residents (82%), having entered Montana State University in the fall semester immediately following their graduation from a Montana high school. A meaningful minority (18%), however, are over the traditional age of 25, often with children of their own. A small minority (2%) are Native American (Johnson, 1999).

During spring term of 1999, the Mathematics Education professors of the Montana State University Department of Mathematical Sciences sought to determine whether student achievement in MATH 130 - Mathematics for Elementary Teachers I was related to one or more demographic factors routinely collected by Montana State University Admissions: ACT composite score; SAT composite score; high school GPA; and/or high school percentile rank. Montana State University institutional researcher Dr. Cel Johnson provided demographic data sets for students enrolled in MATH 130 autumn terms of 1996 and 1997 as part of the database for institutional study. These data were merged with student achievement data from the same courses and delivered to the Montana State University Statistical Consulting Seminar instructor Dr. Jim Robison-Cox for analysis. Under Dr. Robison-Cox's supervision, two master's degree students in the Statistical Consulting Seminar used analysis of variance and logistic regression techniques to analyze the data. The principal finding of this analysis was that there was no useful relationship between the demographic factors and student achievement. As a result, none of the demographic factors had any predictive value relative to student achievement in MATH 130.

Students enrolled in MATH 130 and MATH 131 were typically freshmen or sophomores principally engaged in satisfying university core requirements. These students had declared an elementary education major but had not been formally admitted to the Teacher Education Program.

Students enrolled in EDEL 333 were typically juniors or seniors. They had been formally admitted to the Teacher Education Program with a 2.5 overall GPA, a Basic Skills Core GPA of at least 2.5 and no class in the Basic Skills core with a C- or lower (Montana State University Bulletin, 1998). They also had to present both spontaneous and prepared writing samples as well as demonstrate involvement with children through community services activities. These students were fully engaged in professional development courses at the junior and senior levels and planned to student teach within the next two semesters.

Students enrolled in EDEL 410 had just completed their student teaching, which is part of the capstone course series for their program. Typically, by this time many of them had begun seeking teaching positions. Two of them had already signed teaching contracts for the second semester of the current school year.

Population

The population for this study was all elementary education majors currently enrolled at Montana State University.

Sample

The sample for this study was all Montana State University elementary education majors enrolled in MATH 130 - Mathematics for Elementary Teachers I, MATH 131 -

Mathematics for Elementary Teachers II, EDEL 333 - Teaching Mathematics, or EDEL 410 - Student Teaching during fall semester 1999. Numbers in these groups were:

Figure 4. Student Groups in Study

Group	Number
MATH 130	81
MATH 131	41
EDEL 333	59
EDEL 410	51

Content Focus

For the purpose of this study, research questions were limited to the curriculum standard specifically dealing with statistical data analysis knowledge taken from Standard 5: Data Analysis, Statistics, and Probability of Principles and Standards for School Mathematics: Discussion Draft (NCTM, 1998).

- Interpret data using methods of exploratory data analysis;
  - Find, describe, and interpret mean, median, and mode as measures of the center of a data set; know which measure is best to use in particular situations; and understand how each does and does not represent the data;
  - Describe and interpret the spread of a set of data using tools such as range, interquartile range, and box-and-whisker graphs;
  - Interpret graphical representations of data, including descriptions and discussion of the meaning of the shape and features of the graph, such as symmetry, skewness, and outliers;
  - Analyze associations between variables by comparing the centers, spreads, and graphical representations of related data sets;

- Examine and interpret relationships between two variables using tools such as scatter plots and approximate lines of best fit. (NCTM, 1998 p.238)

Course Descriptions

Content tested in this study, NCTM Standard 5, Data Analysis, Statistics and Probability, is specifically addressed in MATH 131, the methodology for the standard is presented in EDEL 333, and the application in EDEL 333. Descriptions of the pertinent courses are:

MATH 130 - Math for Elementary Teachers I — A student enrolling in this class must have an ACT math score 23, or a SAT math score of 530, or have successfully completed MATH 103 - Introductory Algebra, or have scored at a level 3 on the university Math Placement Test. MATH 130 is an introduction to problem solving, sets, functions, logic, numeration systems as a mathematical structure, introductory number theory, rational and irrational numbers for prospective elementary school teachers. (4 semester hours)

MATH 131 - Math for Elementary Teachers II — Students must have taken and passed MATH 130 to enroll in MATH 131. MATH 131 covers introductory geometry, constructions, congruence and similarity, concepts of measurement, coordinate geometry, simple and complex experiments, odds, conditional probability, expected value, simulation, organizing and picturing information, collecting and analyzing data, and computer application for prospective elementary school teachers. (4 semester hours)

EDEL 333 - Teaching Mathematics — To enroll in EDEL 333, students must have taken and passed EDCI 360 - Foundations of Assessment, MATH 131 and be in good standing in Teacher Education Program. EDEL 333 covers math methods and materials for the prospective elementary teacher. Classroom organization, operation, management, applied technology, evaluation and current theory are also key components of the class. (3 semester hours)

EDEL 410 - Student Teaching — Students must have Senior standing, have completed of all required EDEL methods courses and be in good standing in Teacher Education Program. Student Teaching involves observation and teaching in a K-8 classroom setting; preparation and delivery of lesson plans. The student teaching experience occurs under the supervision of experienced teachers and MSU staff supervisors. (5-12 semester hours)

Independent Variables

For the purposes of this study, the independent variable was the group (MATH 130 - Mathematics for Elementary Teachers I, MATH 131 - Mathematics for Elementary Teachers II, EDEL 333 - Teaching Mathematics, EDEL 410 - Student Teaching) in which elementary education students were enrolled during Fall Semester 1999. Other factors were gender, age, high school mathematics preparation, number of college math and/or statistics classes taken, and enrollment in the elementary education math option.

Dependent Variables

Dependent variables were overall achievement; achievement when finding, describing and interpreting mean, median and mode; achievement in interpreting the spread of a set of data; achievement in understanding the meaning of the shape and features of a graph; achievement in comparing centers, spreads, and graphical representations of related data sets; and achievement in using scatter plots and lines of best fit

Hypotheses

Specific Research questions and hypotheses tested are as follows.

1. Group and gender will not significantly interact on each of the following dependent variables: a) overall achievement, b) achievement when finding, describing and interpreting mean, median and mode, c) achievement in interpreting the spread of a set of data, d) achievement in understanding the meaning of the shape and features of a graph, e) achievement in comparing centers, spreads, and graphical representations of related data sets, and f) achievement in using scatter plots and lines of best fit. If a significant interaction was found simple effects analyses were performed. In the case where the null hypothesis of interaction was retained the following main effects hypotheses were tested.

   1.1 There is no significant difference between the mean of all males and the mean of all females in: a) overall achievement, b) achievement when finding, describing and interpreting mean, median and mode, c) achievement in interpreting the spread of a set of data, d) achievement in understanding the meaning of the shape and features of a graph, e) achievement in comparing centers, spreads, and graphical representations of related data sets, and f) achievement in using scatter plots and lines of best fit.

1.2 There is no significant difference among the means of the four groups in: a) overall achievement, b) achievement when finding, describing and interpreting mean, median and mode, c) achievement in interpreting the spread of a set of data, d) achievement in understanding the meaning of the shape and features of a graph, e) achievement in comparing centers, spreads, and graphical representations of related data sets, and f) achievement in using scatter plots and lines of best fit.

When a significant main effect was detected the Newman-Kuels post hoc multi comparison statistic was utilized to test all possible pair wise hypotheses.

2. Group and age will not significantly interact on each of the following dependent variables: a) overall achievement, b) achievement when finding, describing and interpreting mean, median and mode, c) achievement in interpreting the spread of a set of data, d) achievement in understanding the meaning of the shape and features of a graph, e) achievement in comparing centers, spreads, and graphical representations of related data sets, and f) achievement in using scatter plots and lines of best fit. In the case where the null hypothesis of interaction was retained the following main effects hypotheses were tested.

2.1 There is no significant difference among the means of traditional age students and non traditional age students in: a) overall achievement, b) achievement when finding, describing and interpreting mean, median and mode, c) achievement in interpreting the spread of a set of data, d) achievement in understanding the meaning of the shape and features of a graph, e) achievement in comparing centers, spreads, and graphical representations of related data sets, and f) achievement in using scatter plots and lines of best fit.

When a significant main effect was detected the Newman-Kuels post hoc multi comparison statistic was utilized to test all possible pair wise hypotheses.

3. Group and degree of high school mathematics preparation will not significantly interact on each of the following dependent variables: a) overall achievement, b) achievement when finding, describing and interpreting mean, median and mode, c) achievement in interpreting the spread of a set of data, d) achievement in understanding the meaning of the shape and features of a graph, e) achievement in comparing centers, spreads, and graphical representations of related data sets, and f) achievement in using scatter plots and lines of best fit. In the case where the null hypothesis of interaction was retained the following main effects hypotheses were tested.

3.1 There is no significant difference among the means of all students with different high school mathematics preparation in: a) overall achievement, b) achievement when finding, describing and interpreting mean, median and mode, c) achievement in interpreting the spread of a set of data, d) achievement in understanding the meaning of the shape and features of a graph, e) achievement in comparing centers, spreads, and graphical representations of related data sets, and f) achievement in using scatter plots and lines of best fit..

When a significant main effect was detected the Newman-Kuels post hoc multi comparison statistic was utilized to test all possible pair wise hypotheses.

4. Group and number of college math and/or statistics classes taken will not significantly interact on each of the following dependent variables: a) overall achievement, b) achievement when finding, describing and interpreting mean, median and mode, c) achievement in interpreting the spread of a set of data, d) achievement in understanding the meaning of the shape and features of a graph, e) achievement in comparing centers, spreads, and graphical representations of related data sets, and f) achievement in using scatter plots and lines of best fit. In the case where the null hypothesis of interaction was retained the following main effects hypotheses were tested.

    4.1 There is no significant difference among the mean of number of college math and/or statistics classes taken in: a) overall achievement, b) achievement when finding, describing and interpreting mean, median and mode, c) achievement in interpreting the spread of a set of data, d) achievement in understanding the meaning of the shape and features of a graph, e) achievement in comparing centers, spreads, and graphical representations of related data sets, and f) achievement in using scatter plots and lines of best fit.

When a significant main effect was detected the Newman-Kuels post hoc multi comparison statistic was utilized to test all possible pair wise hypotheses.

5. Group and whether or not the student is in the Elementary Education Program math option will not significantly interact on each of the following dependent variables: a) overall achievement, b) achievement when finding, describing and interpreting mean, median and mode, c) achievement in interpreting the spread of a set of data, d) achievement in understanding the meaning of the shape and features of a graph, e) achievement in comparing centers, spreads, and graphical representations of related data sets, and f) achievement in using scatter plots and lines of best fit. If there had not been at least 10 students in each EDEL 333 and EDEL 410 who had taken more than MATH 130 and MATH 131 and were not in the math option this dependent variable would not have been used for statistical analysis. In the case where the null hypothesis of interaction was retained the following main effects hypotheses were tested.

   5.1 There is no significant difference between the mean of all math option enrollees and the mean of all non-math option enrollees in: a) overall achievement, b) achievement when finding, describing and interpreting mean, median and mode, c) achievement in interpreting the spread of a set of data, d) achievement in understanding the meaning of the shape and features of a graph, e) achievement in comparing centers, spreads, and graphical representations of related data sets, and f) achievement in using scatter plots and lines of best fit.

When a significant main effect was detected the Newman-Kuels post hoc multi comparison statistic was utilized to test all possible pair wise hypotheses.

6. Grade taught during student teaching and whether or not student taught math while student teaching will not significantly interact on each of the following dependent variables: a) overall achievement, b) achievement when finding, describing and interpreting mean, median and mode, c) achievement in interpreting the spread of a set of data, d) achievement in understanding the meaning of the shape and features of a graph, e) achievement in comparing centers, spreads, and graphical representations of related data sets, and f) achievement in using scatter plots and lines of best fit.

   6.1 There is no significant difference between the mean of PreK-2 student teachers, 3-5 student teachers and 6-8 student teachers in: a) overall achievement, b) achievement when finding, describing and interpreting mean, median and mode, c) achievement in interpreting the spread of a set of data, d) achievement in understanding the meaning of the shape and features of a graph, e) achievement in comparing centers, spreads, and graphical representations of related data sets, and f) achievement in using scatter plots and lines of best fit.

   6.2 There is no significant difference between the mean of the student teachers who taught math and those who did not teach math during student teaching in:

   a) overall achievement, b) achievement when finding, describing and interpreting b) mean, median and mode, c) achievement in interpreting the spread of a set of data, d) achievement in understanding the meaning of the shape and features of a graph, e) achievement in comparing centers, spreads, and graphical representations of related data sets, and f) achievement in using scatter plots and lines of best fit.

7. The set of independent variables (gender, age when enrolled in MATH 130, number of high school math classes taken and passed, number of college math classes taken and passed, number of college statistics classes taken and passed and whether or not the student is enrolled in Elementary Education program math option) do not explain a significant proportion of the variability in: a) overall achievement, b) achievement when finding, describing and interpreting mean, median and mode, c) achievement in interpreting the spread of a set of data, d) achievement in understanding the meaning of the shape and features of a graph, e) achievement in comparing centers, spreads, and graphical representations of related data sets, and f) achievement in using scatter plots and lines of best fit.

Instrument

A paper and pencil instrument and scoring rubric for evaluating the achievement of Montana State University elementary education majors relative to these specific NCTM data analysis standards was developed (See Appendix A) using commonly accepted procedures (Desmond, 1997, Bell, 1995, Wilburne, 1997). The specific components of Standard 5 that were tested are shown in Figure 5. The Table of