

THE QUEST FOR THE CONSTRUCTIVIST STATISTICS CLASSROOM:
VIEWING PRACTICE THROUGH CONSTRUCTIVIST THEORY

DISSERTATION

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the Degree Doctor of Philosophy in the Graduate
School of The Ohio State University

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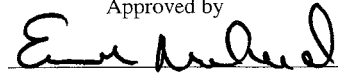
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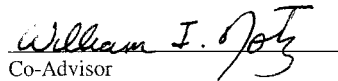
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ABSTRACT

The major assumption underlying this research is that all knowledge and understanding about statistics is constructed. Given that students construct their own knowledge, teaching must be designed to support knowledge construction. In this context, the global purpose addressed in this research is: "How do accomplished statistics educators support knowledge construction in their introductory statistics courses?" This global purpose is studied by attending to two more manageable questions: 1) What instructional strategies are being used in and around the statistics classroom?, and 2) What are the results of an analysis of these instructional strategies when the analysis is grounded in a constructivist perspective?

"The Quest for the Constructivist Statistics Classroom" is a qualitative research study that investigated the teaching of four accomplished statistics educators (Paul Velleman at Cornell University, David Moore at Purdue University, Gudmund Iversen at Swarthmore College, and Beth Chance at California Polytechnic State University). Data collection methods included e-mail questionnaires, on-site interviews, and classroom observations of the participants.

Instructional strategies employed by the participants were grouped into categories: strategies for how students come to know statistics; strategies involving technology; and, strategies for assessing student learning.

For the purpose of data analysis, the following definition of constructivism was used: Constructivism is a theory of learning that allows students to develop and construct their own understanding of the material based upon their own knowledge and beliefs and experiences in concert with new knowledge presented in the classroom. During the analysis, it was decided that the instructional strategies being used in the participants' classrooms did not dichotomously support or not support constructivism, but rather supported constructivism to varying degrees.

Some findings of the study included: 1) all four participants supported student construction of knowledge to some degree; 2) each of the participants employed multiple instructional strategies to involve the students in the learning process; and, 3) class size impacted the ability of the instructors to employ instructional strategies that were more supportive of knowledge construction. In addition, a series of questions intended to inspire further thought and research emerged from the study.

Dedicated to my grandmother, Janet Cole Friedman (1914-1990),
who would have been so proud, and
to my grandfather, Edward Donald Friedman (1913-),
who has been waiting a long time for this document.

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TABLE OF CONTENTS

	<u>Page</u>
Abstract	ii
Dedication	iv
Acknowledgments	v
Vita	vii
List of Figures	xii
Prologue	xiii
Chapters:	
1. Introduction	1
1.1. What is Statistics as a Discipline?	2
1.1.1. What My Students Thought	2
1.1.1.1. Statistics is... [an almost textbook-like definition]	3
1.1.1.2. Statistics is purely a requirement with little use in life	4
1.1.1.3. Statistics is part of an "X-Files"-like conspiracy	5
1.1.1.4. Statistics exists purely to torture me	6
1.1.1.5. Statistics is used to find out pointless things	7
1.1.2. What the Reference Books Said	7
1.1.3. What the Textbooks Said	8
1.2. Why Do We Even Need Statistics?	9
1.3. Statistical Literacy	10
1.4. Assumption(s) Underlying This Research	12
1.5. Positioning My Research	14
1.6. Intentions for This Work	19
1.7. What to Expect in the Following Chapters	19

2. Literature Review	21
2.1. Teaching and Learning	21
2.1.1. Procedural Knowledge, Conceptual Knowledge, and Understanding	24
2.1.2. Dewey's (1938) Experience & Education	26
2.2. Constructivism	29
2.2.1. Constructivism as an Educational Paradigm	30
2.2.2. Cognitive and Social Constructivism	32
2.2.3. Basic Tenets and Principles of Constructivism	36
2.2.4. Teacher and Learner Roles in Constructivism	37
2.2.5. Issues of Concern With Constructivism	40
2.3. The Statistics Classroom That Supports Constructivism	41
2.3.1. Some Strategies for Use in the Constructivist Statistics Classroom ..	42
2.3.2. Examples of Constructivism in Practice	43
2.3.3. Examining Our Teaching	45
2.3.4. Assessment in the Constructivist Statistics Classroom	47
2.3.5. The Use of Technology in the Constructivist Statistics Classroom ..	55
2.3.6. Going Through "The Change"	59
2.3.7. Does Constructivism Come With a Guarantee?	60
2.4. Summary	61
3. Methodology	63
3.1. Introduction	63
3.2. Why Qualitative Methods?	63
3.3. A Global Description of My Study	66
3.4. Time Line	67
3.5. Sampling	68
3.5.1. The Participants	70
3.5.1.1. Paul Velleman, Cornell University, and Statistics 210	71
3.5.1.2. David Moore, Purdue University, and Statistics 113	72
3.5.1.3. Gudmund Iversen, Swarthmore College, and Statistics 1	75
3.5.1.4. Beth Chance, California Polytechnic State University, and Statistics 217	77
3.6. Gaining Entrée	80
3.7. Data Collection	81
3.7.1. The Initial E-Mails	82
3.7.2. The Interviews	82
3.7.3. The Observations	84
3.7.4. The Follow-Up E-Mails	85
3.8. Data Analysis	85
3.8.1. Initial Data Analysis, Reduction, and Re-Presentation	86
3.8.2. Data Coding	87

3.8.3. Analysis Through the Constructivist Lens	91
3.9. Trustworthiness	93
3.9.1. Triangulation	94
3.9.2. Audit Trail	94
3.9.3. Member Checks	95
3.9.4. Peer Review	97
3.10. Politics and Ethics	98
3.11. Summary	101
4. Tales of My Participants	102
4.1. Introduction	102
4.2. Paul Velleman at Cornell University	104
4.2.1. Teaching Philosophy	105
4.2.2. Instructional Strategies	112
4.2.3. Use of Technology	119
4.2.4. Interaction With Students	124
4.3. David Moore at Purdue University	126
4.3.1. Teaching Philosophy	126
4.3.2. Instructional Strategies	139
4.3.3. Use of Technology	151
4.3.4. Interaction With Students	155
4.4. Gudmund Iversen at Swarthmore College	157
4.4.1. Teaching Philosophy	157
4.4.2. Instructional Strategies	163
4.4.3. Use of Technology	176
4.4.4. Interaction With Students	177
4.5. Beth Chance at California Polytechnic ate University	180
4.5.1. Teaching Philosophy	180
4.5.2. Instructional Strategies	189
4.5.3. Use of Technology	203
4.5.4. Interaction With Students	205
4.6. Questions That Arose During Data Collection (and Answers to These Questions)	207
4.7. Summary	217
5. Analysis of the Data	218
5.1. Answering My Research Questions	218
5.1.1. Instructional Strategies Used in the Participants' Classrooms	219
5.1.2. Analyzing the Instructional Strategies Through the Lens of Constructivism	221
5.1.2.1. Instructional Strategies Involving How Students Come to Know Statistics	221

5.1.2.2. An Analysis of the Use of Technology in the Participants' Classrooms	229
5.1.2.3. An Analysis of the Participants' Assessment of Student Learning	234
5.2. Analyzing the Participants' Words Through the Constructivist Lens	237
5.2.1. Paul's Constructivist Allusions	237
5.2.2. David's Constructivist Allusions	239
5.2.3. Gudmund's Constructivist Allusions	240
5.2.4. Beth's Constructivist Allusions	241
5.3. The (Lack of) Presence of Hogg's (1992) Problems in Introductory Statistics Courses	243
5.4. Investigating the Participants' Ideal Introductory Statistics Classrooms	246
5.5. Summary	250
6. Conclusions, Implications, and Directions for Future Study	251
6.1. Introduction	251
6.2. Conclusions	252
6.3. Discussion	252
6.3.1. The Issue of Class Size	253
6.3.2. The Effect of the Ivy League	254
6.3.3. More Questions Than Answers	256
6.4. Implications	260
6.5. Directions for Future Study	261
6.6. Summary	263
Epilogue	265
Appendices	268
Appendix A - Participant Solicitation E-mail	268
Appendix B - Consent Form - Participants	270
Appendix C - Consent Form – Teaching Assistants	273
Appendix D - E-mail Questionnaire	276
Appendix E - E-mail Request for Course Information	278
Appendix F - General Interview Protocol	280
Appendix G - Actual Interview Protocols	283
Appendix H - Follow-Up E-Mail	298
List of References	300

LIST OF FIGURES

<u>Figure</u>	<u>Page</u>
3.1 A Time Line for My Research	67
4.1 The Participants and Their Courses	103
4.2 The Studio Classroom in Which Beth Teaches	190
5.1 The Instructional Strategies Used by the Participants	220
5.2 The Participants' Ideal Classrooms	247

PROLOGUE

TWO STATEMENTS ABOUT STATISTICS

FROM TEACHING STATISTICS AND PROBABILITY (NCTM, 1981)...

Even a cursory glance at newspapers shows the extent to which the language of statistics and probability has become a part of everyday life.

Understanding this language has clearly become important....

Even though the role of both statistics and probability in our lives is significant, it is not the only rationale for including them in the school curriculum. A model of a more complete rationale contains three components—utility, future study, and aesthetics.

Individuals need a knowledge of statistics and probability to function in our society. Such things as consumer reports, cost of living indexes, and surveys and samples are a part of everyday life. Students should be able to interpret such statements as "The probability of an oil spill off Vancouver Island is less than 1 in 10 000" or "Survey Spells Economic Gloom." Competence with the utilitarian aspects of statistics and probability will help them process the many data-oriented messages they receive every day.

A knowledge of statistics and probability is needed to deal with many situations that the student may face later in mathematics and other subjects. Competence in statistics and probability gives the student a sound basis for subjects that require this kind of mathematical orientation and foundation. Such a basis will become increasingly important as more fields of study require mathematical training. Subjects such as biology and the social sciences, which at one time required little mathematical knowledge, are rapidly becoming dependent on sophisticated mathematical techniques, most of them statistical in nature. Simulation techniques and Monte Carlo methods are now used in a wide range of disciplines. In a rapidly changing world, the assessment of probabilities of future events is an important part of decision making.

Aesthetic considerations are an important part of developing an appreciation for the beauty of the topic, both as an area of mathematics and through its applications to science, technology, and nature. This aesthetic appeal draws on both an appreciation of the power of the techniques and an awareness of the responsibility for a "tasteful" application of those techniques. The aesthetics approach is concerned with a selection of material that best develops an appreciation of mathematics. (Pereira-Mendoza and Swift, 1981, pp. 1-3)

FROM STATISTICS FOR THE TWENTY-FIRST CENTURY (MAA, 1992)...

We live in a society which is ever more dependent on statistical reasoning. Major political, social, economic and scientific decisions are made using statistical information. Statistical reports affecting virtually all aspects of our lives appear regularly in all the news media. Business and industry leaders constantly call for greater statistical understanding on the part of our workforce. Statistics has thus become the primary quantitative tool in most areas. In turn, statistics offerings have become one of the fastest growing segments of the undergraduate curriculum.

These trends are almost certain to continue with statistics assuming an ever greater role throughout our society. The students we teach today will spend virtually their entire productive lives in the coming century, a century that will require an even greater awareness of statistical ideas. We should therefore be offering statistics courses geared to the needs of the citizens of the twenty first century.

Yet, far too many of the students who take a statistics course describe it as the worst or most boring class they have experienced in college. While we constantly speak of the introductory statistics course as being the *first* course in statistics, it is actually the *last* course in statistics for the overwhelming majority of students. This is a particularly disturbing commentary when we consider that the material typically covered in an introductory statistics course forms the basis for the statistical reports and analyses that can be found all about us. (Gordon and Gordon, 1992, vii)

CHAPTER 1

INTRODUCTION

The statements about statistics in the prologue of this document initiate the discussion of the teaching and learning of undergraduate introductory statistics in "The Quest for the Constructivist Statistics Classroom: Viewing Practice Through Constructivist Theory." But, before any discussion begins, I must address the following questions: What is statistics? Why do we even need statistics? And, what does it mean to be statistically literate? Answers to these questions can be found in this chapter.

Also in this chapter, I establish the need and purpose for "The Quest for the Constructivist Statistics Classroom: Viewing Practice Through Constructivist Theory" with a brief discussion of current research in statistics education and the emergence of my research questions. In addition, I discuss the audience for whom this dissertation is intended. I conclude this chapter with what the reader can expect in the rest of this document.

What is Statistics as a Discipline?

To set the stage for my research, I attempt to define statistics as a discipline, as opposed to statistics as "the friends of parameters" (E. Norland, personal communication, July 1999). In order to define statistics as a discipline, I first consulted a variety of experts: my students, two dictionaries, and several introductory statistics textbooks. Some definitions within and among these sources were similar, while others, particularly those of my students, were strikingly different. I cannot claim that I have arrived at one single, concise, accurate definition of statistics. However, the study of these multiple definitions provides a springboard for this research.

What My Students Thought

Because this study is an investigation of the teaching and learning of statistics in higher education, the first group of 'experts' whom I queried was made up of undergraduate students in my elementary statistics class. I asked these students to answer the question of "What is Statistics?" at the end of the sixth week of a ten-week class during Summer Quarter 1999 at The Ohio State University. Their answers appeared to follow five themes¹:

- Statistics is... [an almost textbook-like definition];
- Statistics is purely a requirement with little use in life;
- Statistics is part of an "X-Files"-like conspiracy²;
- Statistics exists purely to torture me; and
- Statistics is used to find out pointless things.

¹ The frequencies of each of the following themes are 22, 7, 2, 6, and 2 students, respectively.

² "The X-Files" is an evening television serial that premiered in the United States in 1993. One of the themes of the serial is that there is a government conspiracy behind many of the cases investigated by two FBI agents, Fox Mulder and Dana Scully.

Statistics is... [an almost textbook-like definition]

Some of the students in my introductory statistics class understood what the discipline of statistics involves. The individual responses of these students addressed both descriptive and inferential statistics. On the descriptive side, statistics was described as "the study of numbers, chance, and organization of data" and "systematic measurements of the universe that surrounds us [that are] transcribed into meaningful and predictable data." From an inferential perspective, statistics was defined as:

- "the science of predicting what might happen by looking at what has happened;"
- "a process whereby we can take a limited amount of knowledge and use it to see larger trends and predict future patterns;" and
- "organizing an overwhelming amount of info into readable sets of data, making it (the overwhelming amount of info) useful to many different professions."

These definitions of statistics could all be used as parts of a textbook definition of statistics.

One of the unique characteristics of the field of statistics is its ability to handle variability (Cobb and Moore, 1997), something two students hinted at in their definitions. One student defined statistics as "the study of numbers and percentages where math drops off, i.e., the grey area where math can't be an absolute." Another student said that statistics is "the study of mathematically or numerically consistent occurrences on this planet... created out of the human need [for] equilibrium, consistency, and reliability." While not directly addressing variability in their definitions, both of these students knew that statistics lets us deal with issues not covered by other aspects of mathematics.

Statistics is purely a requirement with little use in life

While none of the students quoted in the section above put a 'value' or 'worth' in their definitions of statistics, other students had strong opinions about studying statistics. The introductory statistics course my students were taking fulfills a General Education Curriculum (GEC) requirement at The Ohio State University. How did the students feel about taking statistics as a required course? The following definitions of statistics spoke for themselves. Statistics was defined to be:

- "a GEC³ that OSU makes you take even if it has nothing to do with your major;"
- "the last GEC I have to take before graduating. The philosophy course for social diversity was full;" and
- "5 credits out of a predicted total of 200 required in order for me to graduate with 2 degrees that have absolutely nothing to do with the class itself."

None of these definitions were ringing endorsements for an introductory statistics course.

Still other students were convinced that statistics had (and, presumably, has) nothing to do with their lives. One student wrote that statistics is "the study of percentages and numbers having to do with solutions. It also does not help much in real life." Another student wrote that, while interesting, statistics is pointless. This particular student defined statistics as:

Trying to understand probability, chance, and experiments through mathematical reasoning. Doesn't that sound great? It's interesting yet somewhat pointless. What are you gonna do with all the information you find out in stats, ya know?

³ The use of the acronym 'GEC' here stands for a course that fulfills a General Education Curriculum requirement at The Ohio State University.

Besides helping me define statistics, these responses also made it clear to me that I need to improve the way that students discover the importance of statistics in introductory statistics courses.

Statistics is part of an "X-Files"-like conspiracy

One of the main themes in "The X-Files" is that there is a government conspiracy behind just about everything. The replies of several of my students made me think about a possible "X-Files"-like conspiracy in statistics. One student said that statistics is "playing around with numbers. You make them fit where you want them to and then explain why they work the way they do." Yet another student said that statistics is

A way to predict certain outcomes in every walk of life. However, they can always be manipulated to predict the outcome a desired person/group may want. They are also great for shock value.

Now, I suspect that there is no such conspiracy in statistics, but I understand that my students felt manipulated by those who control the release of statistics to the general public. Even Mark Twain said, "get the facts first and then you can distort them as much as you please" (in Sanders, 1995, p. 22).

The definitions above made me aware that some of my students do see statistics as a discipline that can be used to convey anything the owner of the information wants. At the same time, I reminded myself that I teach introductory statistics as, what I call, a 'consumer statistics' class—it is my hope that my students leave the classroom being able

to question the statistics that bombard them in their daily lives. As such, I need to concentrate on helping students to think critically about the statistics they encounter in their daily lives.

Statistics exists purely to torture me

Within the theme of statistics as a tool of student torture, I found evidence that statistics caused my students physical pain, emotional pain, and confusion. As far as physical pain, one student wrote that statistics is "a pain in the ass." Yet another student claimed that statistics is "another math course that gives me a headache."

The emotional pain of statistics was evident in several students' statements about statistics. One student said that statistics is "based on chance and probability and agony," while another student said that statistics is "something my college finds amusing to torment the mathematically inept with." One student sensed an 'evilness' to statistics: "the study of the chances of something happening, as well as the evil 3rd math GEC class."

As far as student confusion went, one particular student said it all with the statement that statistics is "a journey into the unknown with a malfunctioning compass." Since introductory statistics courses are probably not intended for student torture of any kind, I wondered why it was that my students found the course so torturous.

Statistics is used to find out pointless things

Recall that I am trying to get a sense for the definition of statistics as a discipline through the eyes of my students. One particular student viewed statistics as something that is used to find out pointless bits of information that are of no use to anyone. This student said that statistics is "the ~~art~~ science [sic] of manipulating data to find out what percentage of seagulls are gay." This definition combined the "X-Files" conspiracy idea (the student's use of the word "manipulation") with an absolutely pointless topic (the percentage of seagulls that are gay). Even so, this student made me consider that some (if not many) introductory statistics students find statistical problems seemingly disconnected from reality.

What the Reference Books Said

While I examined multiple definitions of statistics, I reasoned that it would be a good idea to check a dictionary definition of statistics because someone who did not know what statistics was might look up the definition of statistics in a dictionary.

According to Webster (Agnes (Ed.), 1999), statistics is:

(*pl.n.*) facts or data of a numerical kind, assembled, classified, and tabulated so as to present significant information about a given subject (*n.*) the calculation, description, manipulation, and interpretation of the mathematical attributes of sets or populations too numerous or extensive for exhaustive measurements (p. 1400)

W. Paul Vogt (1999) authored the *Dictionary of Statistics & Methodology: A Nontechnical Guide for the Social Sciences*. The second edition of this book debuted during the 1999 Annual Meeting of the American Educational Research Association, and,

as educational researchers devoured copies, the publisher could not keep it on the shelves. In his book, Vogt defined statistics to be:

(a) Numerical summaries of data obtained by measurement and computation. (b) The branch of mathematics dealing with the collection and analysis of numerical data. "Statistics" originally meant quantitative information about the government or state—"state-istics." (p. 278)

While the definitions I found in these references may have been accurate, I surmised that students in introductory statistics classes were probably not spending their free time looking up multiple definitions of statistics. They probably had read, however, the definition of statistics provided in their textbooks.

What the Textbooks Said

There are scores, maybe hundreds, of introductory statistics textbooks in use across the country and throughout the world. For me to list the formal definitions from each of these texts would be an enormous task. Included in this section are definitions from a convenience sample of four introductory statistics texts in my personal library: two 'mathematical' statistics texts and two 'conceptual' statistics texts.

The mathematical statistics texts in my convenience sample defined statistics in 'simple,' yet mathematical, terms. Moore and McCabe's (1998) *Introduction to the Practice of Statistics* defined statistics as "the science of collecting, organizing, and interpreting numerical facts, which we call *data*" (p. xxv). A similar definition of statistics was found in Mario Triola's (1998) *Elementary Statistics*: "a collection of methods for planning experiments, obtaining data, and then organizing, summarizing, presenting, analyzing, interpreting, and drawing conclusions based on the data" (p. 4).

The conceptual statistics texts defined statistics in 'simple' words, without mathematical terms. In *Statistics*, Freedman, Pisani, and Purves (1998) defined statistics as "the art of making numerical conjectures about puzzling questions" (p. xv). The opening sentence of the introduction to David Moore's (1997b) *Statistics: Concepts and Controversies* defined statistics as "the science of gaining information from numerical data" (p. xiv). While these definitions appeared simple, I assumed that both definitions might encourage readers interested in finding out about the 'art' and the 'science' of statistics.

Why Do We Even Need Statistics?

According to a recent survey by the Conference Board of the Mathematical Sciences, in the fall of 1995, 4,340 sections of elementary statistics were taught to approximately 164,000 students at four-year colleges and universities (Loftsgaarden, Rung, and Watkins, 1997, pp. 7, 52). These enrollment numbers represent an increase of 47,000 students (40.2%) since the fall of 1990. The number of students taking elementary statistics has tripled since 1970 (p. 131). The rise in the number of students taking statistics may suggest that the faculties of colleges and universities believe that statistical literacy is increasing in importance.

If the world itself, the people in the world, and the bits of information flowing throughout the world were always simple and clear, we would not need statistics. Facts would be (obvious) facts, and there would be no questions. We live, however, in a world

of variability. The omnipresence of variability gives rise to the need for statistics as a discipline (Cobb and Moore, 1997). In the words of George Cobb and David Moore:

Individuals vary. Repeated measurements on the same individual vary. In some circumstances, we want to find unusual individuals in an overwhelming mass of data. In others, the focus is on the variation of measurements. In yet others, we want to detect systematic effects against the background noise of individual variation. Statistics provides means for dealing with data that take into account the omnipresence of variability. (p. 801)

Since statistics gives us ways to deal with variability, questions that cannot be answered through direct measurement can be studied through statistics (National Council of Teachers of Mathematics [NCTM], 1989). Students "should recognize that statistics plays an important intermediate role between the exactness of other mathematical studies and the equivocal nature of a world dependent largely on individual opinion" (NCTM, 1989, p. 167). In addition, as a methodology discipline, statistics offers "other fields of study a coherent set of ideas and tools for dealing with data" (Cobb and Moore, 1997, p. 801). Since statistics is used by many other disciplines, many students of statistics, even if they will not actively do statistics in the future, will encounter statistics in their own work if not in their everyday lives.

Statistical Literacy

At the 1999 Joint Statistical Meetings in Baltimore, Maryland, Gail Burrill, a past-president of the National Council of Teachers of Mathematics (NCTM), referred to statistics as "both an art and a science—and necessary for a quantitatively literate citizen in any country" (August 11, 1999). Two days prior, Deb Rumsey, a well-known statistics educator, introduced an invited session at these meetings with the claim that statistical

literacy would lead to "good citizenship qualities" (August 9, 1999). During his portion of this invited session, George Cobb, another well-known statistics educator, stated that "statistical literacy will save the world" (August 9, 1999). In other words, by understanding the statistics that are presented to them on a daily basis, individuals can be informed consumers and participate in discussions about decisions being made in the world. The comments of these three individuals and others at the conference highlighted the desire of both the mathematics education and statistics education communities for statistical literacy for all.

To address the issue of the importance of statistical literacy, we must first consider what statistical literacy is. According to Katherine Wallman (1993), "'statistical literacy' is the ability to understand and critically evaluate statistical results that permeate our daily lives—coupled with the ability to appreciate the contributions that statistical thinking can make in public and private, professional and personal decisions" (p. 1).

If we accept that statistical results "permeate our lives," it is inevitable that each individual will have to deal with statistical results in her/his lifetime. For example, societal decision-makers use statistical information when making major political, social, economic, and scientific decisions (Gordon and Gordon, 1992). The average American is bombarded with statistics daily through all forms of media from print to television to the World Wide Web. "Statistics [can even] offer students insights into problems of social equity" (NCTM, 1989). To think critically about the statistics presented to them in their everyday lives, students must have at least some basic understanding of statistics (Gordon

and Gordon, 1992). And, since understanding statistical results demands statistical literacy, we must consider where students learn to become statistically literate.

Students are exposed to statistical concepts throughout their K-12 education experience. The *Curriculum and Evaluation Standards for School Mathematics* (NCTM, 1989) include probability and statistics concepts throughout the K-12 curriculum⁴. Upon graduation from high school, all students should have been exposed to some probability and statistics during their K-12 experiences. But, because the concepts in probability and statistics in the K-12 curriculum are couched within the mathematics curriculum, students may not recognize these concepts as being a part of statistics. As a result, the undergraduate introductory statistics course may be the first place that these students recognize these concepts as part of statistics.

Assumption(s) Underlying This Research

The major assumption underlying "The Quest for the Constructivist Statistics Classroom" is that: **All knowledge and understanding about statistics is constructed.** In order to understand the implications of this assumption, it is necessary for me to define what is meant by 'knowledge,' 'understanding,' and 'statistics' as well as what it means to construct knowledge.

Knowledge is a difficult concept to define. Returning to the philosophy of Plato, knowledge can be defined as "justified true belief" (Ernest, 1998, p. 2). In this work,

⁴ The *Curriculum and Evaluation Standards* (NCTM, 1989) are a vision put forth by the National Council of Teachers of Mathematics of what good teaching is about. Further discussion can be found on pages 17-18 of this document.

knowledge is considered to be a body of facts (a body of 'justified true beliefs') rather than a process. While we might like to think of knowledge as a process, for the purpose of this work I view knowledge as a body of facts and constructivism as the process involved in learning and understanding the body of facts that characterizes the discipline of statistics. Knowledge can be broken down into two categories: procedural knowledge (how to do something) and conceptual knowledge (what is the basic idea being studied?).

Understanding in this work centers around two questions. The first question of understanding is 'What does the procedure and/or concept actually mean?' This question focuses on the procedure or concept as its own entity. The second question of understanding is 'Why does this procedure and/or concept fit together with the rest of the discipline of statistics in the way that it does?' This question broadens the focus of understanding to the entire discipline of statistics.

Statistics in this work is, as mentioned above, the discipline of statistics. In particular, this research examines the teaching of introductory statistics to students who are primarily consumers (as opposed to users) of statistics. For students of introductory statistics to be *informed* consumers of statistics, they must understand both the individual concepts of statistics and how the concepts fit together within the discipline of statistics.

In the underlying assumption stated above, **constructed** refers to knowledge and understanding that is built by individual students as they encounter new ideas in their learning of statistics. This knowledge construction is an alternative to other forms of learning including rote memorization and behaviorism. Constructivism, a philosophy

that supports student construction of knowledge, is addressed briefly in this chapter and more thoroughly in Chapter 2 of this document.

The implication of this assumption is that introductory statistics needs to be taught in ways that allow students opportunities to construct their own knowledge and understanding. The following section of this chapter positions my research within the statistics education community, and, with the above assumption in mind, introduces the global purpose of "The Quest for the Constructivist Statistics Classroom."

Positioning My Research

Whether or not undergraduate statistics students have been exposed to statistical concepts during their K-12 experience, an introductory statistics course during their college careers may be the only formal statistics course these users of statistics take (Gal and Ginsburg, 1994; Gordon and Gordon, 1992; Roiter and Petocz, 1996). Thus, these students will have only one formal opportunity to understand the statistics they most likely encounter daily. Since we typically only get one (formal) chance to teach statistics to users of statistics, we need to be sure that what we do when we teach is being done in the best possible way. We can begin by examining critically the teaching and learning of introductory statistics and continually trying to improve our instructional strategies.

When we prepare our instruction, we need to keep in mind why students are taking a statistics course (Hogg, 1991). In general, there are two groups of students who take (non-major) statistics courses. First, there are students who will need to work with statisticians, understand statistical results, and even do some statistical procedures

themselves. Second, there are students who will only need to understand the statistics they encounter in their everyday lives. These are the students whom I claim need a course in what I call 'consumer statistics.' The instruction of this latter group of students is the focus of my research.

Whatever the reason students are taking statistics, the goal for statistics instructors should be for students to leave their classes *understanding* statistics. However, understanding cannot be emphasized in courses where: "course objectives... are expressed in terms of the specific topics covered in elementary texts rather than meeting the needs of the students" (Hogg, 1992, p. 6). Nor can understanding be emphasized when "statistics is seen as a 'subject,' rather than a problem solving tool to be used in the scientific method, or a useful way to look at the world around us" (p. 6).

Several problems with introductory statistics courses were identified by statistics educators at an invited workshop on statistics education in 1990. The following five problems with introductory statistics courses are a subset of the problems identified by this group of statistics educators and come directly from Hogg (1992):

- Statistics teaching is often stagnant; statistics teachers resist change. The most popular introductory texts have evolved slowly over the decades. There is a tendency to present the same subjects, the same way, from the same books year after year. Meanwhile statistical methods are progressing rapidly.
- Techniques are often taught in isolation, with inadequate motivation and with no connection to the philosophy that connects them to real events; students often fail to see the personal relevance of statistics because interesting and relevant applications are rare in many statistics courses. The applications, if any, are often contrived, even "phoney." ... The open-ended nature of statistical investigations and the sequential nature of statistical inquiry are not brought out. The students are not pushed to question their environment and seek answers through investigations.
- Teachers are often unimaginative in their methods of delivery, relying almost exclusively on traditional lecture/discussion. They fail to take into account

the different ways in which students may learn, both individually and in groups, or the many possible modalities of teaching. They also fail to use the wide variety of simulations, experiments and individual or group projects which can make statistics come alive while simultaneously enhancing student understanding.

- Many teachers have inadequate backgrounds: in knowledge of the subject, in experience applying the techniques, and in the ability to communicate in English. The word "statistics" has itself acquired bad connotations.
- Statisticians may put their subject in a bad light for the students. They often fail to see any need to convey a sense of excitement. (p. 6)

While the five problems listed above were not overwhelmingly evident in my work with the participants in this study, I leave it to the reader to determine the degree to which each of the five problems above was evident. For example, while lecture was used in some way by each of the participants, lecture was not used solely for the transmission of knowledge⁵. The typical lecture model of transmission of knowledge from teacher to students follows the banking system of education discussed by Paulo Freire (1970/1993): teachers act as depositors of knowledge and the students are the depositories. In response to this model, Freire defined an alternative systems that makes teachers and students partners in learning process.

Constructivism is a philosophy that supports such a partnership. When students are given the opportunities to construct their own knowledge in a way that makes sense to them, the instructional strategies being used are in line with the philosophy of constructivism. Each student's construction of knowledge is individual, even

⁵ Further discussion can be found in Chapter 5 of this document.

idiosyncratic. Since students construct their knowledge in ways that make sense to them, instructional strategies that support constructivist philosophies naturally advocate student understanding.

The teacher in a classroom that supports constructivist philosophy is challenged to create an environment in which students are encouraged to think, explore, and construct their own understanding (Brooks and Brooks, 1993). Constructivism supports the idea that existing knowledge, past experiences, and beliefs of the students coming into the classroom with them. New knowledge construction is integrated with/added to this existing knowledge and these experiences and beliefs in a way that makes sense to each student. The instructor is challenged to actively involve her/his students in the learning process. Instead of playing the traditional role of the lecturer, the instructor becomes a leader and facilitator of knowledge construction (Garfield, 1993; Keeler and Steinhorst, 1995).

Current theorists (and leading practitioners) of mathematics teaching and learning argue for a constructivist understanding of mathematical learning. For example, the National Council of Teachers of Mathematics published three volumes of standards for mathematics teaching and learning that are grounded in constructivist theory. First published were the *Curriculum and Evaluation Standards for School Mathematics*⁶ (NCTM, 1989), which "were meant to be a vision of a mathematics curriculum that

⁶ A new document, *Principles and Standards for School Mathematics* (NCTM, 2000) debuted at the April 2000 Annual Meeting of the National Council of Teachers of Mathematics. This new set of standards "will build on the original messages of the standards [and] also reflect the needs of a different era and the knowledge gained over the past 10 years" (Burrill, 1997, p. 336).

provided a quality education for all children" (Burrill, 1997, p. 335). It is important to note that:

The NCTM standards are not intended to be a national curriculum; they are intended to provide guidelines and a vision for which mathematical concepts are important for all children if they are to take their rightful places as workers and as citizens in a different world. (p. 335-6)

"Recognizing that content alone is insufficient" (p. 335), the original *Standards* document was followed by the *Professional Standards for Teaching Mathematics* (NCTM, 1991) and the *Assessment Standards for School Mathematics* (NCTM, 1995). One of the contributions of the *Teaching Standards* was the suggestion "that students may learn in ways other than by viewing examples and listening to lectures" (Burrill, 1997, p. 335). In addition to the *Standards* documents, there have been other publications about mathematics teaching and learning that support constructivist theory (e.g., Fosnot (Ed.), 1996; Davis, Maher, and Noddings (Eds.), 1990; Steffe, Greer, Cobb, Goldin, and Nesher, 1996).

Moving over to statistics education, the suggestions set forth by the statistics educators in Hogg (1992) support constructivist philosophy. Since 1992, many researchers in statistics education have studied individual instructional strategies that support constructivist philosophy. Such research can be found in Chance (1997), Garfield (1993, 1994), Giraud (1997), Keeler and Steinhorst (1995), Konold (1995), and Soweiy (1995), to name a few.

Given that students construct their own knowledge, teaching must be designed to support knowledge construction (NCTM, 1989). In this context, the global purpose addressed in this research is: "How do accomplished statistics educators support

knowledge construction in their introductory statistics courses?" This global purpose is studied by attending to two more manageable questions:

- What instructional strategies are being used in and around the statistics classroom?
- What are the results of an analysis of these instructional strategies when the analysis is grounded in a constructivist perspective?

Intentions for This Work

The purpose of "The Quest for the Constructivist Statistics Classroom" was to see what accomplished statistics educators do in and around their classrooms and to investigate to what degree these particular statistics educators support constructivism.

The intended audience for this work is the population of teachers of introductory statistics. My hope is that readers of this work will consider critically their own teaching of introductory statistics as well as other statistics courses. The potential for this work to assist teachers of introductory statistics is limited only by each reader's ability to use it in consideration of her/his own teaching of introductory statistics.

What to Expect in the Following Chapters

Chapters 2 through 6 of this document follow "The Quest for the Constructivist Statistics Classroom: Viewing Practice Through Constructivist Theory." Chapter 2 is a review of the literature relevant to the discussion of teaching and learning and constructivism in the undergraduate introductory statistics classroom. Chapter 3 specifies the methodology used to investigate the research questions posed above. Chapter 4 contains the presentation of my data through "realist tales" (Van Maanen, 1988) which

are stories about the goings on in the classrooms of my participants. In Chapter 5, the instructional strategies that are being employed in the classrooms of my participants are analyzed through the lens of constructivism. An analysis between each participant's teaching philosophy and her/his teaching can also be found in Chapter 5. Finally, in Chapter 6, I address conclusions of, discussion about, implications of, and further research in "The Quest for the Constructivist Statistics Classroom."

CHAPTER 2

LITERATURE REVIEW

My literature review establishes a foundation for my research of "The Quest for the Constructivist Statistics Classroom: Viewing Practice Through Constructivist Theory." This chapter begins with an investigation of general teaching and learning issues, continues with a general review of constructivism, and concludes (for the purpose of this research) with a move toward the constructivist statistics classroom.

Teaching and Learning

Because teaching and learning co-exist when teacher and student are partners in the learning process (Freire, 1970/1993), teaching and learning are necessarily connected concepts, each defining the other. As a facilitator of knowledge construction, a teacher needs to first find out what her/his students already know. A teacher can only know the existing knowledge of her/his students through the testimony of the students. Using the existing knowledge of her/his students as a foundation, a teacher and students can work together to determine a path of learning for understanding.

The paragraph above assumes a partnership between teacher and student and also assumes the role of teacher as facilitator of knowledge acquisition. These assumptions,

however, are my own beliefs about teaching and learning, and I felt it necessary to investigate the concepts of teaching and learning as reported by other researchers. The following paragraphs summarize teaching, learning, and education through the eyes of these researchers.

In their investigation of definitions of teaching and learning, Heimlich and Norland (1994) found, common to the definitions they investigated, that "everything a teacher does in teaching is directed toward facilitating learning" (p. 26). Teaching was similarly defined by Leamnson (1999) to be "any activity that has the conscious intention of, and potential for, facilitating learning in another" (p. 3). Neither of these definitions of teaching above implies the existence of learning. Many educators would not like these definitions of teaching, since "as defined here, teaching does not imply necessarily that any learning is going on. In fact, it does not even demand that anyone else be *present*" (Leamnson, 1999, p. 51). Yet, "it is strongly held by a sizable fraction of school teachers that unless students are learning, whatever it is that the instructor is doing, it should not be called teaching (p. 51). Learning is a model of change where "if the learner does not change, learning has not taken place" (Heimlich and Norland, 1994, p. 27).

In general, teaching "is something done *by* someone...not *to* someone" (Leamnson, 1999, p. 52). In fact, "telling students what they need to know is one thing; *doing* something that will inspire them to become motivated and actually learn is quite

another" (p. 55). Good teaching⁷, then, becomes "a matter of doing the right things under appropriate circumstances" (p. 52).

Teaching includes both teaching philosophy and behaviors, and teaching style is the combination of teaching philosophy and behaviors (Heimlich and Norland, 1994). A teacher's "personal philosophy of teaching and learning will serve as the organizing structure for [her/his] beliefs, values, and attitudes related to the teaching-learning exchange" (pp. 37-38). Teaching style "includes the implementation of philosophy" (p. 40) and may include behaviors like "presenting information, facilitating discussion, structuring learning opportunities, planning subject matter, and conducting learning activities" (p. 41). The development of a teaching philosophy happens over time and is based on both exploration and reflection.

In addition to defining teaching, Leamnson (1999) defined learning (admittedly clinically) as "stabilizing through repeated use, certain appropriate and desirable synapses in the brain" (p. 53). Leamnson claimed that learning is self-initiated and not externally caused. This definition of learning implies that "it can't be seen happening" (p. 53). Even though learning cannot be seen happening, it is possible for the teacher to find out what her/his student is thinking. For example:

When a student is required to talk about some topic of the course content for just twenty or thirty seconds, in clear English, and without a script, something desirable seems to happen. The sheer process of fusing personal, *real* language with school facts begins to chip away at the walls... you find out what [the student] is thinking. (p. 57)

⁷ Leamnson (1999) also reported that he was "of the opinion that most good teaching does have elements of performance. In some cases it might even be essential" (p. 69). The issue of teacher as performer emerged from my data collection and will be discussed further in Chapter 4 of this document.

Now, even with Leamnson's (1999) definition of teaching, "learning so defined does not require teaching... But without teaching of any sort, learning is limited entirely to discovery through personal experience" (p. 53). Education, on the other hand, is "learning that has been facilitated by teaching [emphasis removed]" (p. 54). For example, "students need a clear picture of where they are, and where they ought to be" (p. 54). If the teacher only provides a context and direction for the student, s/he has facilitated her/his students' learning and engaged them in an educational experience. With his definitions of teaching, learning, and education, "teaching can be done with or without learning. Learning can be done with or without teaching. Education requires both teaching and learning" (p.54).

Procedural Knowledge, Conceptual Knowledge, and Understanding

In Chapter 1 of this document, it was mentioned that knowledge can be broken down into the categories of procedural knowledge (how to do something) and conceptual knowledge (what is the basic idea being studied?). These two basic types of knowledge were addressed in Hiebert and Carpenter (1992). According to Hiebert and Carpenter, procedural knowledge is a sequence of actions requiring only minimal connections, while conceptual knowledge is represented by rich relationships and by connected networks. Both procedural and conceptual knowledge are necessary for "mathematical expertise.

Procedures allow mathematical tasks to be completed efficiently... Conceptual knowledge extends the procedure's range of applicability" (p. 78)⁸.

There is knowledge and there is understanding. Understanding is defined through the representation and structure of information:

A mathematical idea or procedure or fact is understood if it is part of an internal network.... A mathematical idea, procedure, or fact is understood thoroughly if it is linked to existing networks with stronger or more numerous connections.... [U]nderstanding involves recognizing relationships between pieces of information. (Hiebert and Carpenter, 1992, p. 67)

Students bring with them to the classroom their own prior information, and "the goal is for students to build bridges" (p. 68) between that which is known and unknown to them⁹. According to Hiebert and Carpenter, understanding: generates new knowledge and understanding; promotes remembering; reduces the amount of information that must be remembered (students can reconstruct information instead of strictly remembering a body of facts); enhances transfer of knowledge; and influences beliefs.

Procedural knowledge is not enough on its own (Hiebert and Carpenter, 1992), and teaching symbols and cursory steps does not teach meaning (von Glaserfeld, 1996). In fact, many university instructors find their students have no understanding of many of the concepts studied in their courses (Garfield and Ahlgren, 1988). It appears that while students can carry out the procedures involved in probability and statistics, these same students do not have an understanding of many concepts. As a result, "within the

⁸ This paragraph is not meant to imply that procedural knowledge must precede conceptual knowledge nor vice versa.

⁹ The idea of building new knowledge upon a foundation of existing knowledge supports the construction of knowledge, which is discussed later in this chapter.

conceptual underpinnings, the details they have learned or memorized, for whatever use they might be. therefore quickly fade" (p. 46). Both procedural and conceptual knowledge are crucial for understanding (Hiebert and Carpenter, 1992), and knowledge construction by each student promotes conceptual understanding.

Dewey's (1938) Experience & Education

In order to investigate current issues in teaching and learning, I returned to Dewey's (1938) *Experience & Education*, an exposition on education and educational theory that is classic in nature. Dewey philosophized about the transition from old/traditional education to new/progressive education. According to Dewey, "the history of educational theory is marked by opposition between the idea that education is development from within and that it is formation from without" (p. 17). In contrasting the old/traditional model of education with the new/progressive model of education, Dewey posits traditional education as a model of transmission and progressive education as a model of experience.¹⁰

Dewey (1938) broadly described traditional education in the following manner:

The subject-matter of education consists of bodies of information and of skills that have been worked out in the past; therefore, the chief business of the school is to transmit them to the new generation. In the past, there have also been developed standards and rules of conduct; moral training consists in forming habits of action in conformity with these rules and standards. Finally, the general pattern of school organization (by which I mean the relations of pupils to one another and to the teachers) constitutes the school [as] a kind of institution sharply marked off from other social institutions. Call up in imagination the ordinary

¹⁰ Some thirty years later, Paulo Freire (1970/1993), an advocate for social and political change, still identified the dominant model of education as a model of transmission. A brief discussion on Freire's thoughts can be found on page 16 of this document.

schoolroom, its time-schedules, schemes of classification, of examination and promotion, of rules of order, and I think you will grasp what is meant by "pattern of organization." If then you contrast this scene with what goes on in the family, for example, you will appreciate what is meant by the school being a kind of institution sharply marked off from any other form of social organization. (pp. 17-18)

In traditional schooling, the students must have an attitude of "docility, receptivity, and obedience" (Dewey, 1938, p. 18), while teachers become knowledge and skill communicators (transmitters) and rule enforcers. In the traditional model of education, content is static, a finished product which bears no history. As such, "the traditional scheme is, in essence, one of imposition from above and from outside" (p. 18).

Dewey's (1938) progressive education includes students as participants in their learning by inviting students to *experience* learning. This model of education does not have to reject the knowledge and skills of the teacher. However, by basing education upon personal experience, the progressive model of education "may mean more multiplied and more intimate contacts between the [teacher] and the [students] than ever existed in the traditional school" (p. 21).

While progressive education extols experience as a necessary part of education, "the belief that all genuine education comes about through experience does not mean that all experiences are genuinely or equally educative" (Dewey, 1938, p. 25). It is also important to note that, from Dewey's point of view, traditional education does not exclude experience from teaching and learning, but the experiences are different. The experiences in traditional schooling are more passive than they are in progressive education. It's the quality of students' experiences that is important to their learning, and

the idea in progressive education is to provide engaging experiences that make students desire future experiences.

In practice, progressive education is more difficult than traditional education, because it is harder to provide students worthwhile, challenging, engaging, and meaningful learning experiences than it is to provide them passive learning experiences. An active experience exists because of an interaction between an individual and her/his environment, and the teacher in progressive schooling must provide an environment in which worthwhile, challenging, engaging, and meaningful experiences can flourish.

In fact, the role of the teacher changes dramatically from what it is in traditional education to what it can be in progressive education. No longer is control 'owned' by the teacher; rather, all members of the classroom share control. When the teacher is in sole control of the classroom, "the teacher necessarily act[s] largely from the outside, not as a director of processes of exchange in which all ha[ve] a share" (Dewey, 1938, p. 59). The role of the teacher shifts from that of an "external boss or dictator" (p. 59) to that of a "leader of group activities" (p. 59). The guidance provided by the teacher during meaningful, purposeful activities and experiences becomes "an aid to freedom, not a restriction upon it" (Dewey, 1938, p. 71)

In sum, Dewey (1938) asserted that "education in order to accomplish its ends both for the individual learner and for society must be based upon experience" (p. 89). At the same time, Dewey acknowledged that "the road of the new education is not an easier one to follow than the old road but a more strenuous and difficult one" (p. 90).

However, Dewey believed that by embracing a model of education through experience, we would have education in reality and not just in name.

Constructivism

Traditional teaching treats learning as a transfer of information from the teacher to the student. When taught in a traditional manner, statistics becomes a body of facts and procedures separate from the student's existing knowledge of other subjects. In the following excerpt, Airasian and Walsh (1997) compare this old/traditional view of knowledge with a new/progressive view of knowledge:

In the old view, knowledge is considered to be fixed and independent of the knower. There are "truths" that reside outside the knower. Knowledge is the accumulation of the "truths" in a subject area. In sharp contrast, the constructivist view rejects the notion that knowledge is independent of the knower and consists of accumulating "truths." Rather, knowledge is produced by the knower from existing beliefs and experiences. All knowledge is constructed and consists of what individuals create and express. Since individuals make their own meaning from their beliefs and experiences, all knowledge is tentative, subjective, and personal. Knowledge is viewed not as a set of universal "truths," but as a set of "working hypotheses." Thus constructivists believe that knowledge can never be justified as "true" in an absolute sense. (Airasian and Walsh, 1997, p. 445)

Constructivism may represent a shift from the old/traditional education to the new/progressive education as discussed by Dewey (1938). The advocacy of constructivism has grown in an effort to overcome the shortfalls, including the passiveness, of traditional education in a search for better ways to teach and learn (Perkins, 1999). In fact, "in a broad sense, constructivism represents a shift in the perspective...from a view in which truth is a given to a view in which it is constructed by individuals and groups" (Airasian and Walsh, 1997, p. 445).

In mathematics and science, individuals and groups have developed many 'working hypotheses' over many years. Instead of creating new hypotheses, students in introductory statistics courses re-create these 'working hypotheses.' Following the assumption that all knowledge and understanding of the discipline of statistics is constructed, the teacher of introductory statistics cannot merely act as a transmitter of facts and procedures. Instead s/he must act as a facilitator of knowledge construction resulting in understanding, encouraging students to be active participants in the learning process (Moore, 1993).

Constructivism as an Educational Paradigm

Paradigms are basic belief systems based on certain ontological, epistemological, and methodological assumptions (Guba and Lincoln, 1994). The philosophical beliefs that differ among different paradigms have been the centers of many debates over the years. Constructivism is an educational paradigm and, as such, may be represented by an ontology, an epistemology, a methodology, and a pedagogy (Ernest, 1996). In this section, I define the terms 'ontology,' 'epistemology,' 'methodology,' and 'pedagogy' and state the ontological, epistemological, methodological, and pedagogical assumptions that are the basis for this research.

An **ontology** is "a theory of existence concerning the status of the world and what populates it" (Ernest, 1996, p. 337). Ontology involves the question "What is the form and nature of reality and, therefore, what is there that can be known about it?" (Guba and Lincoln, 1994, p. 108). If there is a "real" world out there, can "truth" be known? For the

purposes of "The Quest for the Constructivist Statistics Classroom," I investigate the teaching of introductory statistics, which is the teaching of existing concepts and procedures and not the creation of new concepts and procedures. Assuming then that there are concepts and procedures that introductory statistics students need to learn, the focus of this research is on epistemology, methodology, and pedagogy and not on ontology.

An **epistemology** is a theory of the nature of knowledge (Ernest, 1996, p. 337) and involves the question "What is the nature of the relationship between the knower or would-be knower and what can be known?" (Guba and Lincoln, 1994, p. 108). Airasian and Walsh (1997) view constructivism as "an epistemology, a philosophical explanation about the nature of knowledge" (p. 444). Airasian and Walsh (1997) add:

Although constructivism might provide a model of knowing and learning that could be useful for educational purposes, at present the constructivist model is descriptive, not prescriptive. It describes in the broadest of strokes the human activity of knowing and nowhere specifies the detailed craft of teaching. It is important to understand at the outset that constructivism is not an instructional approach; it is a theory about how learners come to know. Although instructional approaches are typically derived from such epistemologies, they are distinct from them....

Constructivism describes how one attains, develops, and uses cognitive processes. Multiple theories, such as those of Piaget and Vygotsky, have been proposed to explain the cognitive processes that are involved in constructing knowledge. While constructivism provides the epistemological framework for many of these theories, it is not itself an explanation for the psychological factors involved in knowing. (pp. 444-445)

For the purpose of this research, I assume that, while there are several ways to acquire knowledge (e.g., behaviorism, information processing, constructivism), the best way to acquire knowledge is through knowledge construction.

Assuming that knowledge construction is the preferred way for students to acquire knowledge, I then investigate the methodologies and pedagogies the participants use in their teaching, examining the degree to which these statistics educators support knowledge construction. For the purposes of this research, a **methodology** is "a theory of which methods and techniques are appropriate and valid to use to generate and justify knowledge, given the epistemology" (Ernest, 1996, p. 337). A **pedagogy** is "a theory of teaching, the means to facilitate learning according to the epistemology" (Ernest, 1996, p. 337). The instructional strategies that are analyzed in this document are pedagogies used by the participants based upon each participant's methodology for teaching introductory statistics.

Cognitive and Social Constructivism

Constructivism, a theory that also supports Dewey's (1938) idea of experience in education, is a theory of knowledge acquisition that stemmed from the work of Piaget and Vygotsky (Garfield, 1995; Scheurman, 1998). Both Piaget and Vygotsky examined student-centered instructional philosophies and believed that experience is important in student learning (Steinhorst and Keeler, 1995). I believe that the employment and interpretation of Piagetian and Vygotskian beliefs by other researchers are more relevant to my work than are the direct teachings of Piaget and Vygotsky. Thus, in the following paragraphs, I present a discussion of the work of Piaget and Vygotsky as written about by other researchers.

Scheurman (1998) posited that "the most influential figure in cognitive constructivism is Jean Piaget" (p. 8). In developmental/cognitive constructivism, emphasis is placed on the individual student as meaning maker—"the individual student is considered to be the meaning maker, with the development of the individual's knowledge being the main goal of learning" (Airasian and Walsh, 1997, p. 445).

According to Scheurman (1998), Piaget:

Believed that people develop universal forms or structures of knowledge (i.e., prelogical, concrete, or formal) that enable them to experience reality. This view holds that while an autonomous 'real' world may exist outside the learner, he or she has limited access to it. The emphasis in learning is on how people assimilate learning new information into existing mental schemes, and how they restructure schemes entirely when information is too discrepant to be assimilated. (p. 8)

The learner's access to the 'real' world is, in a sense, self-limited by her/his experiences to date. The disequilibrium caused by encountering new knowledge comes only when there is disagreement or conflict between the 'real' world and the learner's beliefs and ideas about the 'real' world. New learning in cognitive constructivism is based on Piaget's theory of equilibration, the process of restoring equilibrium through assimilation or accommodation of new knowledge.

Piaget's theory of equilibration is the "development of intelligence as a sequence of successive disequilibria followed by adaptations leading to new states of equilibrium" (Shulman, 1970, p. 41). The introduction of new learning causes disequilibrium to occur. When in a state of disequilibrium, the student can either assimilate or accommodate the new knowledge. If the new knowledge fits into the student's existing knowledge web, s/he can assimilate the new knowledge into this already existing web of thoughts and theories. If the new knowledge does not fit into the student's existing knowledge web,

s/he must accommodate the new knowledge into the existing knowledge web by adjusting her/his existing thoughts and theories to include the new knowledge. The equilibration process is a personal process as students assimilate or accommodate new knowledge into their existing individual bodies of knowledge.

Piagetian theory leads to the role of teacher as facilitator of knowledge:

If, as Piaget suggested, knowledge is acquired when cognitive stability is directly challenged, then the primary role of the teacher as facilitator is to pose problems that stretch learners to a point of intellectual disequilibrium (perturbation). Once this point is reached, the teacher provides students with opportunities to manipulate objects and work together on solving problems (action), and to think about and discuss new-found properties of 'reality' as they experience it (reflective abstraction). (Scheurman, 1998, p. 8)

Scheurman (1998) also asserted that "the most influential figure in the social constructivist camp is Lev Vygotsky" (p. 8). From the point of view of this modern researcher, by:

Accepting Piaget's view of how individuals build private understandings of reality through problem solving with others, Vygotsky further explained how social or cultural contexts contribute to a *public* understanding of objects and events. In this view, reality is no longer objective, while knowledge is literally co-constructed by, and distributed among, individuals as they 'interact with one another and with cultural artifacts, such as pictures, texts, discourse, and gestures.' (p. 8)

As such, social constructivism places emphasis on the social construction of knowledge—"knowledge is seen as constructed by an individual's interaction with a social milieu in which he or she is situated, resulting in a change in both the individual and the milieu" (Airasian and Walsh, 1997, p. 445).

Vygotsky is also known for his zone of proximal development, which is more of a social process than Piaget's equilibration. According to Giraud (1997), the zone of

proximal development "poses that learners gain knowledge through interaction with more knowledgeable others" (paragraph 5). The zone of proximal development is similar to the idea of scaffolding where others assist learners in their knowledge construction. A scaffold used in construction or painting is a temporary structure that allows the worker to reach new heights. Similarly, the zone of proximal development provides a temporary support system for the learner until the learner has reached a new understanding of the discussed concept.

Sometimes another student can serve as a 'more knowledgeable other' for a student; however, many times the teacher serves as the 'more knowledgeable other' for all of the students. For example, activities in which students work together could be seen as pointless if none of the students in the group is a 'more knowledgeable other.' However, when students work together in groups, teacher-guided lessons serve to provide guidance for the students working together and the teacher can interact with each group of students while walking around the classroom and interacting with the students.

Vygotskian theory leads to the role of teacher as collaborator:

If, as Vygotsky suggested, cognitive development is 'the transformation of socially shared activities into internalized [thought] processes,' then the primary role of the teacher as collaborator is to monitor classroom learning and participate actively with students in its evolution. (Scheurman, 1998, p. 8)

In this way, the teacher may serve as a more knowledgeable other in the zone of proximal development.

Scheurman (1998) also mentioned that social constructivism leads to two recommendations on the nature of teaching:

First, what teachers have traditionally viewed as errors in student thinking should be understood as misconceptions that both indicate a student's readiness to learn and offer an entry point for teachers to provide scaffolding (expert support) for that learning. Second, students should have frequent opportunities to interact with peers and more experienced people, including the teacher, who becomes another collaborator in the creation of meaning. (p. 8)

Again, social constructivism supports Vygotsky's zone of proximal development.

Basic Tenets and Principles of Constructivism

Constructivism is about the way that individuals arrange building blocks of knowledge to make sense to them. Knowledge is built from preexisting pieces, and understanding is built upon previous understanding (Ernest, 1996). Like architecture, without a foundation the construction is weak. Moreover, each foundation of knowledge is 'personalized' to the conceptual web it lays beneath.

Constructivism involves the learner, the knowledge, and the relationship between the learner and the knowledge (Bettencourt, 1993). The process of knowledge construction is necessitated by our interaction with the world: "we construct knowledge in order to deal with our experience" (p. 40). Knowledge is, therefore, "created by people and influenced by their values and culture" (Scheurman, 1998, p. 6). This is in contrast to

The behaviorist belief that knowledge exists outside of people and independently of them, and that the major goal of a good education is to instill in students an accepted body of information and skills previously established in others. (Scheurman, 1998, p. 6)

Brooks and Brooks (1993) identified five central tenets of constructivism.

According to Brooks and Brooks, constructivist teachers:

1. seek and value their students' points of view;
2. structure lessons to challenge students suppositions;
3. recognize that students must attach relevance to the curriculum;
4. structure lessons around big ideas and not around small bits of information; and
5. assess student learning, not as a separate event, but as an integral part of daily life in the classroom.

Crawford and Witte (1999) identified teaching and learning in context as "a fundamental principle of constructivism" (p. 35). Crawford and Witte specified the following five strategies for teaching and learning in context:

- Relating—Learning needs to be related to students' prior beliefs and experiences.
- Experiencing—Learning needs to be experienced through exploration, discovery, and invention with the use of manipulatives, problem-solving activities, and/or laboratory activities.
- Applying—Learning needs to be applied "by putting the concepts to use" (p. 36) in realistic exercises and/or problem situations.
- Cooperating—Students need to work together to learn by "sharing, responding, and communicating with other learners" (p. 37)
- Transferring—Students need to use "knowledge in a new context or situation" (p. 38).

Teacher and Learner Roles in Constructivism

When s/he employs instructional strategies that support constructivist theory:

The teacher will no longer be a supplier of information, but he or she will remain very much involved in the learning process, coordinating and critiquing student constructions, building his or her own knowledge of constructivism in the classroom, and learning new methods of instruction. (Airasian and Walsh, 1997, p. 446)

With constructivism, there is an emphasis on students interacting with the new ideas and experiences in learning environments fostered by the teacher, instead of on direct transmission from teacher to student:

Constructivism is based on the fundamental assumption that people create knowledge from the interaction between their existing knowledge and beliefs and the new ideas or situations they encounter. (Airasian and Walsh, 1997, p. 445)

No matter what role the teacher takes on, in contrast to more passive types of instruction, constructivist techniques require a substantial time investment of the teacher and require high cognitive demands of the learners. Some students will find constructivist techniques to be "deceptive and manipulative" (Scheurman, 1998, p. 8) and will want the teacher to just tell them what s/he wants them to know.

Constructivism supports "the central role of the learner in his or her own education" (Brooks and Brooks, 1999, p. 18). Other theories of learning do not view the learner as central to her/his education. One such belief is that "students will learn on demand" (p. 18). This belief "is grounded in the conviction that all students can and will learn the same material at the same time" (p. 18). While some students may indeed be able to construct knowledge in this way, others will not be able to do so.

The "simple truth that lies at the heart of the constructivist approach to education" (Brooks and Brooks, 1999, p. 21) is that "learners control their learning" (p. 21). Educators can control what their students are being taught, but, since learning is a personal process, they cannot control what is being learned. Educators need to accept that "the search for understanding motivates students to learn" (p. 21). In the words of Airasian and Walsh (1997):

Constructivism can also be interpreted as a symbol of the emancipation of teachers from the burden of dealing with the difficult issue of motivation, since many constructivists view the student's sense of ownership of and empowerment over the learning process as providing its own intrinsic motivation. (p. 446)

Perkins (1999) named and described three roles of learners in constructivism: active learners, social learners, and creative learners.¹¹ The active learner is a learner who actively acquires knowledge and understanding through discussion, debate, hypothesizing, and investigation. The social learner is a learner who socially constructs knowledge and understanding "in dialogue with others" (p. 7). The creative learner creates or recreates knowledge and understanding. For the creative learner, it is not enough to just be active; rather, the creative learner needs to experience the rediscovery of theories. Perkins described the relationship among these three types of learners as:

An active role for the learner is basic; in practice, social and creative aspects often accompany this role. However, an active learner does not logically require the other two. Teachers can organize learning experiences in active ways that do not require learners to engage in testing and building knowledge in a social manner or to invent or reinvent theories or viewpoints. (p. 8)

Crawford and Witte (1999) said that the one word that best describes the constructivist classroom is energy. An observer of a constructivist classroom is more likely to: see hands-on activities than lectures; see students discussing solution strategies with peers rather than asking the teacher for the one correct answer and/or method of arriving at the correct answer; and see more group work than individual desk work. This "active engagement requires a classroom that looks different from a traditional mathematics classroom" (p. 34) in both content and structure. For example, "arranging a

¹¹ Perkins (1999) cited philosopher D. C. Phillips (1995) as a source for his three roles of constructivist learners. However, Perkins was the researcher who named these roles active, social, and creative. It was because of this naming that I elected to cite Perkins as a primary source. Even so, I have included bibliographic information for Phillips (1995) in my references.

classroom so that students can work together signals an active learning environment, invites student interaction, and supports a learning community" (p. 34).

Issues of Concern With Constructivism

While the tenets and principles of constructivism imply a heavy undertaking on the part of the teacher and her/his students, constructivism still has its critics. Some critics find constructivism to be "overly permissive" (Brooks and Brooks, 1999, p. 22), letting the whims of students dictate the curriculum. Critics also feel that:

[C]onstructivist approaches to education...lack rigor. The concern here is that teachers cast aside the information, facts, and basic skills embedded in the curriculum... in the pursuit of more capricious ideas. (p. 22)

The critics' concern about lack of rigor with constructivist approaches to education centers around a concerned lack of precise and careful thinking by students. However, constructivist approaches to education require "the rigorous intellectual commitment and perseverance of students" (p. 22). Not only is there precise and careful thinking ('rigorous intellectual commitment') in the constructivist classroom, but there is hard work ('perseverance') as well. Organizing a constructivist classroom is not easy because:

Constructivist teachers recognize that students bring their prior experiences with them to each school activity and that it is crucial to connect lessons to their students' experiential repertoires. Initial relevance and interest are largely a function of the learners' experiences, not of the teacher's planning. Therefore, it is educationally counterproductive to ignore students' suppositions and points of view....

Moreover, constructivist teachers keep relevant facts, information, and skills at the forefront of their lesson planning. They usually do this within the context of discussion about bigger ideas. For example, the dates, battles, and names associated with the U.S. Civil War have much more meaning for students when introduced within larger investigations of slavery, territorial expansion, and economics than when presented for memorization without a larger context....

[C]urriculums address *what* students learn. Constructivism, as an approach to education, addresses *how* students learn. The constructivist teacher, in mediating students' learning, blends the *what* with the *how*.... Constructivist classrooms demand far more from teachers and students than lockstep obedience to prepackaged lessons. (pp. 22-23)

It is also important for educators not to "fall into the trap of believing that constructivist instructional techniques provide the sole means by which students construct meanings" (Airasian and Walsh, 1997, p. 447), since "no single teaching method ought to be used exclusively" (p. 447). Instead it is the task of the teacher to:

Find the right balance between the activities of constructing and receiving knowledge, given that not all aspects of a subject can or should be taught in the same way or be acquired solely through 'hands-on' or student-centered means. (p. 447)

Constructivism is not the *only* way, but one of many ways to learn.

The Statistics Classroom That Supports Constructivism

A gap exists in the perceptions of learning statistics between those who teach and those who learn statistics (Gordon, 1995). Those statistics instructors who successfully learned statistics when taught in a traditional manner may not have an inherent drive to find alternative ways to teach: 'If traditional methods worked for me, they will certainly work for my students.' Those statistics instructors who had a difficult time learning statistics in traditional statistics classes may think: 'I can improve my (traditional) teaching methods to be better than the way I was taught.' Whatever the instructor's experience, the gap between her/his perception of learning statistics and her/his students' perceptions of learning statistics is all the more reason to support constructivist philosophy in the classroom.

Some Strategies for Use in the Constructivist Statistics Classroom

The basic concepts of statistics are hard for introductory statistics students:

As teachers we consistently overestimate the amount of conceptual learning that goes on in our courses, and consistently under-estimate the extent to which misconceptions persist after the course is over. (Cobb, 1992, p. 10)

These statements give us insight into "part of what makes learning hard and lecturing often ineffective" (p. 9). In addition, learning is constructive (p. 10). In light of this, "teachers of statistics should rely much less on lecturing" (p. 10) and, instead, foster active learning to allow students to discover existing knowledge and construct their understanding of said knowledge (Cobb, 1992; Garfield, 1995; Scheaffer, Gnanadesikan, Watkins, and Witmer, 1997).

The following strategies support constructivist philosophy and can be used in the statistics classroom:

1. The introduction of topics through activities and simulations (Garfield, 1995; Garfield and Ahlgren, 1988) and demonstrations based on class-generated data (Cobb, 1992).
2. Group problem solving and discussions (Cobb, 1992; Garfield, 1995).
3. Group or individual projects (Cobb, 1992; Garfield, 1995).
4. Written and oral presentations (Cobb, 1992; Garfield, 1995).
5. Activity-based courses (Garfield, 1995).
6. Employing "corrective-feedback" to address student misconceptions (Garfield, 1995).
7. Having students make predictions about the outcomes before they investigate the phenomenon (Garfield, 1995).
8. Allowing students many ways to represent their knowledge, think time and wait time, and interaction time with peers (Hatano, 1996; Tobin and Tippins, 1993).

Some of these strategies have already been employed with the following results:

1. Student ability to transfer knowledge increases with more time spent on developing understanding (Hiebert and Carpenter, 1992).
2. Increased productivity, improved attitudes, increased understanding, and (sometimes) increased achievement are benefits of the use of small groups (Garfield, 1995; Good, Mulryan, and McCaslin, 1992).
3. Open-ended problems allow more student learning than do goal-specific problems with one correct answer (Brooks and Brooks, 1993; Garfield, 1995).
4. Active learning provides realism, engages students in the learning process, and makes some concepts concrete (Garfield, 1995; Scheaffer et al., 1997).

Examples of Constructivism in Practice

Joan Garfield has been an active proponent of implementing instructional strategies that support constructivist philosophies in the statistics classroom. Two of the techniques Garfield has employed and written about include cooperative learning (Garfield, 1993) and using assessment to improve student learning (Garfield, 1994). Other statistics education researchers have studied active learning (e.g., Scheaffer et al., 1997; Sowe, 1995; Steinhorst and Keeler, 1995) and cooperative learning (Keeler and Steinhorst, 1995). The following paragraphs discuss active learning and cooperative learning in practice.

"Learning is situated in activity" (Bradstreet, 1996, p. 73). Active learning, making connections, and drawing upon past experiences are general education pedagogical themes that fit naturally with statistics (Bradstreet, 1996; Cobb, 1991; Rumsey, 1998; Snee, 1993). Students need to see demonstrations of the practical usefulness of statistics in order to be assured that statistics is important in the real world (Hatano, 1996; Sowe, 1995). Activities can be used both to introduce a concept and to put a concept into practice (Rumsey, 1998). But when designing active learning

experiences, we need to consider students' emerging knowledge as well as their existing knowledge (Steinhorst and Keeler, 1995).

Exploratory techniques can be used purposefully and extensively when we relate data collection and analysis to solving a real problem (Scheaffer et al., 1997). George Cobb and David Moore (1997) suggested that "students like exploratory analysis and find that they can do it, a substantial bonus when teaching a subject feared by many" (p. 815). Cobb and Moore also said, "judgment is formed by experience with data" (p. 816). In fact, "unexpected discoveries *that students make themselves* have the strongest impact on learning and remembering" (Sowe, 1995, paragraph 27).

Studying active learning, Scheaffer et al. (1997) found that "the typical student gains understanding by doing activities that is not gained by reading the text or listening to a lecture" (paragraph 51). Activities are good for several reasons including making concepts concrete and engaging students in the learning process (Garfield, 1995; Scheaffer et al., 1997). In addition, in-class collection of data provides realism, meaningfulness, and ownership that textbook problems cannot provide (Scheaffer et al., 1997).

Cooperative learning is one example of active learning in the classroom and represents an opportunity for students to socially construct their knowledge together in small groups. Each group works as a team striving for the common goal of understanding statistics. Sometimes cooperative learning offers opportunities for peer teaching; other times, cooperative learning shows that "two heads are better than one" as the group can learn and achieve far more together than each member could individually

(Garfield, 1993). The success of the group over the individual comes from "positive interdependence" (Johnson, Johnson, and Smith, 1991, as cited in Garfield, 1993), the encouragement and facilitation of each group member's efforts by the other group members (Garfield, 1993).

When they experimented with cooperative learning, Keeler and Steinhorst (1995) found several positive outcomes. Students who worked cooperatively in groups had higher course completion rates and improved performance on tests and papers. In addition, students who worked in cooperative learning groups had improved attitudes towards both the course and statistics in general (Keeler and Steinhorst, 1995).

Examining Our Teaching

According to Tobin and Tippins (1993), "constructivism has been used as a referent to build a classroom that maximizes student learning" (p. 7). In a classroom that supports constructivism, the teacher is a mediator and facilitator of student learning, focusing on the learners rather than the discipline (Tobin and Tippins, 1993). Teaching that supports constructivist philosophies requires a greater interaction between teachers and students than does direct instruction. The move from traditional teaching to teaching that supports constructivism is a process of reform. The following paragraphs discuss the importance of the teacher-student relationship, discussion and group work, and questioning in classrooms that support constructivism.

Building a healthy relationship between teacher and students is important for the "high-quality statistical education of nonstatisticians" (Bradstreet, 1996, p. 72), including

introductory statistics students. A healthy relationship between teacher and students will produce a quality statistical education, no matter what additional resources are available; an unhealthy relationship cannot produce a quality statistical education, even with unlimited additional resources (Bradstreet, 1996). A good relationship between teacher and students can be characterized by caring, commitment, communication, and chemistry (Davenport, 1984). Even if a statistics instructor cares about and is committed to statistics education, "achieving effective communication and experiencing explosive chemistry with a group of students is tricky" (Bradstreet, 1996, p. 72). It is an active partnership between the teacher and the student, with both sharing responsibility for success or failure, that can result in high-quality statistical education (Bradstreet, 1996).

While attempting to create a feminist statistics classroom, Beverly Ayers-Nachamkin (1992) supported ideas that seem to relate to Bradstreet's (1996) idea of the importance of a good relationship between teacher and students. Ayers-Nachamkin suggested de-emphasizing the professor as an authority figure as well as increasing the sense of cooperative learning and decreasing the amount of competitiveness. In her own classroom Ayers-Nachamkin never claimed to be an expert in statistics and invited her students to point out her mistakes (e.g., mathematical errors or misapplication of methods), since they were all in the experience together. She emphasized her role as a partner with her students in the learning process.

In addition to a healthy teacher-student relationship, Craig Nelson (1996) suggests that effective discussion and structured, student-student group work can help student performance. The teacher's role in effective group work is, according to Nelson to

"make sure that the students are prepared for the discussion, that the students participate constructively and fairly evenly, and that the students are addressing questions that are sufficiently challenging" (p. 167).

Questioning is also an important part of the teacher's role in a statistics classroom that supports constructivism. Rather than evaluating questions, the teacher probes with questions, hoping students will learn for themselves (Peterson and Barnes, 1996). Peterson and Barnes (1996) said probing with questions is critical for the development of both mathematical (and statistical) understanding and good learner habits. Probing questions emphasize process over product, but within the context of developing processes that will lead to correct answers. The instructor needs to pose problems and ask questions that find out what the students understand instead of just what the students know how to calculate: "A good conceptual question will have just the right amount of ambiguity" (Steinhorst and Keeler, 1995, paragraph 2).

Assessment in the Constructivist Statistics Classroom¹²

Many students in introductory statistics courses are there because they are required to be there, have no intrinsic interest in statistics, and view the course as one of the last hurdles in the way of obtaining a degree (Gal and Ginsburg, 1994). These students tend to put more of an emphasis on assessment than they would if they were genuinely interested in the course (Hubbard, 1997). In spite of this emphasis, these

¹² While there is not a body of literature that exists about constructivist assessment per se, I do believe that the discussion that follows addresses assessments that support the construction of knowledge rather than rote memorization.

students have been trained to be minimalists in their approach to the assessments. They have learned that they can pass exams by memorizing standard procedures and rules, based on what has been presented in lecture.

For many instructors, assessing becomes a simple matter of asking the same questions over and over again. Exams that ask the same types of questions over again merely reward test taking and not understanding. When students know the types of questions that will be asked on an exam, they are able to match the statistical procedure needed with the correct problem type. The students do not have to understand any of the concepts in order to match procedures with problem types. The students are able to solely memorize procedures and have no motivation to drive for conceptual understanding. All we can tell from these types of examinations is that the students know how to match procedure with problem type.

Tobin and Tippins (1993) feel that "traditional assessment practices seem to be associated with teaching roles akin to judging and rewarding" (p. 12). The judging and rewarding that is done relates to how well the students can reproduce work that has been done by someone else. Students become "focused on completing tasks and getting the grade, and learning becomes a by-product of the main activity of the culture" (p. 12). In other words, these students are not learning for learning's sake. To Garfield (1994) traditional assessments "provide a method for assigning numerical scores to determine letter grades but rarely reveal information about how students actually understand and can reason with statistical ideas or apply their knowledge to solving statistical problems" (abstract). Traditional assessments emphasize the answer, not the process (Chance, 1997;

Cobb, 1993; Garfield, 1993; NCTM, 1995). Hubbard (1997) views traditional assessments as reinforcements of memorization of procedures with little to no emphasis on the understanding of concepts.

With these ideas in mind, traditional assessments may only measure how well the students play 'the game.' It does not matter how the students get to the end, just that they have the correct answer when they get there. Memorization of procedures leads students to be able to apply the techniques to questions in the same format. No extrapolation of statistical techniques is likely, and students quickly forget the procedures they have memorized (Hubbard, 1997). These students are not active participants in their learning experience and have no ownership of their knowledge.

As mentioned earlier, students can take an active role in their learning process if they are involved in the construction of their own knowledge. For example, Chance (1997) posits that students make substantial gains in learning when they debate ideas with each other, an idea that supports the notion of constructivism. She wants "students to do much of the discovery for themselves, because what students construct for themselves they will understand better and remember longer" (paragraph 28).

The assessment of the knowledge constructed needs to be as rich as that knowledge construction itself. Ernst von Glaserfeld (1993) claims that assessment that rewards duplication of standard procedures and standard answers can be accomplished through rote learning without conceptual understanding. In the words of Dana and Davis (1993):

Matching student achievement to predetermined objectives is based on an objectivist view that experts know correct answers, and student answers should

reflect those of the experts. If we believe that learning occurs as meaning is given to experiences in light of existing knowledge, then assessment techniques must permit students to express their personal understandings of concepts in ways that are uniquely theirs. We need to find ways to determine a student's depth of understanding. (p. 332)

Here again we encounter an emphasis on students understanding the process over accuracy of the product. However, part of developing an effective understanding of the process is for a student to follow a situation through to a correct answer.

Garfield's (1994) ideas are in line with constructivist theories. She points out that one of the problems with traditional assessments is that these assessments:

Typically test skills in isolation of a problem context and do not test whether or not students understand statistical concepts, are able to integrate statistical knowledge to solve a problem, or are able to communicate effectively using the language of statistics. (paragraph 2)

It is problematic for teaching and learning if students can perform well on tests but cannot extend their knowledge to the 'real world.' Many times students cram or memorize for the exam without regard to understanding the concepts involved and without being able to talk, the next day or the next week, about the statistics they have 'learned.'

Students should "think of statistics as not just plugging numbers into formulas, but as a process for gaining information" (Chance, 1997, paragraph 5). It is more important for students to engage in data exploration and critical thinking than it is for them to plug numbers into formulas. If we desire our students to think critically, then "a mismatch is revealed between traditional assessment and the desired student outcomes" (Garfield, 1994, paragraph 3). Assessment needs to be partnered with learning goals, an

integral part of teaching and learning (Mathematical Sciences Education Board [MSEB], 1993; NCTM, 1995). As an integral part of instruction, "assessment should be a means of fostering growth towards high expectations" (NCTM, 1995, p. 1).

There are many types of assessments, and it is suggested that multiple methods of assessments be used to provide richer and more complete insight into students' understanding (Chance, 1997; Garfield, 1994; NCTM, 1989). We need to ask questions like: "What tasks, done well, would convince me that a student has learned the most important elements of how to think and work like a statistician?" (Cobb, 1993, paragraph 94). Some proposed alternatives to traditional assessments include quizzes, minute papers, journal entries, projects, portfolios, exams, written reports, open-ended questions or problems, and enhanced multiple choice questions (Chance, 1997; Garfield, 1994).

In addition to the individual assessments listed above, it is important for students to be able to 'talk statistics.' This can be accomplished through group work, peer reviews, or oral presentations. Talking to other students about statistics puts the student in a teaching role, putting her/him higher on the learning pyramid.

Craig Nelson (1996) believes that teachers should be flexible, particularly with assessment deadlines. One-shot deadlines for assignments assume that students can master content with little or no feedback in the length of time dictated by the instructor and also assume that students do not have concerns outside of their schoolwork with which to deal. But, reflection and self-assessment are also important aspects of learning and assessment.

Some instructors practice progressive grading, a cyclic process including submission, feedback, and resubmission carried on until both the student and the instructor are satisfied with the final product (Chance, 1997; Garfield, 1994). Diana Erchick (personal communication, 1997) wants her students to have a final product that is good and useable and has found that progressive grading helps her students achieve that goal. Cobb (1993) agrees that we should not just assess what the students do but should include their assessment of how well they and others have done.

Some specific examples of alternative assessments include:

- Asking students to make up a question based on a statistical concept(s) (Hubbard, 1997).
- Changing one aspect of a standard situation and asking students how this change will affect the solution of the problem (Hubbard, 1997).
- Highlight the concepts covered throughout the course and ask the students to work on a project throughout the term on a specific set of data. This project may not include all of the concepts covered in the course, but the students would have to make the decision as to which concepts were included and which were not, providing a rationale for inclusion or noninclusion (Chance, 1997; Diana Erchick, personal communication, 1997).

Ernst von Glaserfeld (1993) suggests that we could:

Present the students with a problem they have not encountered before (in the sense that it is conceptually different), observe (infer) how they conceptualize it, and judge what they do to solve it. It is each student's approach that is more important than the particular solution. By observing the conceptual tools the student is using, one can usually get some inkling as to how far she is on the way towards a workable conceptual network for the particular area. (pp. 36-37)

Here we can see that von Glaserfeld is suggesting the process, not the product, is most important in assessment. Only by seeing the process at work can we assess whether or not the student has conceptual understanding. But again, an effective process should produce a correct answer. Accuracy of the product is certainly not unimportant. Take,

for example, the recent Mars Polar Lander that, despite what was *thought* to be an accurate process of construction, did not send back results to Earth. In this situation, no matter how worthwhile the process of developing the Mars Polar Lander was, the bottom line is that the Lander failed to send communications about Mars back to Earth because there were flaws in the process¹³.

There are many things that instructors can recognize and do in order to emphasize the importance of process. For example, the point distribution for a particular problem should have an emphasis on explanations (Chance, 1997). In this situation, students would realize that the instructor puts on emphasis on the process over the product and could perhaps learn that it is the process that is most important. In addition, instructors need to provide constructive comments and feedback: "students need to receive feedback not only on their exam performance, but also constructive indications of their strengths and weaknesses, guidelines for improving their understanding, and challenges to extend their knowledge" (paragraph 1). The assessment should be a dialogue between student and instructor, with the goal being increased conceptual understanding of the student.

In the dialogue of assessment, it must be clear to the students that conceptual understanding is more important than duplication of standard procedures. Students need to understand both the purpose and the importance of assessment. Students need clearly

¹³ For more information on the Mars Polar Lander please refer to NASA's official website for the Lander <http://mpfwww.jpl.nasa.gov/msp98/index.html>

articulated goals and objectives (Chance, 1997; Garfield, 1994), but not so explicit that the task becomes so oversimplified that it becomes one of procedure and not conceptual understanding (Tobin and Tippins, 1993).

As we move towards improved assessment techniques, we should keep in mind Webb and Romberg's criteria for good assessment (as cited in Garfield, 1994). Good assessment should:

- Provide information that will contribute to decisions regarding the improvement of instruction.
- Be aligned with instructional goals.
- Provide information on what students know.
- Supplement other assessment results to provide a global description of what students know. (paragraph 6)

To these criteria I add that assessment needs to be a learning experience as well.

When creating any assessment, focus should be on what concepts to assess, the purpose of the assessment, who will do the assessment (e.g., instructor, student, peers), the method of assessment, what action will be taken, and the feedback that will be given to the student (Garfield, 1994). The purpose of the assessment and the instructional objectives combined should be the driving force behind the type of assessment selected, keeping in mind that we need to assess what we value. If the process involved in conceptual understanding is important, an assessment instrument should illustrate the processes that the students undergo when given a statistical concept in a problem situation. It is our challenge to find good conceptual questions that will show the conceptual understanding of the students.

The Use of Technology in the Constructivist Statistics Classroom

In this section, I begin with a discussion of the use of video in the statistics classroom and move on to the use of other technology in the statistics classroom. Throughout the discussion of technology mention is made to how each piece of technology supports student construction of knowledge.

Moore (1993) contains a nice discussion of the role of video in statistics courses, including the history of video and the potential uses for video. According to Moore, the original television instruction in the late 1950s-early 1960s lacked an interaction between the instructor and the students. When video was used in classrooms that had live teachers, the passive nature of the video was striking in contrast to the active learning that could have been happening.

Treating video solely as another way to transfer information to students from an authority figure, therefore, does not do our students justice. We need to use some of the positives of video, including its ability to elicit feelings and emotions. As Moore (1993) said, "Video, when done well and used wisely, shows rather than tells" (p. 174). Moore suggested that video can be used to introduce and motivate a topic, start a discussion, ask an analysis, introduce a simulation, and explain a hard topic.

Of course, technology in statistics goes beyond video: the practice of statistics is heavily intertwined with technology. Many a consulting job has been done using high-powered technology. Since technology is a tool of the statistician, it makes sense that learning statistics involve learning to use the tools of the statistician (i.e., authentic instruction). Additionally, since the practice of statistics "is technology-based, cuts

across many disciplines, and is carried out by teams rather than by individuals" (p. 251), the teaching of statistics should reflect these characteristics as well.

In addition to using technology to provide students of statistics opportunities for authentic instruction, technology can be used to *teach* statistics. In 1993, David Moore was concerned that, despite the advances in software for statistical calculation and graphics, there was a "scarcity of good software designed specifically for teaching statistics" (Moore, 1993, p. 175). Two years later, Moore et al. (1995) still found that despite all of the changes in technology, teaching had changed very little.

Meeker (in Moore et al., 1995) offered the following benefits of technology in the statistics classroom: computers and calculators can remove the plug-and-chug parts of statistics; e-mail can be used as a form of communication with students; lessons, class notes, and activities can be set in an electronic medium; and on-line discussion rooms can be used for students to talk (with or without the professor). According to Meeker, "future technology will permit more improvements in the quality of education, in particular through adapting instruction to the pace and learning style of individual students" (p. 252). In his vision, Meeker sees the instructor's role in a technology-oriented course as meeting with students individually or in small-group discussions.

Joan Garfield (in Moore et al., 1995) had some reservations about the reduction in human interaction by using technology in the classroom:

Human beings are by nature social, interactive learners. We check out our ideas, argue with others, bounce issues back and forth, and increase our understanding of ourselves and others. (p. 253)

It is important to keep interpersonal skills up in classes, especially when we think about the amount of work going on in teams in the corporate world:

We need to explore ways to incorporate technology-based team work into teaching, drawing on the teacher not merely to design courseware, but to be an active facilitator of group work and student learning. (p. 253)

As such, while the use of technology can add to the learning experience in the classroom, we cannot replace the personal interaction between and among teachers and students with technology (Garfield, in Moore et al., 1995).

The potential role of multimedia as an educational tool in the teaching and learning of statistics is a positive one: "multimedia has considerable promise for teaching statistics because it is consistent with major trends in both pedagogy and content" (Velleman and Moore, 1996, p. 217). The image of multimedia proposed by Velleman and Moore included (but was not limited to): video; animations; simulations; manipulations; spoken narrative; sound effects; interaction with the Internet; and software for statistical graphics and calculations.

With multimedia, students can have control over a "highly interactive and individualized environment" (Velleman and Moore, 1996, p. 217). Students can control: the pace of the instruction; review, enrichment, or advancement in concepts; and the type of media that best suits her/his individual learning style. In addition, students are able to do their own analyses and interpret their own results as well as have ownership of the data.

Multimedia emphasizes practical understanding and issues from practice and is better for data and concepts than it is for theory (Velleman and Moore, 1996). In terms

of instructional reform, with the push for active learning and student construction of knowledge (e.g., NCTM, 1989), multimedia allows for students to interact and actively participate in their own learning and supports student construction of knowledge.

What is the role of the teacher with multimedia? Multimedia is not a replacement for the teacher:

The proper goal of teaching technology is not to eliminate the teacher... In practice, the challenge is to organize instruction so that the human teacher, freed from tasks a machine can do as well or better, can concentrate on motivation, interaction, and assessment. (Velleman and Moore, 1996, pp. 224-225)

Multimedia used in the above manner enhances the learning experience in the classroom by allowing the teacher to spend time developing and implementing additional learning opportunities that support student construction of knowledge¹⁴.

Velleman and Moore's (1996) article predated the widespread release of a multimedia package called *ActivStats* (Velleman, 1998a), which was in development at the time the article was published. *ActivStats* supports the vision of the article. David Moore (1997a) wrote a text entitled *The Active Practice of Statistics: A Text for Multimedia Learning* that can be partnered with *ActivStats*. The potential use of these media in introductory statistics course is great¹⁵.

What role does the calculator play? The calculator, like the computer, can reduce the need for tedious calculations and allow more time for discovery and discussion of topics. The TI-83 made by Texas Instruments has the ability to do descriptive and

¹⁴ Here I make the assumption that the teacher is using multimedia to support student construction of knowledge and would therefore foster student construction of knowledge in other learning opportunities.

¹⁵ The use of *Data Desk* partnered with *The Active Practice of Statistics* in Paul Velleman's introductory statistics classroom is discussed in Chapter 5 of this document.

inferential statistics, regressions, statistical graphics, and distributions. The key to using the calculator in the classroom is maximizing its timesaving capabilities without turning it into a 'black box.' By saving time with calculations, the calculator leaves time for constructivism in the statistics classroom.

Going Through "The Change"

With his "gospel of reform" (Moore et al., 1995, p. 254), David Moore discussed a move from Freire's (1970/1993) banking system of education to constructivist teaching. First, the teacher confesses her/his sins of traditional teaching. S/he realizes that traditional teaching has left her/his students with procedural understanding but without conceptual understanding. After confessing her/his sins, the teacher can profess "a new faith: Students bring a complex mix of knowledge and intuition, both correct and incorrect, and learn by constructing their own understanding through interpreting present experiences and integrating them with their existing understanding" (Moore et al., 1995, p. 254). The teacher now realizes that her/his role is to encourage and guide understanding of concepts.

Moore (in Moore et al., 1995) asked how we can actually go about making changes in our teaching. Part of Joan Garfield's response to Moore was that "in order for real change to occur, instructors need to believe that it is important to change their teaching" (p. 256). Instructors need to ask themselves what they want students to come

away with from the course. Garfield mentioned her belief in evolution over revolution, that we gradually change over time, introducing different approaches one at a time and deciding their worth.

Does Constructivism Come With a Guarantee?

Using ideas supporting constructivist philosophy will not guarantee that all students will learn the desired material (Garfield, 1995). Instructors can maximize student learning "if teachers determine what it is they really want students to know and do as a result of their course—and then provide activities designed to help the performance they desire" (p. 32). Constructivism does not dictate what teachers should do; rather, constructivism tells teachers some things that should not be done (von Glaserfeld, 1996).

Constructivism is not a prescriptive method that can be followed. Instead, as a philosophy of learning, constructivism is a theory that allows for the individualization of learning. This is not to imply that the individualization of learning requires that an educator adopt constructivist philosophy. Constructivism is one theory of learning, and educators should support multiple ways of learning in order to reach all students.

However, educators who rely solely on traditional teaching methods cannot reach all students because traditional teaching methods primarily rely on mass knowledge transfer. Knowledge transfer cannot be pure, since knowledge is transformed in the process as it is woven into the existing knowledge of the learner. By examining the existing beliefs and knowledge of each individual learner, a teacher employing

instructional strategies that support constructivism invites the students, as active participants in the learning process, to build upon their own existing foundations of knowledge.

Note: While I strongly support student construction of knowledge, I am not saying that there is no place for lecture and other traditional teaching methods in statistics teaching. In the words of Craig Nelson (1996), "Please note that I did not say that lecture and other traditional techniques have no place in a well-taught course" (p. 172). There are certain types of (procedural) knowledge, like using the parking garage pass, that probably do not need to be constructed in order to be employed. Additionally, the level and intrinsic motivation of the students in the class may impact the effectiveness of lecture. Lecturing is not all bad, but it is better for advanced classes than for elementary undergraduate statistics (Moore, 1993). You will find in Chapter 5 of this document that each of the four participants in this study successfully used lecture as one instructional strategy in their repertoire of instructional strategies.

Summary

This chapter has provided a review of literature relevant to "The Quest for the Constructivist Statistics Classroom." Chapter 4 of this document enumerates the instructional strategies that are actually being employed in the introductory statistics classrooms of four accomplished statistics educators and investigates the ideas and beliefs of these instructors. Then in Chapter 5 of this document, an analysis of these instructional strategies, ideas, and beliefs of these instructors is conducted. This analysis

is done through the lens of constructivism, in light of both the discussion of constructivism in this chapter and my working definition of constructivism (as described on page 92 in Chapter 3 of this document).

CHAPTER 3

METHODOLOGY

Introduction

The methodology discussion in this chapter addresses data collection and analysis as well as other aspects of method. An audit trail helped document the navigation through my study. Member checks served as a way for my participants to make sure that I interpreted their words and actions correctly. Issues of credibility and trustworthiness were important in establishing for others the worth of my study. Of course, politics and ethics also factored into the picture. In this chapter, I address the issues mentioned above and include a global description of and a time line for my study.

Why Qualitative Methods?

The following paragraphs address the reason qualitative research methodology was used for "The Quest for the Constructivist Statistics Classroom." Like the field of quantitative research, the field of qualitative research includes many different methodologies that are each applicable to certain research situations. Some of the common practices in qualitative research have been employed and documented in this

research. Since the methodologies used in this research represent only a subset of qualitative methodologies, interested readers are encouraged to read any of the works cited in this chapter.

There are major differences between qualitative and quantitative research with respect to both purpose and methodology¹⁶. In quantitative research, one goal is to study a sample from a population of interest and to generalize sample results to the population as a whole. It is not the intent of qualitative research to make such generalizations to the population as a whole. Instead, by preserving the context of the data, qualitative research attempts to provide rich insight into the studied situation (Guba and Lincoln, 1994). In some sense, qualitative research provides another dimension (as opposed to or in addition to quantitative research) through which to examine data and phenomena.

To what end was this research conducted? Why bother to do a study that is not generalizable? What is there to gain from this study? My intention is for those who read the results of this study to reflect upon and critically examine their own teaching of introductory statistics. Instead of generalizability, this study has potential for transferability, the intent of which is for readers to make judgments about the study's results in light of their own situations (Mertens, 1998). With generalizability, it is up to the researcher to make inferences to the population of study based on results from the sample data; with transferability, it is up to the reader to construct a link between the research and her/his situation.

¹⁶ In addition to paradigm differences between qualitative and quantitative research, there are also competing paradigms in qualitative research (see Guba and Lincoln, 1994).

Particular to "The Quest for the Constructivist Statistics Classroom," it is up to the reader to construct a link between this dissertation and her/his own classroom. Perhaps there will be something in this document that was said or done by a participant that will give readers of this document ideas for their own teaching. The ways in which a reader can use the findings of this study are limited by the reader her/himself.

Regardless of the research paradigm to which scholars adhere, the research methods must match the type of questions being asked. Recall my research questions:

- What instructional strategies are being used in the statistics classroom?
- What are the results of an analysis of these instructional strategies when the analysis is grounded in a constructivist perspective?

While the instructional strategies being used in the introductory statistics classroom could be quantified with an instrument like a checklist of what 'should be done' in the statistics classroom, I chose not to utilize such an instrument. Instead, I looked into the classrooms of my participants and opened my mind to whatever I was to find. My intention was to explore and describe what I saw in the classrooms of my participants. What I found in the classrooms and the words of my participants did and did not fit with my own research and experience in statistics education. My review of the literature indicated that many mathematics and statistics educators support constructivism in theory. The intention of my research was to examine the use of this learning theory in practice with an analysis of my findings through the lens of constructivism¹⁷.

¹⁷ It is important to note that since I was not an unbiased observer for this research, my own beliefs about constructivism and the degree to which particular instructional support constructivism do impact my analysis through the lens of constructivism. To quote Suzanne Damarin, "speaking as a feminist follower of Sandra Harding and others (and as a qualitative researcher): There is no unbiased research" (personal communication, May 22, 2000).

A Global Description of My Study

This study was conducted over the period of 1.5 years during which I was immersed in the process of study development, participant solicitation, data collection, and data analysis. I traveled to my research sites to collect data for "The Quest for the Constructivist Statistics Classroom." Each site visit included two interviews of the participant (one pre-observation interview and one post-observation interview) as well as two observations of the participant's class meetings. The data collection and data analyses processes will be addressed later in this chapter. Figure 3.1 is a time line of this study.

Time Line	
February 1-15, 1999	Human subjects review
February 16-28, 1999	Participant solicitation
March 1-16, 1999	E-mail questionnaires sent out
March 16-31, 1999	Initial analysis of e-mail responses, including development of additional interview questions that arose from the e-mail responses
April 5-8, 1999	Site visit—Cornell University
April – May, 1999	Transcription of interview tapes
April, 1999 – April, 2000	Initial analysis of interviews and observations
July 11, 1999	Peer review of all writings
July 12 – August 12, 1999	One participant dropped out of study since she would not be teaching in the fall
August 18-25, 1999	Solicitation of additional participants
August – October, 1999	E-mail questionnaires sent out to new participants
	Initial analysis of e-mail responses of new participants, including development of additional interview questions that arose from the e-mail responses
August, 1999 – January, 2000	Writing of realist tales
September 6-10, 1999	Site visit—Purdue University
September 27-30, 1999	Site visit—Swarthmore College
October 31 – November 3, 1999	Site visit—California Polytechnic State University
September – November, 1999	Transcription of interview tapes
November – December, 1999	E-mail follow-ups
February, 2000	Member checks of realist tales
January – April, 2000	Coding of the data
	Analysis through the lens of constructivism
	Writing of conclusions/implications chapters
	Preparation of dissertation draft for defense
April 21, 2000	Final Oral Examination Report given to the graduate school
May 9, 2000	Defend dissertation
May, 2000	Revise dissertation
June 2, 2000	Final documents submitted to graduate school
June 9, 2000	Graduation!

Figure 3.1: A Time Line for My Research

Sampling

The four statistics educators included in this study were a purposeful sample (Patton, 1990) and were selected as potentially information-rich cases (Mertens, 1998) of 'accomplished statistics educators,' cases that would allow me to investigate the use of constructivist theory in the introductory statistics classroom. In addition to purposeful sampling, the selection of these particular instructors also demonstrates intensity sampling (Morse, 1994), as the participants could be considered "experiential experts" (p. 229) in the statistics education community.

I had little prior knowledge about the use of constructivism in the classrooms of these participants. For example, since I knew that Paul Velleman created and developed *ActivStats*, I thought that this might indicate potential for Paul supportive student construction of knowledge. Regardless of my knowledge of the participants' support of constructivist theory, I assumed that, by investigating the instructional strategies of accomplished statistics educators I at least had representatives of good teaching in the introductory statistics classroom. The question then became how constructivism operates in the classrooms of these statistics educators.

The instructors who participated in the study were selected based on their standing in the statistics education community as well as their interest in improving statistics education. My committee members and other statistics faculty were able to provide me with lists of individuals whom they identified as suitable participants for my study. Through discussions with these committee members and my own research in statistics education, I identified several potential participants for my study.

A total of eight statistics educators were contacted for possible participation in my research. All eight of these statistics educators responded to my solicitation e-mail messages and all were interested in my research. The four participants selected (Paul Velleman, David Moore, Gudmund Iversen, and Beth Chance) represent those statistics educators who were identified in the above manner, were interested in and available for participation in my study, and who were teaching undergraduate introductory statistics courses during the calendar year 1999. The remaining four respondents were not available to participate in my research because they were not teaching an introductory statistics course during Fall 1999.

The four educators in this study are nationally known for their work in the statistics classroom. They have all contributed regularly to the body of literature on statistics education. My participants have written textbooks, journal articles, and statistics teaching multimedia and have won awards for their teaching and research.

Through data collection, I found that together the four participants in my study have:

- had around 100 years of teaching experience;
- authored more than 20 books and monographs;
- written over 100 articles;
- reviewed over 50 books, manuscripts, and articles;
- developed multimedia packages for teaching statistics;
- won multiple teaching awards;
- given over 100 presentations at conferences and workshops.

In addition, together the participants in my study are members (and/or have served as elected officers) of more than 15 national and international organizations including: the American Educational Research Association; the American Statistical Association; the

Institute of Mathematical Statistics; the International Association of Statistics Education; and the National Council of Teachers of Mathematics.

My assumption, both prior to and after data collection, was that all four of my participants must be doing something 'right' in their classrooms, as they could not have achieved great acclaim in the statistics education community otherwise. By looking at what these instructors are doing in their classrooms, I intend to inform others in the statistics education community about what can be and is being done in the classrooms of accomplished and accomplished statistics educators. Using constructivism as a lens through which to view these educators' instructional strategies, I also intend to add to the growing body of literature on constructivism in the statistics classroom.

The Participants

The four educators who participated in this study were Paul Velleman at Cornell University, David Moore at Purdue University, Gudmund Iversen at Swarthmore College, and Beth Chance at California Polytechnic State University. In this section of this chapter you are introduced to the participants, their schools, and the courses that they teach. Information about these participants was gleaned from the e-mail questionnaires (Appendix D) and course information requests (Appendix E). These data collection methods are discussed on pages 81-85 of this chapter, and the coding of data is discussed on pages 87-91 of this chapter.

Paul Velleman, Cornell University, and Statistics 210.

When asked to respond to the question "Who are you? Tell me about yourself (e.g., the person, the teacher, the family member, etc.)," Paul first mentioned that he was the father of two boys. Outside of his role as a father, Paul is a statistics educator, trained in the discipline of statistics by John Tukey at Princeton. A software developer and designer, Paul has developed an educational data-analysis package (*Data Desk*, Velleman 1998b) and authored an educational multimedia package (*ActivStats*).

Paul became interested in statistics "by accident." He saw an advertisement about data analysis. The ad made sense to him, so he applied. While his content area happened by accident, teaching was in his blood. Paul's grandfather, aunt, uncle, and mother were all teachers, and his two brothers were professors. Paul thinks that teaching is genetic for his family. He planned to teach college from the time he was in high school. In 1975, Paul went directly from graduate school to Cornell University, an Ivy League research university, to teach statistics.

At Cornell, Paul teaches Statistics 210, a one-semester introductory statistics course taken by approximately 640 students each year. This estimate includes 300 students each in fall and spring semesters as well as 40 students during the summer term. Several other large courses across the campus cover the same material discussed in Statistics 210. Course instruction consists of two 50-minute lectures and one 50-minute section meeting each week. The sections have approximately 20 students each. There is a head teaching assistant (TA) who maintains the course website steps in for lectures (if needed), and handles administrative issues for the course. The section leaders, who are

all undergraduate teaching assistants, meet with the instructor and the head TA once a week to coordinate the instruction in the sections with the instruction in the lecture.

The typical student taking Statistics 210 is a sophomore social science major. While approximately two-thirds of the students are calculus literate, "almost none of them want me to use it" (KC11). All of the students in the course are undergraduates, and most of them are sophomores. Fifty-five percent of the students are women. Paul estimated student grade point averages (GPAs) to be about 3.5 (on a 4.0 scale). Attendance at lecture is usually around 80% of the enrollment. In the past, Paul has given quizzes in lecture as an incentive to attend. Grades for this introductory statistics course are based on the following: two preliminary (midterm) examinations (55%), one final examination (35%), and weekly homework (10%).

Technology is highly integrated into the course, from lecture to homework. Students spend approximately two hours per week on assigned *ActivStats* lessons in preparation for each lecture. Virtually all homework requires working with either *ActivStats* or *Data Desk*. During lecture, computer projection is used. While computers are provided in public facilities, they are not formally scheduled for student use.

David Moore, Purdue University, and Statistics 113.

When asked to respond to the question "Who are you? Tell me about yourself (e.g., the person, the teacher, the family member, etc.)," David said that this was "not relevant, and none of the business of people I don't know well" (DEQ1). David did add,

"the only exception is a physical condition" (DEQ1), a severe hearing impairment from birth. Other than the mention of David's hearing impairment, as a researcher I respect David's desire for privacy.

When asked how who he is affects his classroom instruction, David replied, "I hope it doesn't. I am doing a job at which I am quite good. I do that job well, no matter what my personal state is. I'm a professional, not an artist" (DEQ1). To explain his perception of the difference between a professional and an artist, David quoted Andre Soltner, a great chef:

"I always say this to the young chefs, and mean it: The customer is excited, he says you are an artist but we are not, just crafts people with a little talent. If the chef is an artist, he doesn't succeed. Why? Because he is inspired today but not tomorrow. We cannot do that. We have to serve the customer when he's here. He doesn't come back tomorrow." (DEQ1)

David has a Ph.D. in mathematics from Cornell University, and his thesis was in mathematical statistics under the direction of Jack Kiefer. According to David, he learned "working statistics" (DEQ2) by teaching and doing statistics while at Purdue University. David was attracted to statistics more by Jack Kiefer than by the discipline of statistics itself. At the time David was working on his Ph.D. "prestige in stats came from being close to math.... I did not think of stats as separate until much later" (DEQ2).

While working on his Ph.D., David had a fellowship and did not teach during graduate school. His graduate school days were also at a time "before any preparation [in teaching] was offered [to] graduate students" (DEQ2). David has no formal background in teaching, but both of his parents were teachers. David thinks "that teaching is a natural

companion to learning and an excellent way to clarify one's thinking" (DEQ2). In fact, David does not "understand scholars who appear to love knowledge but try to avoid teaching" (DEQ2).

David was one of the first three professors to be named "distinguished professor for the scholarship of teaching" at Purdue University. According to David, "that carries a reserved parking spot, so in one sense it's real status" (DEQ1). David received state and national teaching awards from the Mathematical Association of America in 1994. To describe his current position in the statistics education community, David said:

You should ask others, for the reason stated above. I guess I'm now the establishment in person, based on offices held etc. A decade ago I was (I hope) innovative, then influential in changing the teaching of intro stats. That was a higher standing. (DEQ1)

David has taught at Purdue University, a Big Ten research university located in the Midwest, for over 30 years. The course that David teaches, Statistics 113, is a one-semester introductory statistics course taken by approximately 945 Purdue University students each year. This estimate includes approximately 440 in the fall, 480 in the spring, and 25 in the summer. The following discussion about the format of the course excludes the summer offering. Students in Statistics 113 during the fall and spring semesters attend a 50-minute lecture twice a week (Tuesday and Thursday) and a 50-minute recitation section of size 30 on each Friday of the term.

Each fall and spring there is one large lecture and many recitation sections. There are five graduate teaching assistants (GTAs) who run the recitation sections. David has weekly meetings with the GTAs during which the five recitation instructors "are given quite specific instructions for each recitation" (DCI2). Students taking Statistics 113 are

required to attend recitations regularly. There is no such requirement for lecture attendance. David has found that attendance in lecture "drops to perhaps 50% after a month or so" (DCI1).

The typical student taking Statistics 113 is an "underclass liberal arts student fulfilling a quantitative requirement" (DCI1). All of the students taking this introductory statistics course are undergraduates, 80% of freshman or sophomore rank and 20% of junior or senior rank. About 60% of the students taking the course are women.

Each student's grade is comprised of weekly homework (worth 20% of her/his grade), weekly quizzes in recitation (20%), and three exams (60%). Students have the opportunity to receive a bonus for participation in recitation that is worth 2% of their grades.

Technology plays a large role in the course. Students need to have a calculator that can perform two-variable statistics. All course material is on a web site, and homework includes some on-line exercises with links to other web sites. In class the students see many video and computer demonstrations, including the use of animations in *ActivStats*.

Gudmund Iversen, Swarthmore College, and Statistics 1.

When asked to respond to the question "Who are you? Tell me about yourself (e.g., the person, the teacher, the family member, etc.)," Gudmund mentioned that he was a 64-year-old white man who is married for the second time to a fellow academic and is father to four children (two from each parent) in their early thirties. Gudmund was born

in Norway and attended the University of Oslo for four years. Gudmund has graduate degrees in mathematics, statistics, and sociology from The University of Michigan and Harvard University.

When asked how he got interested in statistics, Gudmund responded:

I think I have always been interested in numbers and their patterns. As a young boy I used to record the temperature each night for several years and then make graphs and do computations with the numbers. (GEQ2)

When asked how he got interested in teaching, Gudmund said, "maybe it runs in the family" (GEQ2) since Gudmund's father was a professor. During his high school and university years, Gudmund "always observed my own teachers...trying to figure out what they did well" (GEQ2). While a graduate student in statistics at Harvard, Gudmund was a teaching fellow. Gudmund liked teaching "so much I knew I wanted a teaching position more than a research position" (GEQ2).

Gudmund has been teaching at Swarthmore College, a small, very selective, liberal arts college located in the northeast portion of the United States, since 1972. Gudmund left The University of Michigan for Swarthmore College because he was more interested in teaching than research and Swarthmore emphasized teaching. Gudmund's teaching of introductory statistics at Swarthmore "has been very successful" (GEQ1).

Gudmund thinks his statistics teaching is successful because:

I seem to be able to anticipate where students will have difficulties, and I adjust my teaching accordingly. I remember where I had difficulties learning, and I try to help my students across those hurdles. (GEQ1)

In addition to remembering his own struggles learning statistics for the first time,

Gudmund is "patient, and I like helping students understand, either in the classroom or

one-on-one" (GEQ1). Gudmund added, "it is very rewarding when [the students] all of sudden, much to their surprise, understand something" (GEQ1).

Statistics 1 is taught in four sections each academic year, two sections in the fall semester and two in the spring semester. Each section "typically has a limited enrollment of 25 students, since it is a course that requires the writing of papers" (GCI1). Statistics 1 meets for 75 minutes twice a week. The typical student taking Statistics 1 is "a humanities or social science student taking the course as a natural science distribution requirement" (GCI1). All Statistics 1 students are undergraduates, distributed fairly evenly across the four years. Approximately 80% of the Statistics 1 students attend the lectures. Students' grades are based on weekly homework (15% for completion, 10% for performance), two papers (30%, 15% apiece), a midterm exam (15%), and a final exam (30%). Technology, particularly *Data Desk*, is typically used only for homework problems.

Beth Chance, California Polytechnic State University, and Statistics 217.

Beth grew up wanting to be a teacher. Beth was "frustrated when my friends hated math, and I thought it was only because they didn't have some of the great teachers I did" (BEQ1). While an undergraduate student, Beth "discovered psychology and became very interested in how people learn and how to promote 'meaningful' learning" (BEQ1).

After graduating from college, Beth wanted to pursue her Ph.D. so that she could teach at the college level. Beth considered graduate school in educational psychology, her "bigger love" (BEQ1), but decided on mathematics, "believing it would be easier to

change my mind in [the] direction [of educational psychology] down the road than vice versa" (BEQ1). However, during her senior year of college, Beth "discovered Operations Research and loved using math to solve problems (as opposed to only proving theorems)" (BEQ1). She wound up going to graduate school in operations research, but found operations research to be more theoretical than she liked and gravitated back towards more applied statistics courses and advisors.

After earning her doctorate, Beth began her career as an assistant professor. Over time, and due in part to the lack of rich technology in her first tenure-track appointment, Beth's research "gradually shifted more and more into statistics education" (BEQ1). Her research was supported both at her former institution (University of the Pacific [UOP]) and at California Polytechnic State University¹⁸ [CalPoly].

Beth and her husband, a consultant who works out of their home, have "very similar work ethics" (BEQ1) and often work late into the night and on weekends. According to Beth, she can "reconcile this by saying that some of my workshops and research are not just my job, but also my hobbies" (BEQ1).

When asked about how who she is as a person impacts her classroom instruction, Beth responded, "I feel I am very reflective of my teaching and am constantly trying to improve what occurs in the classroom every day" (BEQ1). Beth reported that she is "very committed to providing the highest quality of instruction possible" (BEQ1) in her classroom. Beth also mentioned that she does feel "my background influences my pedagogy and I'm constantly striving to find a better way to teach my students" (BEQ1).

¹⁸ My site visit was done during Beth's first semester at California Polytechnic State University.

Despite being a first year assistant professor at CalPoly, Beth had five years of experience at UOP. During her time as a statistics educator, Beth has developed "a good understanding of currently recommended pedagogical practices for introductory statistics" (BEQ2) which she is "constantly striving" (BEQ2) to incorporate into the courses that she teaches. In addition to learning from the statistics education community, Beth has also been contributing to that community:

I feel I myself am starting to have a reasonably strong presence in this community. I have my hand involved in many different pots right now, from workshop presenter to journal editorial boards to conference presenter. My research efforts, classroom ideas, and curricular developments seem to be known in the community. I feel I'm currently crossing a new level as more of my presentations are being invited, my committee posts are becoming slightly more respectable, etc. (BEQ2)

In addition to teaching at CalPoly and UOP, Beth was a teaching assistant while in graduate school at Cornell University. About her experience teaching at the university level, Beth said:

I am amazed that college professors are not required to take any education courses and some how it's felt that knowing the highest levels of the subject matter is sufficient for you to be qualified to teach. I am very grateful for my courses in cognitive psychology, curriculum design, social psychology, and math education. (BEQ2-3)

About teaching statistics, Beth said, "I love explaining things to people and helping them understand" (BEQ3). Beth added:

I felt too often students were turned off to mathematics and statistics because they weren't showed the applications of the material, nor sufficient multiple representations to have a fair chance of understanding the material. (BEQ3)

CalPoly is a polytechnic university in the western portion of the United States.

Beth joined the faculty of CalPoly partly because of the university's:

Commitment to quality undergraduate education. Class sizes are capped under 50 and faculty are encouraged to focus primarily on teaching. Research is needed, but teaching is first. Faculty need to set a minimum number of office hours, etc. (BC11)

Undergraduate research is encouraged at CalPoly, and Beth believes that one mission of CalPoly is "learning by doing" (BC11).

Statistics 217 is taught in three sections, each section capped at 48 students. The course is taught in a studio classroom. The course meetings are in two-hour blocks twice a week. The typical student taking Statistics 217 is a "Liberal Arts major, not terribly thrilled to be there, not the most computer literate, but a wide variety" (BC11). During Fall 1999, Beth taught 94 students in two sections of Statistics 217. Ninety-three of the students were undergraduates, fairly evenly split over four years, and one student was a graduate student. Beth estimates that 80-90% of her students attend class regularly, but there are "a few I've never seen" (BC12). Assessment of the students is based on homework (15%), labs (15%), quizzes (10%), two midterm exams (30%, 15% apiece), a final exam (15%), and a term project (15%).

When asked about the role technology plays in Statistics 217, Beth responded:

Big. Students are expected to work with a computer every lecture and use it for homeworks outside of class as well. Students are supposed to be using *Minitab* for much of their analysis, some other software programs for visualization (mostly in class, but also some Java applets) and all course notes and handouts are available on the web. (BC12)

Gaining Entrée

Gaining entrée with these participants was much easier than I had thought it would be. Before sending out emails to my prospective participants, I asked the two

members of my committee who are from the Department of Statistics if they thought that any of these people would ever be interested in my study. The short answer was that I would not know until I asked.

So, I went ahead and sent an email (Appendix A) to each prospective participant, including a brief summary about my research intentions and the names of my committee members. It was really a painless process. Once the prospective participants indicated their interest in and availability for participation in this study, I sent consent forms (Appendix B) via regular mail explaining the data collection process to them to obtain formal consent.

Additional consent forms (Appendix C) were developed for my work with Paul Velleman at Cornell University and David Moore at Purdue University, since each gentleman had teaching associates teaching recitation sections of his course. Formal consent was obtained from these teaching associates during the on-site visitations at both universities.

Once I had gained entrée with my participants, I was ready to begin data collection. The following section addresses the methods I used to collect data for "The Quest for the Constructivist Statistics Classroom."

Data Collection

My methodology included a variety of data collection methods in order to achieve both breadth and depth of data. The intention of this study was to provide a rich description of current instructional strategies in the introductory statistics classrooms of

accomplished statistics educators and to analyze the data through the lens of constructivism. It is also the intention of this study to inform the teaching of other statistics educators not involved in the study. Data collection for this study included e-mail correspondence, observations, and interviews.

The Initial E-mails

E-mail allowed me to gather some information prior to my site visits. E-mail helped to maximize my interview time by allowing me to ask some basic background questions about the participants outside of the interview time (see Appendix D). My review of participant responses prior to the initial interviews gave me the opportunity to develop clarifying and/or additional questions that arose from their responses. The following questions are examples from the initial e-mails:

- Who are you? Tell me about yourself (e.g., the person, the teacher, the family member, etc.).
- In what ways does who you are impact your classroom instruction?
- What is your background in statistics? How did you get interested in statistics?
- What is your background in teaching? How did you get interested in teaching?
- What does your ideal undergraduate introductory statistics classroom look like (e.g., environment, size, pedagogy, knowledge acquisition, interaction, technology, and/or assessment)?
- Why is the picture you painted above the ideal undergraduate introductory statistics classroom?

The Interviews

All interviews were conducted on-site at the participants' institutions. Interviews were audio taped and transcribed by the researcher. Interviews were conducted both

before and after the observations and included questions about teaching, learning, constructivism, and the observations.

There were three interviews of each participant: an initial interview, pre-observation, and post-observation interviews. The introductory interviews lasted approximately forty-five minutes each and involved questions about teaching and learning issues. The following questions are examples from the initial interviews:

- How do you define "effective teaching"?
- In what ways do you consider yourself to be an effective statistics teacher? What evidence do you have of your effectiveness?
- How do you believe students acquire knowledge?
- How do you assess the conceptual understanding of your students?
- How do you indicate to students what you want them to learn in this course?
- How do your assessments match your intentions for student learning?

The pre-observation interviews included some personalized questions based on each participant's e-mail response to the initial questions I posed and responses to questions from the initial interview. The following are examples of the questions that emerged:

- (Paul) You mentioned a "casual classroom presence" and attempts to convey accessibility. Why are these important to you?
- (David) Could you explain why you personally would define teaching as a natural companion to learning, even though it may seem obvious to you?
- (Gudmund) What was it about statistics that you had difficulty with?
- (Beth) Can you talk to me about the term-long project that you use with your students?

Similarly, the post-observation interviews included some personalized questions about what I saw during the particular class meetings and including questions like:

- (Paul) How did you make the decision to change your flow mid-Tuesday in terms of you going in there deciding to do one thing and then to change?
- (David) Could you explain why you think it's important for you to write out the outlines that you do for your recitation instructors?

- (Gudmund) Why do you make students reading and responding to chapter exercises an important part of the class?
- (Beth) What do you think about the teaching technology in that room? How does it help or hinder the students?

Pre-observation interviews took approximately fifteen minutes and were conducted at the time of the initial interview with each participant. Post-observation interviews took approximately forty-five minutes.

The general protocol for all of the interviews can be found in Appendix F. A complete list of the questions that were actually asked of each participant can be found in Appendix G.

The Observations

Observations were conducted during two class meetings of each participant. Because one of my research questions was to identify the instructional strategies being used in introductory statistics classrooms, my focus was on pedagogical styles, which should not be concept-specific but should carry across concepts. I assumed that the class meetings I attended were representative of the types of instructional techniques the participants employ in the classroom. Because of this assumption of representativeness of each participant's teaching as a whole, the observations were an attempt for critical case sampling (Morse, 1994). In order to verify this assumption of representativeness, part of my interview protocol involved asking the participants if/how the instructional strategies I observed were typical of their teaching.

In addition to observing pedagogical styles and instructional strategies, I paid attention to the physical aspects of each classroom. Data about the physical aspects

included: the structure of the room; the lighting of and sound in the room; and, the technological capabilities of the room. I also collected information about the students in these classes, including the number in attendance at each class meeting and visual characteristics of the students.

The Follow-up E-mails

There were a few issues that emerged from my site visits that I needed to address further. For example, after observing the time and effort that Paul, David, and Beth spent preparing for classes, I felt that I needed to ask all four participants about their preparation for and reflection upon individual class meetings. The follow-up e-mail questions allowed me a forum in which to ask the participants about issues that emerged during data collection. The follow-up e-mail questions addressed: preparation for and reflection on teaching; classroom environment; introductory statistics students; the roles of a teacher; and future plans. A complete list of the questions sent in the follow-up e-mail messages can be found in Appendix H.

Data Analysis

Qualitative data is massive and overwhelming. As such, it was necessary for me to anticipate ways that I could reduce the amount of data only to reconstruct it into a telling picture. Making qualitative data manageable requires synthesis, data reduction, and re-presentation.

Initial Data Synthesis, Reduction, and Re-Presentation

My data work began with multiple readings of my data, allowing for the emergence of patterns in the data, which could not have emerged without multiple readings. In a sense, these patterns bubbled to the top, becoming obvious after these multiple readings.

In an attempt to synthesize my data, I wrote stories about what I had heard and observed. The "realist tales" (Van Maanen, 1988) in Chapter 4, with each "tale" telling the story of what happened in the introductory statistics classrooms of one of my participants, are not solely the results of multiple readings of the data. Instead, they are the products of a multi-staged process of data analysis.

In an attempt to organize my data, I wrote the first draft of Paul's realist tale in chronological order of my data collection. I sent this draft to one of my peer reviewers (a non-committee faculty member who is a qualitative researcher) indicating my concerns about the organization and flow of the story. Her review of my writing suggested an organization around four major themes (teaching philosophy; teaching methods; interaction with students; and, the use of technology in the classroom) that came forth from her reading. These themes fit with my thoughts about the data, so I decided to organize my realist tales around these four themes.

After her review, I submitted the same draft of Paul's tale to my writing group, asking these peers to concentrate on identifying aspects of the tale that fit these four themes. The discussion my writing group and I had about these themes helped me to work through my own theming of the data. For example, I had found that the themes of

teaching philosophy and teaching methods were difficult for me to separate decisively. My writing group peers found this separation of data into clear-cut cubbyholes difficult as well, and the conversation we had around this issue was extremely helpful to me. As you will find in Chapter 4 of this document, the realist tales are indeed organized around the four themes of teaching philosophy, teaching methods, interaction with students, and the use of technology in the classroom. However, the analysis in Chapter 5 of this document highlights the problematic nature of pigeonholing the fluidity of teaching into neat slots by addressing the intertwining of these themes.

In addition to illuminating the themes in my work, my peer reviewer asked me about my coding of the data. The next section of this chapter enumerates the process I went through coding my data.

Data Coding

Readers of this document will find indications for tracking each excerpt from the data in the form of a code following the excerpt. The raw data is available in the form of transcripts, and each code identifies the location of the excerpt in this raw data. The coding scheme that I used was:

Code	Source
<u>CI</u> #	Course information e-mail
<u>EQ</u> #	E-mail questionnaire
<u>FE</u> #	Follow-up e-mail
<u>II</u> #	Initial interview
<u>FI</u> #	Follow-up interview
<u>FCM</u> #	Observation of first class meeting
<u>SCM</u> #	Observation of second class meeting

In this coding scheme, the "_" at the beginning of the code indicates the name of the participant (**P**, **D**, **G**, and **B** represent Paul, David, Gudmund, and Beth, respectively). The "#" following the code indicates the page number of the interview or observation transcript or printed e-mail response.

Take for example, the following excerpt from Paul's realist tale (found on page 121 of this document):

I tell my students that "if only" we had the technology, the exam would be that they would sit with their computers, I would give them data sets and questions and guide them through an analysis. (**PII9**)

This excerpt is coded with **PII9**, meaning this quote can be found on page 9 of the transcript from my initial interview with Paul.

In addition to developing a coding scheme for the identification of the source for the data, I had developed a coding scheme that I had based on what I expected to find during data collection. The initial coding scheme for my data was:

	Code	Meaning
Evidence of teaching type:	CONST-	Supports constructivism
	AL	Active learning
	CL	Cooperative learning
	INT	Interaction between teacher and students
	MP	Supports multiple pathways to solutions
	SL	Student-guided learning
	TRAD-	Supports traditional instructional strategies
	LS	Lecture style
	ON	Supports one correct answer
	OS	Supports one solution strategy
Class format:	SIZ	Issues with class size
	TECH	Use of technology
	ENVI	Environment
	INTE	Interaction
	ASSE	Assessment

Teaching and learning: **TEAC** Issues with teaching
LEAR Issues with learning

My experience with data collection indicated to me that the coding scheme above was naïve. It was at this point that I decided to write the first draft of my realist tales without coding the data first, using chronological data collection as the organizing theme. As mentioned above, this organization method was abandoned for an organization by themes.

The codes used for the themes of teaching philosophy, instructional strategies, interaction with students, and the use of technology in the classroom were:

Theme Code	Theme Meaning
TP	Evidence of teaching philosophy
TM	Evidence of instructional strategies
WS	Evidence of interaction with students
TN	Evidence of the use of technology in the classroom

Each of the four themes above had smaller themes (sub-themes) within them that emerged from readings of the data. The sub-codes for these sub-themes were:

Theme Code	Sub-Theme Code	Sub-Theme Meaning
TP	OT	Relating to participant's own teaching
	ET	Relating to effective teaching
	CP	Relating to the purpose of the course
	KLT	Evidence of knowledge of learning theories
TM	TRANS	Relating to knowledge transmission (direct instruction) from participant to students
	INT	Relating to interaction between participant and students
	EXP	Relating to exploration and discovery of knowledge
	VIS	Relating to visualization of concepts
	LINK	Evidence of a link between new knowledge and prior learning from students lives and/or class
	ASSE	Relating to the assessment of students
	MISC	Miscellaneous instructional strategies

WS	DC	Relating to contact during class
	OC	Relating to contact outside of class (e.g., office hours, email)
	ET	Relating to effective teaching
	INT	Relating to interaction between participant and students
TN	ADV	Relating to the advantages of technology
	AS	Relating to <i>ActivStats</i> in particular
	EM	Relating to the use of email
	LINK	Evidence of a link between new knowledge and prior learning from students lives and/or class
	SIM	Relating to using technology for simulations

As an example of coding the data using the codes for the four themes and sub-themes, the following is an excerpt from my initial interview with David:

Well, the normal way to define effective teaching is that it helps students learn. And that, of course, means that effective teaching is very difficult to measure, because learning, in the end, is something students do. (DII4)

The data after coding looked like this:

TP Well, the normal way to define effective teaching is that it helps students learn.
ET And that, of course, means that effective teaching is very difficult to measure, because learning, in the end, is something students do. (DII4)

The codes for the excerpt above indicate that this excerpt (from page 4 of my initial interview with David) was evidence of teaching philosophy (**TP**), specifically dealing with effective teaching (**ET**).

It was possible for data to be coded with more than one label. For example, the following is an excerpt from my post-observation interview with David:

TM But when we do the data analysis part of the course, then a lot of the tools
VIS from *ActivStats* are relevant. You could do things to show them how the mean and median respond when you pull an observation out. You can actually do that on the screen instead of just talking about it. (DFI5) **TN**
AS
SIM
ADV

The codes for the excerpt above indicate that this excerpt (from page 5 of my post-observation interview with David) was not only evidence of an instructional strategy

(**TM**), specifically dealing with visualization of concepts (**VIS**), but also evidence of the use of technology (**TN**), specifically dealing with *ActivStats* (**AS**), simulation (**SIM**), and the advantages of technology (**ADV**).

Since I had already begun the realist tale about Paul Velleman, I coded from this tale and reorganized and rewrote the tale based on this coding. The rewritten tale can be found in Chapter 4 of this document. For the realist tales of David Moore, Gudmund Iversen, and Beth Chance, I coded directly from the data. Once all data collection sources from these participants were coded, I wrote the remaining realist tales that can also be found in Chapter 4 of this document. After all four realist tales were completed, I moved on to the analysis of the data through the lens of constructivism.

Analysis Through the Constructivist Lens

By this point I had read and considered my data many times over. The development of the realist tales had helped me to synthesize the data, but I had yet to do my formal analysis through the lens of constructivism, although some informal analyses were evident in the tales. In order to do my formal analysis of my data through the lens of constructivism (found in Chapter 5 of this document), I used what I consider to be my working definition of constructivism.

After troubling the idea/philosophy/theory of constructivism over the course of several years (including time during my coursework, my qualifying exams, and dissertation research), I arrived at my working definition of constructivism:

Constructivism is a theory of learning that allows students to develop and construct their own understanding of the material based upon their own knowledge and beliefs and experiences in concert with new knowledge presented in the classroom.

While reading through my data multiple times, I considered the degree to which each instructional strategy supported student construction of knowledge, instead of judging each instructional strategy used by the participants as being supportive or not supportive of constructivist theory.

I viewed the instructional strategies as they fell on a continuum of constructivism instead of viewing them from a dichotomized view of supporting or not supporting constructivism. I consider constructivism to be *a* theory of learning instead of *the* theory of learning. However, I do feel that learning through knowledge construction makes a student's understanding deeper and more meaningful than learning through rote means. Given that all knowledge and understanding about statistics is constructed, *all* instructional strategies promote some level of knowledge construction. For example, even lecture, if done well, can foster knowledge construction: In his classroom Gudmund presents material in a 'simple' manner (GFI2, GFI3) which perhaps may somehow challenge his students to go out and construct their knowledge of introductory statistics outside of the classroom. For this reason, my examination of the instructional strategies needed to be on a continuum of constructivism instead of dichotomizing the instructional strategies into those that did support and those that did not support knowledge construction.

How do we know that the students are constructing their knowledge and understanding about statistics? Assuming still that all knowledge and understanding

about statistics is constructed, some construction of knowledge must be happening for the students. Even so, it is non-trivial to determine the extent to which knowledge and understanding of statistics is being constructed.

Trustworthiness

Trustworthiness is a quality criterion in qualitative research that is similar to validity and credibility in quantitative research (Creswell, 1994). So, just like a quantitative researcher accounting for the validity and credibility in her/his research, I include here an account of the trustworthiness of my research. The trustworthiness of this research begins with providing assurance that I am qualified in qualitative research methodology and I am familiar with the available literature relating to my research. These points are particularly important since the researcher is really the research instrument in qualitative work.

My credentials in qualitative research methodology stem from my experience as a student in three courses in qualitative methodology under the direction of Dr. Patti Lather, an expert in the world of qualitative research. In addition to this experience, this chapter and my work products, including this entire document, serve as evidence of my qualifications in qualitative methodology. My familiarity with the available literature relating to my research is documented (in part) in Chapter 2 of this document.

The following sections of this chapter deal with other issues of trustworthiness. These aspects of trustworthiness include triangulation, an audit trail, member checks, and peer review.

Triangulation

Many researchers consider triangulation to be an important aspect of qualitative research (e.g., Creswell, 1994; Glesne and Peshkin, 1992; Huberman and Miles, 1994; Mertens, 1998). Triangulation is the use of multiple sources of data to contribute to the trustworthiness of the researcher's data (Glesne and Peshkin, 1992). Using multiple sources of data allows the researcher to check for the "consistency of evidence across sources of data" (Mertens, 1998, p. 183).

Triangulation of my data sources came in the form of e-mail responses, interviews, and observations. I looked for consistency of the instructors' beliefs about teaching and learning through their words (the e-mail responses and interviews) as well as their teaching (the observations). For example, the following discussion demonstrates a consistency between Paul Velleman's actions and words. During our initial interview, Paul told me that one of his strongest endorsements for discovery learning is when his students "invent the reasoning of hypothesis testing for themselves" (PII13). During class, Paul told his students that "doing the experiments yourselves on the computer should give you far greater insight than anything I can do up in front of the room" (PSCM1)¹⁹.

Audit Trail

An audit trail was important both for me to follow my own research process and for someone else to reconstruct the process by which I reached my conclusions (Morse,

¹⁹ See page 106 in Chapter 4 of this document for the portion of Paul's tale dealing with discovery learning.

1994). Mertens (1998) mentions two types of audits: the dependability audit and the confirmability audit.

A dependability audit in qualitative research "can be conducted to attest to the quality and appropriateness of the inquiry process" (Mertens, 1998, p. 184). Artifacts from my research that can be used for such an audit include data collection protocols (Appendices D through H) and transcripts of interviews and observations. In addition, the documentation of my methodology in this chapter can also serve as part of a dependability audit. My work products included: field notes from my observations; coding and categorizing information; multiple prior drafts of my document.

Confirmability in qualitative research "means that the data and their interpretation are not figments of the researcher's imagination" (Mertens, 1998, p. 184). This implies first that "qualitative data can be tracked to its source" (p. 184). Secondly, the logic of the data analysis needs to be explicit.

As mentioned above, a confirmability audit also implies that the logic of the analysis has been made explicit. A discussion of the codes used in the construction of the realist tales and the logic of the analysis can be found in this chapter on pages 87-92.

Member Checks

Member checks allow participants to review the material related to them (Morse, 1994) to check this material for accuracy. Once my realist tales were completed, I sent each participant a copy of her/his tale. Participants had the opportunity to bring any inaccuracies of form or content to my attention. Although I wrote this document, my

participants own the raw data from which my writing came. As a result, I considered my participants' comments about their tales. For example, as an overall response to her tale, Beth said, "I finished reading through the tale - nice job! It was interesting to read :)" (e-mail communication, March 29, 2000). Beth added the following specific comments about her tale:

- I wondered if in a couple of spots it would be helpful to show what was on the slide [the students] were looking at while I was talking? For example, with the CI review earlier in it seems very hand-wavy depending on what the slide showed?
- You talked about my interaction with students and mostly referred to earlier discussion on student responses during lecture. When you visited was there any time of students working and me wandering around and asking questions? Should that type of interaction be discussed more?
- The only think that seemed to strike me as a little over-represented, though I may be being too sensitive, was the "negotiation" at the very end. I'm not sure that's the best example of "interaction with students" or something I do all that often (as often as it seemed in the excerpts). I'm not totally opposed to the examples but might group them more with letting students know why the assignments have been structured the way they have, sharing that decision making with the students and allowing them to feel some ownership in the process. But I guess I don't want it to seem like moving due dates around is something I do everyday. In fact, while I like to discuss the purpose of assignments with students a lot, and get their feedback, "normally" I never move a due date if I can help it (so some of that was a consequence at being new to the university and the course). (e-mail communication, March 29, 2000)

Keeping the above comments in mind, I have made the appropriate changes to Beth's tale²⁰.

²⁰ Gudmund, David, and Paul's responses to their tales were such that none of the three men requested any changes be made to their tales.

Peer Review

As the researcher, it was hard for me to step back from my work to look at it with a fresh eye. Peer review is a strategy used by qualitative researchers to increase credibility (Huberman and Miles, 1994). My peer review allowed my dissertation to be read and scrutinized by others who were knowledgeable about research and scholarly writing. In addition, my colleagues who served as peer reviewers for this document were also looking at the research from the outside. It was important for them to let me know if the writing made sense to them and if it was scholarly.

The colleagues who served as peer reviewers for this document were faculty members (non-committee members) from the fields of mathematics education and literacy and doctoral students from the fields of educational policy and leadership and natural resources. The two faculty members who served as peer reviewers were also authorities on qualitative methodology.

Peer reviews were done throughout the writing of this document. As each chapter or section of a chapter was completed, I submitted it for peer review. The two faculty members reviewed all portions of the document as they were completed. The doctoral students reviewed portions of the document after I had revised them based on suggestions of the faculty reviewers.

Once I received comments from the doctoral students, I revised the document sections yet again and submitted them to Dr. Emmalou Norland, my education co-advisor. Following one more set of revisions, the sections were given to both Dr. Emmalou Norland and Dr. William Notz for "final" review so I could prepare the

document for my oral defense. Lastly, final revisions were made following my oral defense, and the completed document was submitted to the graduate school.

Politics and Ethics

Even if politics and ethics were not a concern in the research community, they would still be concerns for me. Initially I could not think of any political issues that would affect my study. My research questions were my own, and my participants were people that I chose. There was no pressure, political or otherwise, for me to conform to anyone else's ideas. However, my choice to use accomplished instructors was intentional. I believed (and still do believe) that more people will be interested in the outcome of my research if the participants were people, like Paul Velleman, David Moore, Gudmund Iversen, and Beth Chance, who are already established in the statistics education community. My belief was that with such participants, my reading audience would increase and more people would be interested in my results. For this reason, my choices were quite intentional and may, in some ways, be considered manipulative. In addition, there was some intrinsic value for studying the works of these participants.

There is a political issue that is also of a personal nature. Through my research, I was able to network with prominent members of the statistics education community. It is my belief that my initiation into the statistics education community was much more powerful and prominent because of my research than it would have been otherwise. This troubles me, because this was certainly not my intention.

The Ohio State University's Human Subjects Review Committee granted me permission to do "The Quest for the Constructivist Statistics Classroom." But, there were other ethical issues besides permission to do my research:

Ethics is not something that you can forget once you satisfy the demands of human subjects review boards and other gatekeepers of research conduct.... Rather, ethical considerations are inseparable from your everyday interactions with your others and with your data. (Glesne and Peshkin, 1992, p. 109)

For example, I obtained informed consent outlining expectations of my research participants and explaining that participation in the study was voluntary, that they could withdraw at any time with no penalty (Glesne and Peshkin, 1992).

Glesne and Peshkin (1992) suggest several roles in which the researcher may function, all of which involve ethical dilemmas of some type. The role that I identified with periodically was that of an exploiter, feeling guilty for how much I was receiving and how little I was giving in return (Glesne and Peshkin, 1992). However, with respect to reciprocity for my participants, I believed that they were (and are) satisfied with my commitment to improving statistics instruction at the university level. As an example of my willingness to provide reciprocity to my participants, I helped David evaluate the teaching of an graduate teaching associate and also provided comments and feedback about the participant's own teaching assistants.

The issues of privacy and anonymity were other ethical issues that I considered while doing my research. Many times during the 1.5 years I was immersed in this research I was asked by colleagues to name the participants in my study. In the case of my colleagues who are quantitative researchers, I explained that part of the ethics of qualitative research is confidentiality. Still, some of my colleagues tried to guess who the

participants were by saying things like "Well of course so-and-so is in your study..." My reply was standard: "I'm sorry, but I cannot divulge the identities of my participants."

After much of my writing was done, complete with pseudonyms for all participants, Paul Velleman sent me an e-mail asking:

Can you explain to me exactly why I should want anonymity? The only part of the material you sent earlier that made me at all uncomfortable was the feeling that someone else was saying my lines for me. Unless there is some good reason for not doing so (that I don't know of), I'd be happy to grant you permission to name me. (E-mail communication, March 27, 2000)

After some discussion with Emmalou Norland (co-advisor) and Suzanne Damarin (committee member), I sent the following response to Paul:

Okay, I've done some research about anonymity and confidentiality. Since I know who you are, you are not anonymous, however, by using a pseudonym in the dissertation instead of your name, you have confidentiality. "[T]here is a strong feeling among fieldworkers that settings and respondents should not be identifiable in print and that they should not suffer harm or embarrassment as a consequence of research" (Punch, 1994, p. 92). The reason for confidentiality in research is to protect you against any invasion of privacy. Now, in the case of my research, I don't believe that harm and embarrassment are issues, however, I was following tradition and went with pseudonyms.

However, since you brought the issue up, and since I think that my discussions of you in the dissertation would be much richer if I could address you as creator of the materials you use, I would be more than happy to use your name in the dissertation. So, I pose the following:

Please select the name of your choice to be used in the dissertation. If you would like the name used for you to be your actual name, I would be happy to use your name. Just send an email back to me indicating your selection of your name in the dissertation.

Not surprisingly, Paul decided to have his own name used in my writing.

Since Paul was going to be named in my work, I asked the other three participants if they would also like to be named. After discussions of various lengths with me, each

participant decided to use her/his real name in my work. As such, you the reader now know that my four participants were Paul Velleman, David Moore, Gudmund Iversen, and Beth Chance.

I recognize, however, that the ethical dilemma with using actual names did not end with the naming of my participants and that there are some researchers who would disagree with my choice to use actual names. For example, it would not be appropriate for the reader to contact a participant directly in order to question her/him about what was written in this document. Any such questions arising from the reading of this document should be addressed to me as the researcher and not to the participants in order to prevent any invasions of the privacy of the participants.

Summary

In this chapter I enumerated and described the research methodology that I followed in "The Quest for the Constructivist Statistics Classroom." In addition, I provided a global description of the 1.5 years spent on this project and a detailed time line of the activities included in my research. I also provided discussions of trustworthiness and political and ethical concerns. The methods and discussions contained in this chapter should be kept in mind and referred back to when reading the remaining chapters of this document.

CHAPTER 4

TALES OF MY PARTICIPANTS

Introduction

This chapter is primarily made up of four tales, one each about the four participants in my research. Each tale explores the following four themes: teaching philosophy; instructional strategies; interaction with students; and the use of technology in the participant's introductory statistics classroom. Information for each tale has been gleaned from the transcripts of interviews with, observations of, and correspondence with the participants. Excerpts in the tales that come directly from the data have been coded as mentioned on pages 87-91 in Chapter 3 of this document. Figure 4.1 is a matrix of the participants and their courses, which the reader can use as a reference while reading the tales in this chapter.

The Participants and Their Courses					
Participant	Paul Velleman	David Moore	Gudmund Iversen	Beth Chance	
Institution	Cornell University	Purdue University	Swarthmore College	California Polytechnic State University (CalPoly)	
Course Name	Statistics 210	Statistics 113	Statistics I	Statistics 217	
Course Title	Statistical Reasoning I	Statistics and Society	Statistical Thinking	Applied Statistics for the Liberal Arts	
Students	Social science majors, 300 students per lecture, 20 students per section	Liberal arts majors, 480 students per lecture, 30 students per recitation	Humanities or social science majors, 25 students per section	Liberal arts majors, 48 students per section	
Class Meetings	50-minute lectures twice a week; 50-minute section meetings once a week	50-minute lectures twice a week, 50-minute recitations once a week	75 minutes twice a week	2 hours twice a week	
Environment	Large lecture hall for lectures, small traditional classrooms for section meetings	Large lecture hall for lectures, small traditional classrooms for recitations	Traditional classroom	Studio classroom (see Figure 4.2)	
Assessment	Weekly homework: 10% Midterms: 2 prelims (55%) Final exam: 35%	Weekly homework: 20% Weekly quizzes: 20% Three Exams: 60% (20% each) Bonus for recitation participation: 2%	Weekly homework: 25% (15% for completion, 10% for performance) Two papers: 30% (15% each) Midterm: 15% Final exam: 30%	Homeworks: 15% Quizzes: 10% Midterms: 30% (15% each) Final exam: 15% Term Project: 15%	
Materials Used	<ul style="list-style-type: none"> • <i>AcrisStats</i> (Velleman, 1998a) • The ActivePractice of Statistics: A Text for Multimedia Learning (Moore, 1997a) • <i>Data Desk</i> (Velleman, 1998b) • Internet 	<ul style="list-style-type: none"> • Statistics: Concepts and Controversies (Moore, 1997b) • <i>AcrisStats</i> (Velleman, 1998a) • Internet 	<ul style="list-style-type: none"> • Statistics: The Conceptual Approach (Iversen and Gergen, 1997) • Statistics: A Guide to the Unknown (Tanur et al., 1989) • <i>Data Desk</i> (Velleman, 1998b) 	<ul style="list-style-type: none"> • Workshop Statistics: Student MiniLab Version (Rossman and Chance, 1998) • <i>MiniLab</i> 	

Figure 4.1: The Participants and Their Courses

The ordering of the tales in this chapter follows the order in which I made my site visits. The chapter begins with Paul Velleman's tale, followed by the tale of David Moore, followed by Gudmund Iversen's tale, and concludes with the tale of Beth Chance. The analysis of the data that constitute these tales has been reserved for Chapter 5 of this document.

During my site visits, questions emerged that I asked the participants after all site visits had been completed. A section addressing the questions that arose during data collection and the participants' answers to these questions follows the participant tales.

Paul Velleman at Cornell University

This is the story of Paul Velleman at Cornell University. During my visit to Cornell, Paul's class was discussing inference (confidence intervals and hypothesis testing). The story discusses Paul's teaching and his students' learning of inference and centers around the four themes that emerged from the data of all four participants. The following four themes are explored in this story: Paul's teaching philosophy; Paul's instructional strategies; Paul's interaction with students; and Paul's use of technology in his introductory statistics classroom. The analysis of the data that constitute this story is reserved for Chapter 5 of this document.

Teaching Philosophy

This section of Paul's tale addresses Paul's teaching philosophy. The following paragraphs talk about Paul's teaching philosophy through four sub-themes: Paul's own teaching; effective teaching in general; the purpose of the course; and, Paul's knowledge of learning theories.

When asked how who he impacts his classroom, Paul responded: "I have a casual classroom presence. I try to convey accessibility, but that can be difficult in a large class" (PEQ1). During my initial interview with Paul, Paul said that a casual presence and accessibility were important to him because:

Statistics is a course that is inherently intimidating. It's very easy for students to feel stupid, to feel that if they don't understand something it's their fault. I want them to feel, to the greatest possible extent, that if they don't understand something it's at least partly my responsibility and they should accost me. So I want them to feel that they can. (PII1)

Paul's response highlights the importance of student understanding to him and indicates his sense of responsibility for that understanding. Paul also feels a responsibility to his students even after the course has ended:

I do tell all of my students that I don't stop being their teacher just because the term has ended and that they are invited to come back and talk to me about any projects that have a statistical component if they want, or about anything else. But, in particular they're invited to use me as a resource and as a consultant. (PII3)

Instead of using direct instruction during class time as the only opportunity for learning about confidence intervals, Paul planned to "fortify [student] learning from the disk" (PII13). Paul believed that each student's individual learning of confidence intervals with *ActivStats* was "discovery learning, or whatever phrase you want to use"

(PII13). Paul's intention for the students was "for them to develop these concepts for themselves" (PII13). In fact, for the second class meeting I was to visit, the students who did their *ActivStats* homework were:

Placed in a situation where they are, without being told that, they're asked to test a hypothesis. And they invent the reasoning of hypothesis testing for themselves, because I've trapped them in a corner where that's about all that they can do. (PII13)

As a result of this particular exercise, Paul has found:

What previously was a very, very difficult subject to teach the students come to me and say, "What did you leave out? This is supposed to be hard." And it isn't hard anymore. (PII13)

Because of his students' reactions to this particular hypothesis testing activity in *ActivStats* Paul has found this particular activity to be:

My strongest endorsement of discovery learning.... When the students can discover a concept for themselves, it's really lasting... It's really making sense to them, because they figured it out for themselves. (PII13)

In fact, during class on Thursday, Paul told his students:

Doing the experiments yourselves on the computer should give you far greater insight than anything I can do up in front of the room. So, I can't stress enough that you do those lessons and work through the simulations and get the understanding from that. There's nothing I can do up here that would have comparable impact and would let you learn the material as well. (PSCM1)

In addition to acting as a vehicle for discovery learning, *ActivStats* provides an opportunity for Paul to be there with the students as they work. In Paul's words:

The impression I would like the multimedia to give is that I am standing by the student's shoulder, suggesting things the student might want to do on the screen and then standing there patiently while the student tries them. To the extent I can, that's what I've tried to do. (PII5)

In this situation, *ActivStats* acts as the 'more knowledgeable other' for the student.

Paul mentioned that inference is "where [the students] can really benefit from [*ActivStats*] pedagogically, and the teachers are a little afraid of it" (PFI2). Paul feels, however, that the students "are really learning [statistics] on their own at this point of the course" (PFI2). When I asked Paul if he felt threatened by students learning on their own, he said that learning on their own is what students really need to do at this point in the course (PFI2).

Since Paul encouraged student learning outside of class, I asked Paul what he thought students gained from the lecture time that they could not gain from working in section or working with *ActivStats*. Paul said, "It's a good question, I try and answer that myself" (PFI1). He had even asked his students that same question at the end of the previous term. Past students reported that hearing the material again, from a human, perhaps in a slightly different way, helped them to understand.

Paul had himself mentioned that he likes to take some of the things students have heard and put the pieces together in a different way. I asked him if that was another advantage of the lecture. Paul said, "well, I try to do that" (PFI1). For example, with inference, "there are so many different ways to talk about it that it helps to do that" (PFI1).

When I asked Paul if the class meetings I observed were typical, he said that they were "fairly typical" (PFI2). Paul went on to explain to me that "the course divides roughly into thirds, and the nature of the class changes" (PFI2). The course begins with data analysis and graphical summaries and actually thinking about data. The inference "part of the course is much more theoretical, simulation based, more formulas on the

board, and we're pushing their thought processes a lot more" (PFI3). Even so, Paul reported, "in terms of my lecturing style or the way in which I go back and forth between the board and the computer, that's pretty typical" (PFI3).

Paul teaches the way that he does "because it works" (PFI4). He knows that his teaching 'works' because:

Students come into the course not knowing very much statistics and they leave the course knowing statistics. I have more than that, though. About every other year I get a communication, sometimes it's a postcard or a letter, lately it's e-mail, from a student who has graduated who's been out maybe 5 years, which means it's been seven or eight years since they took my course. And the nature of it tends to be, "you don't remember me I was in this big class. I'm sure you don't know my name. I just wanted you to know I didn't really appreciate the introductory stat course when I took it. I did okay, but I didn't do great in it. And I didn't really enjoy it that much. But, I want you to know that you got me my latest promotion, you got me my job, I'm the only one around here who really understand regression." Things like this. "And I now realize this was the course that mattered. I just wanted you to know." And I get these... It's not a one-time thing. I get it periodically. And other members of the department do too. We know the course is an important course. And I know the students take with them enough knowledge that, at least for some of them, it makes a difference. And that's always a great feeling, to get that kind of feedback. (PFI4)

In addition to feedback from former students, Paul uses a (school) standard, quantitative, five-point scale course evaluation questionnaire. Unfortunately, Paul does not find this questionnaire helpful: "I don't believe a word of it, so I don't think it tells me a thing" (PII3). In order to improve the usefulness of the form to him, Paul adds open-ended questions to the course evaluation, but:

Lately they've been much more about the materials than about me personally—I've been teaching long enough that I know what my strong and weak points are, I don't need to hear it again. I've improved as much as I can in the ways that I need to improve, and... I'm not gonna talk slower—I grew up in New York and, even though some people think I talk too fast, I can't change that and not be boring, so that won't change. There's a limited amount of time for doing examples in class, I know the students would like me to spend the entire class

period just doing examples. I can't do that. So, I know they're gonna ask for more examples, they like it when we do examples, but there's a limited amount of time and we can't always do that. So, I know those questions, so I've been asking lately much more about the multimedia materials, how they're used, and about their experiences on the computer, and how I can be more accessible by email and things like that. So, it's been more practical. (PII3-4)

Just because Paul attempts to create an atmosphere in which students can learn and understand statistics, it does not mean that he is an effective teacher of statistics. Paul described himself as an effective statistics teacher in the following manner:

I teach to different audiences. For the broad audience, an introductory course, I take a very practical attitude. I want my students to be first acquainted with how statisticians think. I think there's a mode of thought, a certain degree of skepticism, about sources of data, about the way that data's collected, about sources of variation, that can be taught, and that people don't have naturally. In fact, I think there's good psychological research to show that humans don't think that way naturally. So you need to be taught some of those tools.

I think it's helpful for many of them to have pure skills, just to know how to do a t-test or a regression analysis or how to interpret a correlation coefficient, although I doubt much of that stays with most of my students for very long. If I've affected their ability to read the news when statistics comes up and to be more skeptical about it, I count the course a success, although certainly they have to show more knowledge than that to get out with a decent grade. And if I'm accomplishing that there's almost a citizenship angle to that. I think I am making them better citizens, making them better scholars for those who want to be scholars, but many of them don't want to be scholars. (PII2)

Since he had mentioned a citizenship component for the broad audience of introductory statistics students, I asked Paul if he looked at the introductory statistics course as a 'consumer statistics' course. He agreed with my term. As a follow-up question, I asked him if he tries to work some of the conceptual understandings that he uses in his advanced classes into the introductory course for the broader audience as well. Paul wholeheartedly agreed: "Oh, absolutely. The more they can understand, the more they can visualize it, the better off they are" (PII2).

Students take Paul's introductory statistics class because "it's required" (PII10).

Paul doubts that any of his undergraduate introductory statistics students are there voluntarily. According to Paul:

Some of [the students] may see the wisdom in taking the course, some of them may actually think it's a good course, but the most frequent compliment that I get is "I didn't hate this course as much as I expected to." (PII10)

Even though students take the class as a requirement, Paul tries to "have them leave the course with an understanding of why they were there" (PII10). It used to be that "the answer we had always given to the question 'why am I here?' was always 'it's required. Shut up and sit down'" (PII10). Now, Paul tries to show his students that "statistics is worthwhile, and we're teaching them how to think in a useful way, that this mode of thought is a useful mode of thought" (PII10). It is Paul's hope that the students "really are coming away with new skills and new concepts that are valuable to them" (PII10).

The differentiation between skills and concepts above is important. While he hopes that students learn both new skills and new concepts, Paul would rather teach concepts to his introductory statistics students. Paul's hope is that:

Students come away from this course with a deeper understanding about how statisticians think, and, as a result, with a deeper understanding of how scientists think, how to think like a scientist. (PII7)

To Paul, this differentiation between skills and concepts and his preference for teaching concepts to his introductory statistics students is political in nature (PII7). As Paul said:

I think we are really doing battle against New Age thought. I think these are people, these are students who can walk into a pharmacy and find homeopathic medicines. They need to understand what it means to test for efficacy and safety and what it means that these medicines have not been tested.

These are people who find horoscopes in their local paper. They need to understand what the difference is between that and science.

These are people who hear outright demagoguery about sampling in the Census. I think it's really important that they understand what a sample is and why you could assert that the accuracy of a sample could be known, *even* if the population is huge. And, in fact, regardless of the population size. Much of the demagoguery focuses around "but it's such a small fraction of the population we are sampling," and they just have to understand that that just isn't so.

I think it's really important that we teach people to think. And, too rarely does that happen. I think more and more college courses are teaching skills. And we're not teaching students to think. And, almost universally, high school courses are teaching skills and not teaching people to think. So I almost feel I'm taking a political and moral stance here in trying to teach my students to think. I would much rather do that than teach them skills. The skills sort of go along the way, but anybody can do skills.

And one of the great advantages of the technology is that it offloads the skill a great deal. You say to the students: Don't worry about that formula, the computer knows how to compute it. What I want you to know is what it means. I don't expect you to memorize the formula. I don't expect you to be able to do it by hand, with a calculator. In fact, calculators are forbidden on my exams. I expect you to interpret the result. That's what I want you to think about—I want you to think "Does it make sense?" I want you to be able to tell me, in words, "What does this mean? What is it supposed to mean? And do we know enough to know what it means?" So that's the emphasis. And, that makes me old-fashioned, I'm afraid. In some sense I'm afraid that's not what many people think they're teaching. (PII7-8)

I asked Paul upon what learning theories he bases his teaching. He answered very frankly, "I don't base my teaching on theories. I don't know learning theories, so I have no theories to base it on" (PFI3). When I asked Paul what the word "constructivism" meant to him, he responded, "it doesn't mean anything to me. In fact, I only heard it very recently. So, it certainly is not a theory I identify" (PFI4).

I reminded Paul that earlier in the week he had asked me if constructivism was somewhat of having students construct their own knowledge. Paul now said:

If you asked me to invent a theory of learning that might go under the rubric of constructivism, I guess I would say that I am very much aware of the fact that we

learn, everybody learns, by constructing our own understanding and by fitting that understanding into an image of that part of the universe that corresponds... in trying to maintain a consistent view of how things are. And that, until you have fit new knowledge into that overall understanding, you're not going to retain it. It's just a random fact; it's very hard to retain. So, if that's what is meant by constructivism, I can imagine that term being applied to that approach. I'm very much aware that students have to do that. (PFI5)

I then asked if Paul would believe in his definition above as a learning theory. He

continued:

Oh, I firmly believe that you don't learn anything until you have constructed the learning for yourself in some sense. You, at the very least, have to paraphrase it for yourself and rephrase it to fit it into your understanding of things, to fit it into your worldview. And if you can discover it for yourself even, then you're much more likely to fit it into your worldview. Just being told something is not a very good way to learn. (PFI5)

Working from Paul's own definition of constructivism, I asked how he allows or encourages his students to construct their own knowledge. Despite not liking my wording of the question, Paul responded:

If you accept the statement that that's the only way we learn, then it's not "Do you allow them?" If I forbid them to do it, they won't learn. So, it's what they have to do. Because I have a large class, I can't do it with discussion. I can't do it with a Socratic method. So, part of the design of *ActivStats* was to put students in that sort of situation where they were free to construct their own knowledge. (PFI5)

Instructional Strategies

Paul's instructional strategies can be grouped into four basic categories: direct instruction versus interaction between his students and him; exploration into and visualization of the concepts; linkage between statistics and students' life experiences and/or homework; and miscellaneous strategies. The following paragraphs address Paul's instructional strategies, beginning with direct instruction and student/teacher interaction.

Despite his casual classroom presence, there is not a lot of interaction between Paul and his students during class time. Even so, Paul does solicit questions from his students "and sometimes I'm able to elicit questions" (PII4). I asked Paul in what ways interaction could be increased in a large statistics classroom. He responded:

Well, it could be increased by...having various discussions where you elicit suggestions from the class. I just don't think that's particularly helpful. I don't think that that accomplishes what you want. (PII5)

Although discussion during class time would get students engaged in their learning and understanding of statistics, Paul has not been overly successful with generating discussion:

I've tried a little bit, and I don't think the subject lends itself very well to that. You can't have an opinion on the Central Limit Theorem, whereas in many of the other subjects taught in this school you can have at least two sides and often four or five sides, and the class benefits from hearing the union side and the management side. And having those argued between two students with a professor mediating and evoking opinions on both sides, I don't have subjects on which I can do that. (PII4)

Even though Paul does not believe that statistical concepts lend themselves well to discussion, Paul would like to increase the amount of interaction in his introductory statistics class. The size of Paul's class (approximately 300 students) has an impact on the instructional strategies he employs in the course:

I far prefer the smaller class, because I can get more interaction, because I can assign projects and have students work on things more on their own. I think once the class gets to about 50, I really don't care if there are 50 or 500 or 5000 around, as long as I have enough teaching assistants. At that point, then it's mostly just a question of whether there are enough humans who know the subject for the students to talk to when they need to. (PII4)

Typically, there interaction between Paul and his students consists of Paul "trying to find out where they are and what they understand [and] figur[ing] out how to make the

assignments appropriate to catch up to where we should be" (PII12). Paul has used one interactive lesson in class that works well in his large classes:

There's a lesson I like to teach in which I try to get the class to design an experiment and elicit from the class what the treatments ought to be, who the subjects ought to be, how we'll sample them, how we'll treat them, how we'll observe them—whether we'll double blind, whether we'll use a placebo, things like this. And there it helps to have a large class of people because no one person among the students will think of all of those things. (PII5)

Even so, Paul reported that this brainstorming activity on experimental design is "an unusual class for me. What you'll see is much more likely to be a lecture" (PII5).

Paul tries very hard to be dynamic even when he is lecturing to his students. In fact, Paul reported that he is:

Aware of the fact that it's a performance. That, for a group of that size, all of whom are there because it's a required course, I have some obligation to grab their attention. (PFI4)

He would not "ever go so far as to think I was just an entertainer" (PFI4). Instead, Paul said, "I do try to convey the enthusiasm that I genuinely feel for the subject" (PFI4). Paul mentioned that he has been successful in this, since many a student has told him that s/he appreciates the enthusiasm Paul has for statistics "even though I couldn't muster it" (PFI4).

The performance that Paul puts on for his students is not dependent upon the number of students attending class:

I don't mind performing in front of a large group. And it is a performance, and I know that. But I don't think the performance is all that much different before 50 or before 300. (PII4)

For large classes, Paul does "think that the physical facilities matter more" (PII4). For example, Paul reported that:

I do worry about having rooms where I have adequate computer projection facilities and adequate control over the lights and enough board space when I have to write letters that are 3 inches tall or numbers that are 3 inches tall. That becomes a little bit more of a problem. (PII4)

In addition to lecturing, Paul typically works examples in class, but "there's a limited amount of time for doing examples in class" (PII3). Paul is very aware of the fact that "the students would like me to spend the entire class period just doing examples. I can't do that" (PII3).

During one example in class, Paul presented his students with the formula for a general confidence interval. Paul mentioned the tradeoff between the level of confidence and the width of the interval by using the students' midterm scores as an example:

I can tell you what your grade is going to be on the next prelim with a high degree of confidence—it will not be less than 20 nor will it be greater than 99. Didn't help you much though, did it? Doesn't make you feel good. You'd much rather have a narrow interval, you'd like precision... Okay, I can tell what your grade is going to be on the next prelim—it's going to be between 88 and 89, and I'm about 5% confident of that. But you're not happy about that either. I gave you a precise interval, but I couldn't be confident about it. Well, that is our dilemma—that's the problem we have here. (PFCM7)

Following this mention of the tradeoff between the confidence level and the width of the interval, Paul used *ActivStats* to demonstrate this tradeoff pictorially.

For class on Tuesday, Paul had intended to talk about confidence intervals using both the normal distribution and Student's t-distribution. Instead, he talked only about the normal distribution. Paul had finished up Tuesday's class by telling the students that he "pushed hard enough for the first day back after two weeks off. I can see I pushed you to your limits" (PFCM10). Paul readjusted the homework assignments to fit with what was

covered. When asked on Thursday how he made the decision to change his lesson plan in the middle of Tuesday's class, Paul responded:

It seemed to me that the class wasn't going to take much more than that. I can usually get a feeling for the class as paying attention and sharp or whether they're out of it. And this group has been a very good group by and large. I can usually push them fairly hard as I did today. On Tuesday I didn't feel that they were willing to take anymore. (PF11)

I asked Paul what clues he had gotten from his students to indicate that he should make this change. Paul's clues included "people not paying attention, people doodling, minor hubbub of chatting, an undercurrent of chatting" (PF11). Paul mentioned that he has taught in rooms where he could not get this same sense from his students and that, as a result, he did not like these rooms.

The room in which Paul taught was equipped with technology for playing videos and doing computer work, including working with *ActivStats*. Paul's use of *ActivStats* as a teaching tool is discussed beginning on page 120. In this section the discussion is limited to the use of *ActivStats* as an instructional strategy for students to explore and visualize statistics concepts. The concept that students were learning during my visit was inference.

Paul took advantage of *ActivStats* by having students develop their own understanding of p-value²¹. During the time between Tuesday and Thursday's classes, the students who did their *ActivStats* homework were:

Placed in a situation where, without being told, they're asked to test a hypothesis. And they invent the reasoning of hypothesis testing for themselves because I've trapped them in a corner where that's about all that they can do. (PII13)

²¹ In hypothesis testing, the p-value is defined to be the chance that you would see something as extreme as or more extreme than the data that you saw, assuming that the null hypothesis is true.

In this exercise, students each found a "personal p-value to see how unlikely what they observed had to be under the null hypothesis until they got uncomfortable" (PII13). Paul reported that "it's interesting, the majority of [the students] have a personal p-value pretty close to 5%. Five percent is a psychologically pretty good value for most people" (PII13). After students had done the *ActivStats* exercise on their own, Paul was able to ask them in class how they came to their conclusions.

By asking students to work on a particular unit in *ActivStats* outside of class time, Paul has found that he can tie concepts from class time in with the students' experiences with *ActivStats*. Paul can draw from the students' experience by saying:

"You remember seeing this... let's make sure you understand where the pieces were or how it worked" or "Let's pull out that data set you saw and look at it again" or something like that. (PII5)

Paul is also able to repeat some of the simulations that the students have done on their own during class time. Paul repeats such simulations as a confidence interval simulation:

To be sure [the students] understand what they're doing—where the population is, where the sample is, where the sample statistic is, and what we're developing as a sampling distribution, and why we can use that as the basis for a confidence interval, and things like that. (PII13)

By building upon what students already knew, Paul was able to make each aspect of the process of building confidence intervals seem matter of fact. Paul told the students that what they were doing now was "not new information, it's just another way to write the same old stuff" (PSCM8).

Paul was also able to use a tool in *ActivStats* to reinforce the notion of the confidence interval. Following his discussion of the tradeoff between the confidence

level and the width of the interval (see page 115 of this chapter), Paul returned to the tool in *ActivStats* to show the students what he had just described. With this tool, Paul illustrated the "tension between the precision of the interval, which is how narrow the interval is, and the certainty that we have about that interval actually catching the true value, which is our confidence level" (PFCM7-8). He explained that this "tension" is the "underlying lesson of confidence intervals" (PFCM8).

For the most part, Paul tries to make statistics "colloquial, to try to bring it into everyday discourse" (PFI4). In fact, Paul mentioned that:

As much as possible I try to bring current events into the classroom, I try to discuss things that have been in the news lately. Don't tell my students, but the next exam is about the Dow Jones average since it reached 10,000, so I was able to come up with some questions related to that. I was just writing those questions last week. That's typical that I'll take something that's current and either use it in class or have it show up on an exam. (PII2-3)

Students in Paul's introductory statistics class take two preliminary exams and one final exam. The format of the preliminary and final exams is primarily of the short answer variety. The two preliminary exams make up 55% of a student's grade, and the final exam is 35% of a student's grade. Weekly homework assignments constitute the other 10% of a student's grade.

When writing the exams, Paul takes real data (usually current) and analyzes the data on his computer. He then takes parts of the computer outputs, includes a story about the data, and asks students to tell him what it means. I asked Paul how this helps him evaluate student understanding. He responded:

We give them enough rope to hang themselves... The best way to find out what their understanding is to give them an open-ended question and let them bullshit. And they will! (PII10)

If he had the technology available, Paul "would give [the students] data sets and questions and guide them through an analysis" (PII9).

When I was visiting Paul's classroom, Paul took some of the things his students have already seen/heard and put the pieces together in a different way. He linked new reasoning with past reasoning and experiences. Paul told his students a story about William Gosset, employee of Guinness Brewery and founder of Student's t-distribution. Paul even used the students' upcoming exam as an attention-getting device for his students by slipping in the statement: "how to save yourself 10 points on the next prelim... When I put it that way, I get your attention a little bit more perhaps" (PFCM8). Paul reported that what I saw during my classroom visits was pretty typical: "in terms of my lecturing style or the way in which I go back and forth between the board and the computer, that's pretty typical" (PFI3).

Use of Technology

As a believer in authentic instruction, Paul mentioned that we need technology in the statistics classroom since "that's how we do statistics, we use computers" (PII5). Throughout his tenure at Cornell University, Paul has insisted on using computers in the classroom, from batch computing to interactive computing and *Minitab* to microcomputers and desktop computers and *ActivStats*. Now Paul has been arguing for the use of multimedia. According to Paul, "each step of the way I've sort of dragged the school kicking and screaming into the next step" (PII6).

In addition to authentic instruction ("they [the students] are learning to do what statisticians do and what anybody does when they use statistics" (PII6)), Paul mentioned that technology "permits experiential learning that's not possible otherwise" (PII6). Instead of hiding what is going on in simulations, multimedia (in this case *ActivStats*) can:

Show you what happens with what happens with every single value or number. You see them generated and you see them migrate from where they're generated and fall into a bin where something then happens to them. That imagery I thought was vitally important. (PII6)

Paul added, "I think it's very important pedagogically that students see where the simulated instances are coming from and where they're going" (PII6).

Each student in Paul's introductory statistics class owns a copy of *ActivStats*. Typically, Paul asks the students to work on a particular unit in *ActivStats* on their own. Paul reported that he does not spend class time playing activities from *ActivStats* that the students could do on their own. Instead he uses the work that the students have done in *ActivStats* to discuss ideas during class time (see the discussion on page 117 of this chapter).

Paul did say that multimedia, particularly *ActivStats*, provides a form of (individualized) interaction for the students, albeit by a computer. In fact, this kind of interaction was one of the reasons why he designed some of his multimedia packages:

One of the reasons I designed some of the multimedia things was to provide that kind of interaction, when I couldn't provide it myself. The impression I would like the multimedia to give is that I am standing by the student's shoulder, suggesting things the student might want to do on the screen and then standing there patiently while the student tries them. To the extent I can, that's what I've tried to do. (PII5)

In addition to interacting with students, technology "offloads the skill a great deal" (PII8). Technology prevents the students from having to memorize and use formulas. Paul said that with technology "you say to the students: Don't worry about that formula, the computer knows how to compute it. What I want you to know is what it means" (PII8).

Paul has found that students in recent years are savvier with technology than students of the past. In the past, Paul had to spend a week or two of class time teaching students to use the computer, including:

How do you sign on, how do you get your user id, once you get on how do you get to *Minitab*, how do you launch it, how do you read your data in, where's the archive of the data files for the class, how do you print things out, which printer is it going to go to, how do you collect it, how do you hand it in... (PII7)

Now, Paul can write down the URL²² for the course website without students asking what a URL is and how to use it. As Paul said, "Sure, class URL, write it down" (PII6). As Paul said, "the world has changed. There has been an entire shift in the course of a year or two" (PII6). Paul said that this change in use of technology is:

As sudden a change as anything I've seen in all my years of teaching. I've never seen anything change that rapidly. And, of course, it's remarkable to me, because I've been hounding on it for twenty-five years hoping that it would change, and then it has changed overnight. (PII7)

Despite the recent changes in technology, Paul still does not have the students use the computers during exams:

I tell my students that "if only" we had the technology, the exam would be that they would sit with their computers, I would give them data sets and questions and guide them through an analysis. (PII9)

²² The term "URL" is an acronym for "Uniform Resource Locator." A URL is the address for a website and specifies the home machine of, path to, and protocol of the website.

Paul has tried to use computers for exams on two occasions, and both Paul and the students thought the exams were successful. However, "the technological hassles were enormous, of things not working, and things breaking, and stuff like that" (PII9). Paul has not given computer exams since. Paul did say, "If I taught at one of the schools where everybody coming in bought the same portable [computer], I would almost certainly give exams that way" (PII9).

Paul told me that the classes I would observe were "a good place to see the technology used, because this is an area where I use simulation very heavily" (PII23). By the time of my site visitation, Paul's students had been doing simulations with *ActivStats* for several weeks. The students had been doing simulations in *ActivStats* that were intended to help them visualize the Central Limit Theorem. The simulations the students' used had:

A bar that might be colored red and blue in stripes or multiple colors or go from one to zero or whatever. A little cursor moves along that really is random. It moves rapidly and stops according to [the student's] control, generating truly random values. The bar has stripes of color in it and there's a little dot next to the bar that takes on the color of the stripe that the cursor is stopped over. And it's that color that we look at; it's the proportion of red outcomes that we are looking at as our statistic. (PII13)

During class on Thursday, Paul told his students that the inference section of the course was "set up very much for you folks to learn using the computer" (PSCM1). In fact, Paul told his class that "this is the part of the course where having a computer really has changed the way we do things, because so much of it can be understood by simulation" (PSCM1).

At this point in the class, the striped bar in *ActivStats* is hidden so that students cannot see the proportions of red and blue. Students generate random data from the (hidden) striped bar and are asked if, based on their results, they believe that the striped bar is half red and half blue. Paul said that:

While everybody has his own experience, because the reality is in fact randomly generated each time you run it, it is randomly generated so that the true answer is not within 2% of 50. So the closest anybody gets is 48% or 52% red. And, therefore, as they collect data they will ultimately reject the hypothesis of equal red. They generate outcomes, they watch the percentage of red settle down, and at some point they're asked to make a conclusion whether they believe it is [50%] red or not. (PII13)

Paul told me that "part of the design of *ActivStats* was to put students in that sort of situation where they were free to construct their own knowledge" (PFI5) as they did when developing their understanding of p-value.

I asked Paul about his use of *ActivStats* in the classroom. He talked to me about its role as a "core piece of learning" (PFI2) instead of as merely a supplement. Paul has found that some teachers "bail out of *ActivStats*" (PFI2) when teaching inference, and "go back to their old ways and miss the benefit of all the work the students have done to get to this point" (PFI2). Paul mentioned that inference is "where [the students] can really benefit for it pedagogically, and the teachers are a little afraid of it" (PFI2). Paul feels, however, that the students "are really learning [statistics] on their own at this point of the course" (PFI2). When I asked Paul if he felt threatened by students learning on their own, he told me that students really need to do learn on their own at this point in the course.

In addition to having the students use *ActivStats* outside of the classroom, Paul uses it in the classroom as well. Paul had explained the meaning of 95% confidence in confidence interval construction without the use of *ActivStats*:

If we keep doing this procedure, calculating a mean and a margin of error for it, or any statistic and a margin of error for it, drawing another sample or doing another experiment, and once again calculating a statistic and a margin of error for it, all of them calculated to be 95% confident, one out of 20 of those intervals will fail to cover the true population parameter. (PFCM4)

Later in the class, Paul had *ActivStats* construct multiple 90% confidence intervals and had the students notice that only 1 of the 25 confidence intervals did not contain the true parameter. Here *ActivStats* was used as a visual confirmation of theory.

Also during his class, Paul had been able to quickly draw random samples with *ActivStats*. I asked him how he thought this ability to quickly draw random samples helped in the classroom. Paul's response was:

I hope it gives them a visualization to talk about. Those tools are... animations of things that I used to try to do with chalk or with my hands. You know, "imagine doing this..." And it's just so much more effective to do it in real time. I didn't change my lecture at all in doing that, it's just I can do it this way instead of having to write my answer out, so it's more efficient. I can do it quicker, I can do more of it, but it didn't change anything. That's what it was designed for. (PFI2)

Interaction With Students

Even though Paul tries to "convey accessibility" (PEQ1), Paul said that it is hard for his students to actually come to his office to talk to him. Some students do attend Paul's office hours. Since he had called statistics a "course that is inherently intimidating" (PII1), I asked Paul if the students who attend his office hours seem intimidated when they come to see him. His response was:

No. No. They're sometimes diffident, but I don't think they're intimidated. But they're most likely to come to see me when there's a personal problem or they need an exemption from something. (PII1)

Paul has noticed that students do seem to feel that they can email him with questions. Paul said that email access has been a real advantage for individual students to establish and maintain contact with him (PII1). In fact, email has proven to be Paul's most constant form of feedback about his students' understanding of statistics:

The feedback... the most constant feedback is my email, is what kinds of questions I get. And, if the question is "How do you know how many degrees of freedom you have?" then I know that they're worrying about the details. If the question is "I said this as my interpretation of the confidence interval, I said that I was 95% sure that the true mean was between 3 and 5 and it was marked wrong. I don't understand what I did wrong," then I think learning is taking place and I can talk about concepts. (PII8)

During class time Paul rarely has the opportunity to assess his students' understanding. Question and answer periods prior to exams help Paul to get a sense for student understanding, but there are only a few opportunities for this. During class time Paul does look for nonverbal cues of student understanding, including looking in the eyes of the students: "if they're obviously totally lost, then I have a sense" (PII10). Paul said that he also gets a sense of the students' understanding through the types of questions that students ask in class, in office hours, and through e-mail. In addition, he "constantly" (PFI3) asks his teaching assistants to give him feedback about the students' understanding.

Paul has found that teaching this introductory statistics course to be rewarding, particularly from the aspect of knowing that he has been effective as a statistics teacher:

Well, the introductory course is very rewarding from that point of view, because these students come in really knowing nothing. Those who think they know

something, like what a correlation is, usually don't. And they leave knowing a fair amount by the time...and I know that they got it in class, so I can tell that there's a fair amount of knowledge that they got. I guess that's my primary measure. (PII3)

According to Paul, "students come into the course not knowing very much statistics and they leave the course knowing statistics" (PFI4).

David Moore at Purdue University

The following story is about David Moore at Purdue University. At the time that I visited Purdue, David and his class had just finished talking about sampling and were beginning a section on experimental design. This story discusses David's teaching and his students' learning about experimental design and centers around the four themes that emerged from the data of all four participants. The following four themes are explored in this story: David's teaching philosophy; David's instructional strategies; David's interaction with students; and David's use of technology in his introductory statistics classroom. Again, the analysis of the data that constitute this story is reserved for Chapter 5 of this document.

Teaching Philosophy

This section of David's tale addresses David's teaching philosophy. The following paragraphs talk about David's teaching philosophy through four sub-themes: David's own teaching; effective teaching in general; the purpose of Statistics 113; and, David's knowledge of learning theories.

David reported that he finds teaching his 480-student introductory statistics class difficult. In one sense, "it's not satisfying because you don't have that sense of personal connection to the students" (DII13). In addition, "you feel that you're spending a lot of time keeping the big machine functioning smoothly" (DII13). To David, running the 'big machine' that is Statistics 113 is "not nearly as satisfying as teaching a course where you get more feedback, direct and indirect, from the students" (DII13).

The size and structure of the room in which he teaches also impacts David's satisfaction with Statistics 113. For example, David reported that "in a class of 150 I can walk into the class, and I do" (DII6) because there "nobody is more than 40 feet away" (DII6). However, in Statistics 113 there are students "who are a couple hundred feet away in the big lecture hall I have now" (DII6). David has found that "there's a lot in just the physical layout which creates less of a barrier between you and the students. And these psychological things are important" (DII6). The following is one experience David had that relates to psychological creation of a barrier between David and his students stemming from the physical layout of the room:

I once taught in a room in the physics building in which the front of the room had this immense back topped with black marble or something set up with instruments of torture for the physics class that was coming in, and the overhead projector was behind this bank. You know this is a 30 foot-long bank and the overhead projector is behind the bank. And you couldn't make an end run around the bank; it was just hopeless. Even though that was a class of only about 150, there was that barrier between teacher and student. Being able to move, being able to get into the students, is a good way of helping to change the attitude in a class. And of course being able to ask questions and get answers... And I can't ask questions and get answers in a class of 400. (DII6)

Even if David could ask questions and get answers in Statistics 113, "the people in the back can't hear answers from people in the front anyway, so it's not an all class experience" (DII6).

So that all of his students can see what David is writing, David uses transparencies and two overhead projectors. During my observations, I noticed that David does not write notes verbatim on the transparencies. Instead, his transparencies are more of an outline of the major points of the lesson. When I asked David why he writes only the main points on the transparencies, David said:

If you write everything down, I'm sitting there staring down at the transparency writing instead of looking up at the class, and the students are looking up at the big screen writing, and nobody is thinking. (DFI2)

David also mentioned that "I don't get much feeling for how a class goes in a lecture this size" (DFI4). By not writing the notes down verbatim, David has the opportunity to look around the classroom to "see if students are paying attention" (DFI4). However, David pointed out the following:

Of course, the students that you notice most are the students who chose to sit closer, down near the front. Of course that's a biased group, because the ones who choose to sit there are always paying more attention than the ones who choose to sit way up in the back. (DFI4)

David believes "any teacher who's honest will always recognize that the students do the learning. It's hard to say how much of that learning we help" (DII5). Even so, David did address the issue of effective teaching:

The normal way to define effective teaching is that it helps students learn. And that, of course, means that effective teaching is very difficult to measure, because learning, in the end, is something students do. And, whether we can effectively

help them learn varies with our setting. I'm not convinced, for example, that much of anything I do in our 400-student lecture is a great help. Although, some students seem to think it is. (DII4)

David's students do find him to be "relatively effective" (DII5) as an agent in the learning process. Proof of his 'relative effectiveness' can be found in historical student ratings of his teaching:

I think it's literally true that I have the highest student ratings ever recorded in every course I've ever taught in my 30 years here...from top to bottom. The ratings, of course, go down in a class of 400 professional liberal arts students and up in a class of graduate students, but they're still at least as good as anybody else's. (DII5)

Despite high ratings with his students, David is "not sure what that means" (DII5), especially in large lectures. David does think that he is effective with "groups of students that I interact with often enough and closely enough" (DII5), like the graduate students in education who take a two-semester introductory statistics sequence. David described these students to me:

These students are grown-ups. Education students have often been out teaching for a while and now have come back to get a Ph.D. They're often not strongly quantitative. They want a Ph.D. in education for vocational reasons—they want to be a superintendent of schools or a principal. But the faculty say the Ph.D. is always and everywhere a research degree. So there's some tension there, and the fact that they have to take two semesters of statistics is a locus of that tension. But these students will work and want to learn. And I'm convinced from their response, from long experience, that I probably know better than anybody else in the university how to explain statistics to these students, how to bring them along so that they learn they can actually do it. So there's a group that, yes, I think I am effective with. (DII5)

I asked David how he knew that he has been effective with the graduate students in education. David told me that, in the past, the graduate students in education have thrown a surprise party for him, written him notes, and told "their friends to take the

course and not to take it from anybody else" (DII5). David also mentioned that the graduate students in education:

Don't expect to be able to learn statistics, many of them. And when they find that they can learn statistics, they're so obviously grateful. And I tell them that it's their hard work, which is true because they do work hard—they're grown-ups and they work hard. But they didn't think they'd have a setting in which hard work would lead to learning. And I do know how to create such a setting. (DII5)

Following the statement above about his effectiveness with graduate students in education, David addressed the issue of effectiveness in Statistics 113:

Now for [Statistics 113], for these 400 freshmen and sophomores, I'm not sure that I'm effective. I'm not sure what it means to be effective with that large a group. ... I actually spend a lot of my effort in what you might call organizational and administrative things—having a very elaborate website, which the students indicate that they like; and working with the TAs to try to make them more effective, because they're the ones who see the students in small enough groups that there can actually be some interaction. And the students actually come to recitation, where they may or may not come to the big lecture where they're anonymous. (DII6)

When thinking about effective teaching, the organization that David mentioned above is first in his mind (DII4). According to David:

Statistics has a lot of structure. And students don't find it easy to see the structure. And being organized, in my informal experience, helps students at any level learn. (DII4)

David said that it is important to have organization on both local and global levels. One method of local organization that David uses in his lecture is to "adopt a little more of an outline style than you normally would in writing" (DII4). Global organization is more of an overarching concept:

Global organization, of course, in content is also important—know where you're going, what pace you're going there at, and let the students know in advance just where they'll be going when, so that they can look... They aren't always flowing

clearly. [The students] can look and see what's coming next and how rapidly it's coming and when the next exam is. Students seem to profit from having that kind of structure. (DII4)

In his experience, David has found that organization is:

One of the things that experienced teachers do a much better job of than inexperienced teachers. They have a better sense of how fast you can go and how difficult different topics are and what things are clearly important to spend time on and so on. (DII4)

In addition to organization, David mentioned that "clarity of presentation" (DII4) is also a necessary component of teacher effectiveness. While clarity of presentation is important, it is difficult to guarantee:

Because what's clear is judged by the receiver, and students have a lot of unexplained individual variation, including unexplained individual variation in what kinds of explanations that they find clear. (DII4)

Besides organization and clarity, David mentioned that "there are the interpersonal aspects of teaching" (DII4) that are important as well for effective teaching. The interpersonal aspects of teaching that David mentioned included:

Your own enthusiasm for the subject, your attitude toward the students... Never letting it slip out that you think the students are idiots, which seems to be a somewhat natural feeling among college professors. But, whether you feel that way or not, this is something that the students should never glimpse. Not putting down individual students when they ask questions and so on and so on. Being perceived as fair in the standards that you set and the way you apply these standards. (DII4)

According to David all of these interpersonal aspects of teaching "help the students trust you, and they learn from you better if they trust you" (DII4).

In his own teaching experience, David has found it easier to employ these interpersonal aspects of teaching in his smaller classes of "say, 50 students so they are really interacting with you" (DII4). In addition to his own difficulty of including

interpersonal aspects in his large lectures, "students in a big lecture are anonymous, and so they don't feel responsible" (DII7). David has found that:

One of the big differences between a lecture and a small recitation is in the recitation the recitation instructor knows their name and is, in the end, going to have a component of their evaluation on how well they participated in the recitation discussions. So lack of anonymity is important. (DII7)

In the past, David considered requiring attendance at and assigned seats in lectures, but decided against doing either of those two things:

I decided not to on two grounds. One is sort of philosophical: [the students are] at a university now, they're not in high school any longer, they need to make their own decisions about things like coming to class and find out what the consequences of those decisions are. And I can't blame some students too much if they don't come to the large lectures because I think they're only marginally effective. But the second reason is if you require attendance in a group of 400 students, what you get is a bunch of people sitting in the back listening to headsets and reading the newspaper and talking, so that it degrades the quality of the experience for students who really wanted to come. (DII7)

The students who take Statistics 113 are primarily from the School of Liberal Arts at Purdue University. Other students come from other non-science programs at Purdue. Students at Purdue take Statistics 113 to "partially fulfill their school's quantitative requirement. So relatively few of these students are going to use statistics directly" (DII). To David, the question about the purpose of Statistics 113 is:

What do they need to know as part of their general education that will help them in a broad range of other subjects and help them in those many different directions they're going to go in everyday life? (DII9)

David has found that the answers to this question:

Tend to be along the lines of larger ideas rather than technical details. [The students] ought to know why random sampling beats voluntary response. And they ought to know why randomized comparative experiments are the gold standard for getting good evidence for cause and effect. (DII9)

Such concepts "really are a core of statistical ideas but are not technical in nature" (DII9). In addition, students in Statistics 113 "often get more of a taste than we give in our other courses about how statistics contacts other disciplines and other issues" (DII9).

As I had asked Paul during my interview with him, I asked David whether he viewed Statistics 113 as a 'consumer statistics' course. David responded:

They certainly are going to primarily be consumers of statistics, but they won't see themselves as consumers of statistics. They're consumers of information, which often has a statistical component. (DII9)

David mentioned that he thinks students "should know how to look for the clue words" in articles in the newspaper. To David, one trait that students should develop from Statistics 113 is "being intelligent consumers of information which has a statistical component" (DII9). Additionally, students in Statistics 113 will learn to think critically about numbers:

Students don't like irrelevant information. They come convinced that this feeling that every number that they see should be part of the answer. And since this is a course for liberal arts students, of course, one of the things I'm trying to teach them is you have to look at all this and find what's relevant in it. (DII12)

Statistics 113 is also an arena in which students can learn about important experiments and surveys that have been done. For example, "the physicians' health study is something they should know about because that's an important experiment" (DFI3). Two of the surveys that the students learned about in a video about survey sampling were the current population survey. David told me that he thinks the students "should know what the current population survey is. That's a very important government survey" (DFI3).

David also believes that it is important for students "to have their actual quantitative skills improved, but not just by going over stuff they did in high school" (DII9). This is the reason that David has his students:

Actually do some quite simple data analysis just using pencil and paper and calculators rather than software. There are some ideas there, but they also need to do some quantitative work, because they will almost certainly need not to lose what quantitative skills they brought with them out of high school. And this is one of the few places, if they're a liberal arts student, that will help them keep those skills. (DII9-10)

According to David, "what I think about learning theory doesn't help a lot" (DFI7) to teach Statistics 113. David mentioned that "learning theory very often doesn't pay enough attention to" (DFI7) is organization of the course material:

So that it's accessible for the students. Students have great difficulty seeing the larger picture, seeing how all the pieces fit together, seeing how what we're doing this week flows into what we're doing next week. And educational psychologists don't seem to pay much attention this. That is, they seem to think locally rather than globally. So giving clear organization, having everything available at the beginning of the semester for example, so the students aren't wondering where you're going, so that they can see just what they're going to cover and at what pace. Having things outlined clearly in handouts and in lecture and so on, just giving them an organized framework, I think is quite important and I always try to do that. (DFI7)

Another aspect of teaching and learning "that we do learn from the educational psychologists is that the students really have to learn by their own activity" (DFI7). David assigns weekly homework and gives weekly quizzes in an effort to support students learning through their own activity. David said the following about quizzes:

The quizzes are really intended to be learning tools. All assessment is intended to be in part a learning tool, but the quizzes have that emphasis very strongly. The quizzes are supposed to cover, and I hope I adhere to this most of the time, are supposed to cover really major points. (DFI7)

The quizzes David administered during the week of my site visit were examples of what David intends for student learning. David described the quizzes as follows:

[The students] all have to read something from a medical journal, and 3 of [the quizzes] just say "use a diagram to outline the experiment" and the other 3 say "the design section in what you just read said this was a randomized double-blind placebo-controlled trial. Tell me in a sentence each what each of those terms mean." (DFI7)

David's intention for these particular quizzes was to:

Give the students feedback that if they can't do that that they know they've missed something essential and they need to fix it up before an exam happens. (DFI7)

David writes quizzes like the one he mentioned above to promote student learning:

The quizzes are really intended to be learning tools. All assessment is intended to be in part a learning tool, but the quizzes have that emphasis very strongly. The quizzes are supposed to cover, and I hope I adhere to this most of the time, are supposed to cover really major points. (DFI7)

David also assigns his students weekly homework to keep the students "interacting with the material" (DFI7). The homework and the quizzes together are "intended to get the students going" (DFI7). The reason that David supplements his lectures with homework and quizzes is because "in the lecture I can't really do much that makes that part of what I think about learning operational" (DFI7).

Another belief that David "learned from the education people is that different media communicate differently" (DFI7). David mentioned that the videos he shows to his students "have an effect that my saying the same thing would not necessarily have" (DFI7). Multimedia in the classroom:

Communicates at a level which is not completely rational. If you want to be broad, you could say there is some learning theory behind mixing the media in the big lecture. (DFI8)

The teaching philosophies above were not learned by David during his formal schooling since he had no formal training in teaching. David has learned about teaching philosophy through his own reading of review or survey papers and through university-wide committee work (DFI10). The reading that David has done includes handbooks of research in teaching and learning as well as "several survey papers by Joan Garfield, for example, which specifically address statistics" (DFI10). David has found these papers on statistics to be "new and useful because traditionally education researchers have paid much more attention to probability" (DFI10). David also mentioned that "when I have responsibilities... for example two years ago I was on a university-wide committee on assessment of teaching" (DFI10) he does more reading.

David knowledge of learning theories does include knowledge about constructivism. When I asked David to define constructivism, he responded that asking for the meaning of constructivism is "like asking what democracy means to you" (DFI8). Even so, David defined constructivism first by saying:

At the simple level it simply means that learning is something the students do themselves. That learning is not information transfer. In fact this is a party line, you know all this, right? You take what the students have, they combine what they're now taking in with what they already have, and construct another level of knowledge and this iterates. And that I think is obviously true. (DFI8)

David added, "stronger forms of constructivism suggest that you can't do much to teach them, and I don't think that's true" (DFI8). David moved on to talk about social constructivism:

And then finally you get to social constructivism which essentially says there isn't anything to teach them, and that's a blunt way of putting it. But all knowledge is socially constructed and if we construct one way and they construct it another way in Uganda who's to say who's right and who's wrong? All we're trying to do

is get our students to buy into social conventions. And, well, I'm a scientist and I think that's blatant nonsense, without denying that there are social aspects to what questions we ask and what framework we answer them and so on. (DFI8)

With these definitions of constructivism in mind, David said, "I'm a constructivist in sort of a general sense" (DFI8). When talking with other teachers, David says, "learning is a student responsibility. Teachers like to hear that" (DFI8). David did chuckle after he said the part about teachers liking to hear that learning is a student responsibility, but he does believe that "students learn through their own activity" (DFI8).

I asked David if he would "buy [constructivism] as a general statement" (DFI8).

David response was that he would, however, he mentioned:

There are subtleties here. How far should you go in structuring the students' activities? Or how far should you go in the direction of discovery learning? (DFI8)

David admitted, "perhaps because I'm old fashioned, that I've never been a big fan of discovery learning. It works, but it's time consuming" (DFI8). In addition, discovery learning:

Requires an environment in which you can interact almost constantly with the students, because they go off in all sorts of byways and they have to be pulled back. (DFI8)

David added the following about discovery learning:

I have very mixed feelings about discovery learning. I'm traditional enough to think that I have a responsibility to help the students acquire a certain body of knowledge. And I only have them for so long, and the people in other fields who sent them to me have expectations for what they'll know coming out. And they would undoubtedly get a really deep appreciation of a very small body of knowledge by an intense discovery-oriented course. But we don't have the resources for that and we wouldn't get very far through the body of knowledge that I think they need to carry away from the only statistics course that they're ever going to take. I look at exercises like that as exercises in teaching the students how to learn rather than exercises in teaching them material. (DFI8)

When I asked David how good a job he thinks he does in setting up opportunities

for the students to learn for themselves, he responded:

I don't think we do a great job of that in these very large introductory lecture courses. We try to make it easier to learn by giving them a clear structure and by giving them multiple paths. We give them lectures, we give them the text, which often say pretty much the same thing but in different words with different examples. In the lectures it may be easier to see the big points because I can shout them out or underline them and so on.

But the lecture and the text convey pretty much the same material. The introductory video that I show often contains pretty much the same material. The recitation instructors will lead a discussion that pretty much goes over the same material. They have office hours, so the students can come in and ask questions.

We're trying to give them not only opportunities, but you might even say alternative paths. Some students learn better by reading, some students learn better by listening to the lecture, some students have to ask their recitation instructor and get specific answers to specific questions. But we aren't doing a lot directly to help them learn how to learn. (DFI9)

As a follow up to David's response, I asked him if he knew of any way that we could help the students learn how to learn. David said that resources and student maturity limit what can be done in courses like Statistics 113:

I don't know any way to do it for 450 students with the level of resources that we can afford to give for this course. In smaller courses group learning works very well. So in the graduate methods course for doctoral students in education that I keep coming back to by way of contrast, I tell them that I expect them to form study groups. And I'm not going to form the study groups because they know different people and they come from several different departments. But I expect them to form study groups and to work together on the assignments, especially on the SAS aspects of it which are frustrating for them because you can make one trivial mistake and get hung up.

And if you have 3 or 4 people working you tend to see each other's trivial mistakes. So they do form study groups. And this is a big help. And the study groups, often it turns out, have natural leaders. And the study group will send the natural leader to come see me and ask a question and then report back.

With undergraduates you might have to form the groups yourself. And with undergraduates it's harder to get them to get together outside of class, both because they're more scattered physically and because they're doing so many

different things. Graduate students are more focused and graduate students, of course, tend to form study groups with people in their own departments, so they're people that they're physically close to.

One thing you learn fairly quickly is that maturity and responsibility and willingness to work are more important than being smart and having the right background. Relative to the demands of the course, the education graduate students are much less ready to take the course than my liberal arts freshmen and sophomore students are. They've been out teaching for 10 or 15 years; it's been 10 years since they last did anything formally quantitative. And now they have to do statistics and, at the end of the year, end up with repeated measures designs with several factors and nesting. But they're grownups so they do it. The undergraduates... you've seen the figures on what percent of them have 5 or more drinks in a row each weekend... It's maturity much more than preparation. And it's very hard to motivate immature students. They're still in the growing up process. That of course is one reason why the course has so much structure: there's going to be homework every week, there's going to be a quiz every week. (DF19)

So what instructional strategies does David use in his classroom to help undergraduates learn introductory statistics? The following section investigates this issue.

Instructional Strategies

In Chapter 3 of this document, it was mentioned that David had no formal background in teaching, but that both of his parents had been teachers and that he had always had an interest in teaching. It was also mentioned that David did not teach during graduate school since he was on fellowship. During our initial interview, David discussed the model of teaching that he saw during graduate school:

In graduate school you get a model of teaching that's not appropriate for teaching introductory courses. Because in graduate school, it's assumed that the students are able to create their own interaction, and so the professor just spews out material as rapidly as possible, and the students are supposed to go home and interact with it themselves, or get together with their peers. But the model of teaching that we're exposed to in graduate school, although it may be appropriate

in graduate school, is not appropriate for undergraduates. And so when you come out of graduate school having just been exposed to that, and never having been taught how to teach you have to learn. But, after 5 or 10 years if you haven't learned, you may never. (DI11)

Now, with over 30 years of experience teaching, David has developed his own style of teaching. Still, he finds that some of the interpersonal aspects of teaching that are present when he teaches smaller classes are harder to employ when he teaches large lectures. In his tenure at Purdue, David has found that:

When you look across the campus, it appears that the lecturers in really big lectures whom the students find most appealing are people who can put on a show. The chemistry people are often good at this, they have explosions and colors changing and so on. (DI15)

When he was a student, David did not like it when his professors put on a show — "in fact I disliked it intensely. And I won't do that when I'm teaching" (DI15).

Instead of putting on a show, David sticks to instructional strategies that he thinks are appropriate for a large group, including showing videos and doing computer demonstrations. David uses videos because "we understand that videos have advantages in showing things that I can't tell and in changing student attitudes" (DI15). For his computer demonstrations, David uses "a lot of the little animated toys in *ActivStats* which can be launched independently and used to do classroom demonstrations" (DI15). David believes in using instructional strategies that are "appropriate for a large lecture. But I just can't bring myself to show rock videos and so on just because the students would like to see rock videos" (DI15). David's use of technology in Statistics 113 will be discussed further in the section on technology beginning on page 151.

One of the instructional strategies that David uses a lot during class is what he calls 'Key Ideas.' During our initial interview, David told me about these Key Ideas and how uses them in class:

I try to give them in most lectures 1 or 2 key ideas that I hope they'll pay attention to in their notes. So in the earlier unit we had Key Idea 1: To avoid bias let chance choose your sample. And Key Idea 2: To assess a sampling method ask what would happen if we took lots of samples from the same population.

And so tomorrow we'll have, now that we're on experiments, Key Idea 1: The most important thing about a statistical study is where the data came from. And observation versus experiment is a key part of that. And then Key Idea 2: Randomized, comparative experiments are the gold standard for evidence about cause and effect.

These are the sort of big, general things that subsume a lot of the details. And I actually try to say—again this is following the outline style—these are key ideas. And I tend to repeat these fairly often. When I come to Key Idea 2, I say, "Well, you remember that Key Idea 1 was..." and if I get to Key Idea 3, I'll say, "Well remember that we've two key ideas so far, here's the third..." You need to keep helping them see what the flow of ideas is. (DFI14-15)

David's Key Ideas were indeed present during both class meetings that I observed, though he talked about them in class as 'Big Ideas.' When introducing the importance of where data comes from, David linked the concept to what the students had seen in a video he had just shown them and told his students that the:

Big Idea is: The important fact about any statistical study is where the data came from. And with [what] you just saw in the video, between observational studies and experiments. Observation versus experiment is a key part of the answer to the question of where the data came from. (DFCM2)

When introducing the importance of randomized, comparative experiments, David said:

Big Idea 2: Randomized, comparative experiments. That's our name for this sort of thing. Randomized because we randomly assign subjects to groups, comparative because we compare more than one treatment instead of just applying one treatment to one group. (DFCM3-4)

David did not use the Big Ideas only to introduce concepts. The Big Ideas served as reminders later in discussion. At the end of class on Tuesday and at the beginning of class on Thursday, David reminded the class about the Big Ideas for the week. Both reminders were similar, and the following is his Big Idea reminder from the beginning of Thursday's class:

We already announced in the last lecture two big ideas for this week. Big Idea 1: The most important fact from any statistical study is where did the data come from and the distinction between observation and experiment is critical. Big Idea 2: Randomized comparative experiments are the gold standard for getting evidence for cause and effect. (DSCM1)

Lastly, when talking about randomized, comparative experiments, David was able to give relative importance to the Big Idea of randomized, comparative experiments:

And so randomized, comparative experiments have changed the way lots of fields do their business. This is a really Big Idea among all our Big Ideas. (DFCM4)

In addition to telling his students about the big ideas, there were also other concepts and/or nuances that David 'just told' his students. The following statements are examples of transmission from David to his students:

- That's an experiment, where you actually *do* something in order to observe the response. (DFCM1)
- So, observation we just gather data about some group or situation, with no attempts to change the situations. (DFCM2)
- An experiment, on the other hand, is active data collection and the key thing about an experiment is that it imposes some treatment in order to observe the response. And so a well-designed experiment is one whose design allows you to say that the response I saw really is the result of the treatment that I imposed, and not the result of something else in the environment. (DFCM2)
- Now a placebo is the medical term for a dummy treatment that ought to have no real effect... (DFCM2)
- Randomized comparative experiments are the gold standard for getting evidence for cause and effect. (DFCM4)
- The second principle is comparison. Always compare several treatments. Don't just use one treatment and let it go at that. (DFCM5)

- And then the third principle, which we've only talked about indirectly, but I ought to mention explicitly, is replication. The idea of replication is to use enough subjects so that the effect of the chance selection that you made averages out. (DFCM5)

Often, while telling his students about concepts concerning experimental design, David used examples. The examples that David used were typically issues that the students were familiar with, thus providing a link between a relatively new statistical concept and some existing knowledge of the students. The following is one such example:

Observational studies very rarely, I'm tempted to say never, but I'll say rarely... Observational studies rarely give good evidence for causation because of confounding. Let's illustrate that by an example. Pregnant women are told they shouldn't smoke. Of course everybody's told that they shouldn't smoke. But pregnant women are told even more strongly. Does smoking during pregnancy effect the child? (DFCM5)

Another example of connecting relatively new statistical ideas to the students lives' can be found in the following excerpt from Thursday's class meeting:

Usually when we want to talk about a change in the welfare system we just argue back and forth. It would clearly be better, now that we know about randomized comparative experiments, to do a good experiment where some families stay on the existing system, some families stay on a proposed new welfare system, and we actually see what the results are. Those experiments, in fact, have been done, and they were the basis for the major change in the welfare system that was made just a couple of years ago. (DSCM2)

During class, David also highlighted links between and among statistical concepts. Since the students had completed sampling just prior to learning about experimental design, David mentioned several links between the two sets of concepts. The following are examples of links between sampling and experimental design that David provided to his students:

- The first key idea of statistical design of experiments is the same key idea of sampling: Let impersonal chance choose your sample; let impersonal chance decide who gets each treatment. (DFCM2)
- And this has the same immediate justification in experiments that it did in sampling. (DFCM4)
- Remember when we talked about sampling we first talked about the big ideas and then we talked about whether you can use designs that are more complex than a simple random sample. There are practical difficulties that stand in the way of getting good conclusions from a sample. And we need to follow those same kinds of thought for experiments. (DSCM3)
- Well, similarly here in talking about designed experiments, there are simple and more elaborate designs. ... Completely randomized experimental designs are the analog of simple random samples. ... And the idea of block designs is like the idea of stratified samples. (DSCM4-5)

Although David did 'tell' his students about many concepts, David does like to have some interaction between the students and him during class time. David told me:

I like to ask the students questions in the flow of what I'm doing. So if the students should know what the next step is, then fairly often you should ask them "What's the next step?" (DII7)

This kind of interaction with his students is easier for David when the class size is small:

As the class gets smaller, I'm more likely to ask the class "What do you think about that question?" before I respond myself. Somehow that gets easier to do as the class gets smaller. (DII7)

As an example of interacting with his students in a smaller class, David told me about a typical interaction in his class for graduate students in education:

I'll describe a problem setting and describe how the data was produced and say "Okay, what's the first thing we should do?" Well, they're supposed to know, really know, the first thing you always do is look at your data. So even if we're studying repeated measures analysis of variance or something, the first thing we do is make plots of the data and see what they look like. "So what would you plot here?" And then they suggest things that they'd plot, most of them good ideas. I say, "Okay, those are good ideas, we don't have time to do them all." If it were your thesis of course you'd do them all. These people are going to write theses and they will certainly have to do this; that's one reason they pay attention. "But here are a couple of plots that I've prepared." And then I put up the plots. "Okay, now what do you see?" And we talk a little bit about what you see. "Okay, so

now we have some feelings for what the data show us. Now we're ready for the formal analysis." And this they don't know, so now I'll start telling them a little bit about the formal analysis, doing more lecture-type exposition. (DII7)

David does not ask the same types of questions of his students in Statistics 113 that he does of his graduate students in education. For example, David does not ask the Statistics 113 class "questions for which I expect individual responses. I sometimes ask a question to which I want the class, as a whole, to respond" (DII7). David gave me an example of such a question:

When I then want to talk about a particular study as an example, I might say "Okay, now is this an observational study or an experiment? Everybody who thinks it's an observational study put up your hand. Everybody who thinks it's an experiment put up your hand. Everybody who abstains put up your hand." (DII8)

David was true to his word; during class he asked the students:

Is this an experiment or an observational study? How many vote for experiment? How many vote for observational study? How many take the 5th amendment? (DSCM1)

David does not ask questions to which he expects individual responses "because the spread of the class is so large that I couldn't hear them and other students often couldn't hear them" (DII8).

David and I talked about ways to increase interaction in a large introductory statistics class. David said:

In principle you can try to get the students to form groups of 3 or 4. And pose problems for them and give them several minutes to work on them in their groups to try to come up with a reasonable resolution. Now what you do after that if you've got 400 students is not so clear, because again it's going to be hard for the groups... You can at least get them working with each other and try to concentrate their minds on the problem before you bring them back together and talk. And I have never done that in a very big class. I do that in the classes of 50 or 60 also. (DII8)

Other aspects of interaction between David and his students include David paying attention to his students during class. In fact, one reason David uses an outline form for notes on an overhead projector is so that he can see his students. David does not want to provide the environment where:

I'm sitting there staring down at the transparency writing instead of looking up at the class, and the students are looking up at the big screen writing, and nobody is thinking. (DFI2)

To avoid such a situation, David tries to "sort of step away from the transparencies and walk back and forth and wave my arms a little bit and talk to the class to engage them a little bit" (DFI2). David does such things because:

Students do indicate by their facial expressions whether or not they're getting it. If the class as a whole isn't getting it, that's usually pretty clear. And often people, the braver student, will be asking questions. Nonverbal things are always important. And that's important for the teacher also. It's deadly to stand at a podium, for example. You really have to move and be active.

I once had an educational psychologist sit in on a class I was teaching. This was a class of about 35 and it was a graduate class, so I was doing a lot of the talking, pushing them along. Afterwards he said, "It's very interesting. After about 20 minutes they started to wear out. And all of a sudden you walked faster, you raised your voice, you put your hands in your pockets and you shook your keys." I had no idea that I had done that. That's clearly just a nonverbal response to nonverbal, even subliminal, messages from the students. (DII13)

One aspect of David's comment above is informal assessment. In-class assessment of student understanding is hard to do, and formal assessments make it easier for David to see student understanding. During class time, "those who don't understand are often not saying anything. And that's one reason why it's so important to be grateful to students that do say something" (DII12). Through formal assessments, however, David can see learning:

I'm an empiricist since I'm a statistician. So from my point of view, you've learned something when you can do something. I have no idea what's in your mind. And I can only see what you're able to make operational. (DII11)

As a result, David has in mind:

Certain things I would like students to be able to do. Some of them are very simple, like make certain types of graphs and do certain types of calculations. One step above that are things that are still straight forward like be able to outline the design of a randomized, comparative experiment, making sure that you get in the randomization, that you include the sample sizes, the response variable, all those things that are essential. And then a step beyond that—explain why it is that a randomized, comparative experiment gives good evidence for cause and effect, not in the abstract, but in a particular problem setting. Or Gallup says 95% confidence such and so is true. Explain to me clearly what 95% confidence means. Or if I tell you a student says this about 95% confidence explain to me why that isn't. Try to show me that you have some understanding for what 95% confidence means by responding to both positive and negative statements about it. (DII11)

By asking questions like those above, David attempts to "get at what understanding is in the student's mind, but I can only see that indirectly through what kinds of things they're able to do" (DII11).

Even so, formal assessment of student understanding is an enormous task for

David in Statistics 113. In the following excerpt, David describes formal assessment in Statistics 113:

I'm trying to get at what understanding is in the student's mind, but I can only see that indirectly through what kinds of things they're able to do. And the size of the course impacts that too. Until the course got up to about 250, we had exams that were a mixture of multiple choice and long answer questions. And then they usually had an essay question. And... I'd grade the essay question. Well, this semester we're up to 480, and it takes a long time to grade 480 exams, so we gave up and made the exams multiple choice. ... It restricts the kind of responses you can get.

I try to use the weekly quizzes to get other kinds of responses. But I have to keep in mind that each of the TAs has to grade 90 of these plus the homework. But I often have different kinds of intellectual skills in mind. For example, this week the quiz forces them to read quite a bit, and that's actually deliberate.

There's almost a whole page. What it is is it's the summary of an article from a recent Journal of the American Medical Association. We're doing randomized, comparative experiments this week so it's a straight-forward randomized, double-blind, controlled clinical trial. But they have to read through all this and then answer a question. And the question is actually pretty easy, and if I had just excerpted the 3 lines that answer the question, I hope they'd all get it right.

But the real challenge this week is to dig out the answer to that question from this half a page or so of verbiage. And that's what they're going to have to do in the future. And they'd rather if I didn't... Students don't like irrelevant information. They come convinced that this feeling that every number that they see should be part of the answer. And since this is a course for liberal arts students, of course, one of the things I'm trying to teach them is you have to look at all this and find what's relevant in it.

So I use the weekly quizzes to try to get at other kinds of intellectual skills, but the exams are just multiple choice. In fact, I've decided over a number of years of doing this now that multiple choice exams are not as bad as most education experts think. That, in fact, by the time you've asked 40 or so multiple choice questions you can get a pretty good handle on what the students are able to do intellectually with the material. ... I think you get a pretty good handle on whether they understand the basic ideas, especially if you write good plausible distracters.

What you don't get is a sense of whether they can say these things clearly and precisely. And the answer at this level is that they probably can't. Even students who can understand what 95% confidence means have great difficulty saying it precisely. And so I typically tell TAs when grading quizzes and homework is that most of the credit should be for having the right idea. Because they are going to say things that are not technically correct when they try to say it precisely. And if you grade it as if they were math students, there would just be this hopeless disjunction between you and the students. (DII12)

During our follow-up interview, David returned to the idea of the precision he mentioned above:

As we know, students who have the right idea are often not good at precisely expressing that idea. You know, they haven't been trained in the way that graduate students are trained to be precise in their expression. ... When you ask them to write things out you see a lot of students who appear to have the idea but just can't find the words to express it clearly. So that sometimes makes it difficult to see how good their understanding is, because they may in some sense understand it better than they can say it. (DFI6)

David mentioned that in some ways it is easier to assess students in statistical methods courses:

Statistical methods courses in this sense are easier. You just ask them to do things. So you can give them a problem, say. And if they can figure out what the substantive question is and then translate that substantive question into a statistical question and apply the right statistical methodology and get a conclusion and then circle back... And often the hardest thing is to say what that conclusion is in the context of the problem.

But there you find that the weaker students will do the calculation, but then when you ask them for a conclusion, amazingly enough they often ignore the calculation that they just did. That circling back to the context of the problem is hard. But that whole thing is a little more cut and dry than you have in this course. It's still not easy because they've got lots of different methods for lots of different settings that they have to learn.

But students in a methods course who are better prepared quantitatively will have the same difficulty as students do in this liberal arts course in telling you what things like 95% confident means even though they can calculate 95% confidence intervals and so on. In this course there's no refuge; we don't teach them to calculate them. We just say, "This is what the news report said. Now tell me what it means." (DFI6-7)

One last instructional strategy that David employs in Statistics 113 is story telling.

There are three stories that David told during my visit that bring the static content

(Dewey, 1938) of statistics to life. The following story is about randomized, comparative experiments:

If I had to nominate one idea for the most important idea in all of statistics, it would be this one. Randomized, comparative experiments were invented in the 1920s and they are the most important invention in the history of statistics. And by the way you'll notice here that there are no formulas or anything. It's a big idea, but it's a statistical idea, it doesn't involve any formulas.

Randomized comparative experiments were invented by R. A. Fisher, Sir R.A. Fisher, Fellow of the Royal Society and all of that. He worked at an agricultural experiment station in England. And agriculture was one the first fields to systematically use careful experiments. You want to know which variety of wheat yields best, which fertilizer is most effective. And because the environment is so varied, we get different rainfall, different winds every year, they realized they had to do side-by-side comparisons of several varieties of wheat.

But plots of ground are not identical. They have different soil types, different fertility, and agriculture people are very sensitive to this. So when Fisher arrived at the agricultural experiment station, he found that the people there were using handbooks that had very elaborate checkerboard arrangements in them. So if you were trying to compare two varieties of crop, or three varieties, or four varieties, and still have them be insensitive to whichever way the facilities were able to plant the fields.

And Fisher got this brilliant idea: why not just assign the crops to plots of land at random? Well, that really was a bright idea. Because when you randomly assign people to drugs or crops to little plots of land you make the groups equal in every way, in all the ways you can measure and in all the ways you can't measure, because the averaging effect of chance does that for you. So this started in agricultural, and then it spread into, as you have observed, to medicine.

Randomized comparative experiments are universally accepted in medicine. Before a new drug can be approved for use... that you have an elaborate set of randomized comparative experiments to demonstrate that it's both safe and effective. And so randomized comparative experiments have changed the way lots of fields do their business. This is a really big idea among all our big ideas. (DFCM4)

During Thursday's class meeting, David told his students stories about randomization and bias in experiments:

Let me tell you a couple of stories. When you're testing a food product, especially one of the instant food products, and want to make sure it's nutritionally okay... The way people do that is they feed it to rats. You know rats are just like people, they eat everything... Well, let's not go into how rats are like us... So you feed the stuff to rats and you see if the rats grow normally.

So we do a randomized comparative experiment, we feed half the rats a standard diet, we feed half the rats our new instant food product, and we want to compare how fast the rats grow. So here I've got a batch of these big stainless steel cages with wonderfully happy lab rats running around in them. And of course it'd be easy for me to take the top half of the cages and say they get one diet, the bottom half of the cages get the other diet.

It turns out that rats in high cages grow faster than rats in low cages. I have no idea why. But apparently it's well known by people who do these experiments with rats. So if I put all the rats in the top cages in one group, there's a bias in favor of that group. Not all subjects are being treated alike because the rats in the top cages grow faster.

This is an example of why it's hard to treat all subjects alike. You might not even have thought of that. What you need to do of course is randomly assign the rats to cages so that the cages are mixed up, so you don't know ahead of time where they will go.

Another story. Often we do tests on things like diet and drugs to lower your cholesterol with animals before we do them with people. So let's say we do things with rabbits. Now we've got our big rack of cages, bigger cages with happy furry rabbits in them, and some of them are getting the high cholesterol diet and some of them are getting the low cholesterol diet and we want to compare their cholesterol.

Well, the technicians who feed the rabbits and clean their cages really liked them, so some of the rabbits they started to pet. They scratched their furry ears regularly and so on. Well, having your furry ears scratched makes you feel good, it relaxes you and it lowers your cholesterol. So the rabbits who were getting their furry ears scratched will have lower cholesterol than rabbits on the same diet who are not getting their furry ears scratched.

And so if the techs are scratching the ears of some of the rabbits, essentially turning them into pets, they're not treating all the subjects exactly alike. Well, one can go on and on with stories from different fields about how easy it is not to treat all the subjects exactly alike. And when you don't do that, you bias your experiment. (DSCM7)

Use of Technology

I asked David why he thinks that technology is so important in the statistics classroom. His response was:

Well, that's sort of a vague question, so let me enlarge it. You can ask about technology for learning or about technology for doing. And when you teach statistical methods there is, justifiably, a lot of emphasis on technology for doing, because statistics in practice is always automated, at least the calculation and graphics aspects of it are automated. So if you're going to teach people to do statistics, you need to teach them to use the tools. We keep that aspect of it to a minimum in this course because our prime objectives are not to teach them to do statistics. I want them to be able to do simple things without taking forever to do calculations by hand, so I ask that they have a two-variable statistics calculator so that we can go as far as correlation and least squares lines with that automated. But the real emphasis in a course like this is on technology for learning. This is influenced by the large lecture setting. (DII10)

The technology David uses in Statistics 113 includes websites, videos, *ActivStats*, and on-line applets. David mentioned that "it's because good current technology is interactive that I think it's effective for learning statistics" (DII11).

David began Tuesday's class by visiting the class website, "our famous website" (DFCM1), on the computer. He showed the students how they could access their grades for the course on the web. In addition to grades, "all [of] the course material [is] up on the web" (DII10).

David also visited the website of the *Journal of the American Medical Association* and talked about a paper presented on that website. David told the students that for homework that week, they would "be going the *New England Journal of Medicine*, the other major medical journal" (DFCM1). By having students use the Internet for their homework, "you're making use of something they're familiar with" (DII10).

David's next use of technology in the classroom was showing the students an excerpt from the *Statistics: Decisions Through Data* (Moore, 1992) series. David shows videos because "we understand that videos have advantages in showing things that I can't tell and in changing student attitudes" (DII5). David told me that the students "like the videos. And the videos are good" (DFI3). According to David, "the videos present the stuff in a nice orderly fashion. [The videos] take [the students] out of the classroom" (DFI3). Since David created the *Statistics: Decisions Through Data* series, the videos "fit very much with what I was going to say anyway" (DFI3), and David reaps the benefits of video presentation while still teaching the students about concepts he would have done anyway (and in a similar manner).

Once a video has been shown during class, David can refer back to the videos later in the class period or during subsequent classes. For example, the video that David

showed on Tuesday introduced the students to experimental design. Following the video,

David said:

Well there you have it. From the title up here [points to video title], you can tell that we are going to talk now, not about sampling, but about designing experiments, and the video actually started with our first Big Idea for this week. (DFCM1)

David also used the video as a reference for the first step in experimental design:

"the first thing they did was, as you heard in the video, let impersonal chance decide which treatment these adults are going to get" (DFCM2). During Thursday's class meeting, David referred back to the video again:

We talked last time in the video about the physicians' health study which was a randomized comparative experiment seeing if aspirin helped prevent heart attacks. And it found convincing evidence that it does help prevent heart attacks. ... And it helps so clearly that that part of the study was stopped early as you saw in the video. (DSCM4)

While David does use both videos and computer demonstrations throughout the course, "there's a switch from doing more videos to doing more computer demonstrations" (DFI5) at some point during the term. Computer demonstrations involve the use of *ActivStats* and on-line applets.

David's use of *ActivStats* in Statistics 113 is used only in the classroom. David employs "a lot of the little animated toys in *ActivStats* which can be launched independently and used to do classroom demonstrations" (DII5). David has found that when teaching the data analysis portion of Statistics 113, "a lot of the tools from *ActivStats* are relevant" (DFI5). For example:

You could do things to show them how the mean and median respond when you pull an observation out. You can actually do that on the screen instead of just talking about it. (DFI5)

For these reasons, David reported that he likes the "interactive tools in *ActivStats* a lot" (DII11) and finds them to be "effective" (DII11). In addition, "the students have liked them when I've taught with *ActivStats*" (DII11).

When David and his students get to "the part of the course that's more data analysis, [the students] go to lots of applets" (DII10). The students' use of on-line applets during the data analysis portion of the course is an example of David's attempt "to replicate some of [what the interactive tools in *ActivStats* can do] for students at a different level" (DII11). As such, the use of the on-line applets is "to some extent, a replacement for not using software in the course" (DII10). While the on-line applets serve as a replacement for not using software in the course, David also likes to use on-line applets because "the applets are inherently interactive in a way that software for doing statistics typically isn't" (DII10). David has found on-line applets to be:

Better than software in the sense that you actually add points to the scatter plot with the mouse and watch the correlation change, and drag a point around and watch the correlation change, drag a point and watch the least squares line chase it. Drag along the axis to increase the number of bins in a histogram and watch the shape change. (DII10)

David also mentioned that:

I usually keep what they have to do with the applet pretty straight forward and simple, and I give them clear instructions for what I want them to do. And this is a matter of judgment too. If the students were more mature I'd give less guidance and leave more room for unstructured exploration. These students are not mature. The one thing they don't like about all the stuff on the web is the on-line assignments, because a lot of them would really like to do their homework a half-hour before class. In fact, the TAs say that they arrive at class early there are people sitting there writing out their homework. And of course they can't do that with the on-line exercises. They aren't mature students, they need quite a bit of structure, and so I try to make very clear what they're supposed to do when they

visit the applet sites and hope that at least some of them will get hooked and play around a little more... (DII11)

The students' lack of interest in using the on-line applets surfaced in a survey David conducted late in the course the semester before I had my site visit. In the survey, David asked the students "about all the elements of technology" (DFI2). David said, "roughly speaking, I got very favorable responses to everything except the on-line exercises" (DFI2-3).

Interaction With Students

During class time, David has as much interaction with the students in Statistics 113 as he believes possible. Some interaction between David and his students was addressed in the section on instructional strategies beginning on page 139.

One of the biggest issues in Statistics 113 is the size of the lecture:

Students in a big lecture are anonymous, and so they don't feel responsible. One of the big differences between a lecture and a small recitation is in the recitation the recitation instructor knows their name and is, in the end, going to have a component of their evaluation on how well they participated in the recitation discussions. So lack of anonymity is important.

I considered requiring attendance in lectures and assigning seating and so on and so on. And I know that some people who teach large lectures do that. And I decided not to on two grounds. One is sort of philosophical: they're at a university now, they're not in high school any longer, they need to make their own decisions about things like coming to class and find out what the consequences of those decisions are. And I can't blame some students too much if they don't come to the large lectures because I think they're only marginally effective. But the second reason is if you require attendance in a group of 400 students, what you get is a bunch of people sitting in the back listening to headsets and reading the newspaper and talking, so that it degrades the quality of the experience for students who really wanted to come. (DII7)

As was mentioned in the section on instructional strategies, David asks different questions of students during his Statistics 113 than he does students in smaller classes. He asks for group responses to questions instead of individual responses. In lieu of asking questions to which he expects individual answers during lecture, David encourages his teaching assistants to ask students questions during recitation:

There are lots of ways in which you interact with students and respond, of course, to student questions. And as the class gets smaller, I'm more likely to ask the class "What do you think about that question?" before I respond myself. Somehow that gets easier to do as the class gets smaller. And that's one of the things I try to get the TAs to do in the recitation, especially when the question just concerns the homework problems, because everybody in the recitation is supposed to have thought about them, so the class ought to be able to help you answer the question. (DII7)

In addition, David wants the recitation sections to be a forum in which there is a lot of interaction with the students:

I don't want [the TAs] standing at the board solving problems. I want them to try to lead a discussion in the class. But to keep the discussion and moving forward on what the students need to learn this week, because the recitation is important for the students. It's the small group where they're not anonymous, where they all come, where they can get their questions answered.

And so I try to help the recitation instructors do that by giving them almost a script for a structured discussion, starting with the homework papers which the students have in their hand and make them feel a little more secure in talking about it. (DFI3)

Lastly, David has found that students in Statistics 113 do not seek out his help outside of class as much as students from upper-level classes do. David's interaction with Statistics 113 students outside of class:

Depends on the students and these are fairly immature students which means that relatively few of them step forward. There are almost always some questions after lecture. In fact, often from the same students who sit there, listen, and then always have questions after lecture. There are some students who come to office hours. (DII8)

David has found that the Statistics 113 students are:

More likely to go to recitation instructors' office hours, because the recitation instructor is the person they know more closely and who grades their homework and so on and so on. (DII8)

Gudmund Iversen at Swarthmore College

The following story is about Gudmund Iversen at Swarthmore College. At the time I visited Swarthmore, Gudmund and his students were finishing up descriptive statistics and moving on to probability. The following four themes are explored in this story: Gudmund's teaching philosophy; Gudmund's instructional strategies; Gudmund's interaction with students; and Gudmund's use of technology in his introductory statistics classroom. Again, the analysis of the data that constitute this story is reserved for Chapter 5 of this document.

Teaching Philosophy

This section of Gudmund's tale addresses Gudmund's teaching philosophy. The following paragraphs talk about David's teaching philosophy through four sub-themes: Gudmund's own teaching; effective teaching in general; the purpose of Statistics 1; and, Gudmund's knowledge of learning theories.

When I asked Gudmund what appeals to him about teaching, he replied, "I think seeing students' faces when they understand something after I explained it to them. That's very rewarding" (GII1). But when Gudmund took statistics for the first time, he "almost flunked my first course" (GII1). When he teaches Gudmund is able "to see [the

students'] understandings that I didn't understand when it was explained to me at one time, so obviously it wasn't explained as well as I was able to explain it" (GII1). Because Gudmund "had some troubles understanding these things myself when I got in statistics" (GFI2), he has found that his "simplified explanations go across very well" (GFI2).

As an observer of Gudmund's teaching, it was very clear to me that Gudmund enjoys teaching. When I asked him if he feels that enjoyment while he is teaching, Gudmund responded:

Oh sure. It's probably the secret actor that's hidden in all of us. I think it's great fun. You know, I never tried any acting, I don't think of myself as an actor, but sometimes you feel that you're putting on a show. It's nice to be in charge of that, to have everything under control. So I can see why people get highs on that, like comics just standing up and telling jokes, knowing the audiences are eating out of their hands. (GFI3-4)

In order to continue his own growth as a teacher of statistics, Gudmund is always "looking out for the role played by statistics, the information in newspapers and what have you" (GII2). Gudmund also mentioned that his own maturity has played a role in his growth as a teacher:

And I think my understanding [of statistics] has matured over the years and to the extent that I'm stressing the point now that the result of a statistical analysis isn't just the data. But the statistical method plays a big role in how we end up with the results that we do, and different methods will lead to different results for the same thing.

That's been a revelation to me over the years, so I try to teach that. And it always surprises the students because they think the data are there and then the truth comes out of it using statistics. But of course that's not the way it is, it's whatever we construct this to be. ...

You know there's this neat graph that I showed in class the other day—it was all pretend [sic] about salaries for management and workers. And the same data were presented in three different ways, and depending on which graph you looked at one group would do better than the other group. It's just an eye opener for the students. So I think that maturity has changed me. (GII2-3)

Despite his own growth and maturity as a teacher, Gudmund told me that he "sometimes feels bad about not doing all the stuff I hear of other people doing" (GFI4).

Through his own reading and talking to friends and colleagues, Gudmund knows that:

They have small groups and they do minute papers. Minute papers I'm all in favor of, but I can't see somehow having class time and having [the students] sit down in groups and discover the stuff for themselves, when I'm in the room and I know it, I learned it, and so on. Obviously if they did something, they did discover it on their own, they would absorb, I think, quicker. But it seems to me you don't have time for that, and I don't how people do it. I certainly don't do everything other people do. (GFI4)

With Gudmund's statement above in mind, I asked him if he is happy with his style of teaching. Gudmund replied:

Yeah, because I've been at it for so long and it comes natural to me and I wouldn't want to change. And people seem to learn and they seem to enjoy statistics. We used to have student evaluations published with comments and means from scales from 1 to 5. So the comments were always: "This was the greatest course;" "I'm so glad I took statistics." And I think I just do better doing what I feel comfortable doing than trying to invent something else. (GFI4)

Although Gudmund does not implement some of the "trends going on in the field of statistics with group activities and group participation" (GII4), he does "challenge people to give me reasons why they're doing it" (GFI4).

While Gudmund's teaching methods are somewhat traditional (see the section on Gudmund's instructional strategies beginning on page 163), Gudmund still emphasizes conceptual understanding over procedural understanding for his students. For example, Gudmund does not have his students calculate the equation for the least squares regression line because "it serves no purpose for the understanding" (GII5). And, if a student tells Gudmund that the mean is when "you add up all the numbers and divide by how many you have" (GII7), Gudmund responds by saying, "that's very fine but that

doesn't tell us anything" (GII7). Instead, Gudmund has his students focus on what the least squares regression line does or what the mean actually represents.

Gudmund has found students in the United States to be different than students were during his own school days in Europe:

You know growing up in Europe and having a European model of education, just lectures and people being motivated and studying on their own, is very different from the American way. But, of course, that's because so few people have a higher education in Europe so there's just a select few, a motivated select few, not the way it is here. I grew up in a country... When I finished high school back in '53, only 4% of the kids born my year finished high school. And among that 4%, half of us went on to the university. So we were highly selected. So we just studied, there wasn't any quiz section or studying questions in class. We just studied. But you can't expect that here. (GII7-8)

In his experience teaching statistics in the United States, Gudmund has found that his students "don't always keep up with the readings of material" (GFI2). For Gudmund, "one way to have [the students] prepared each time" (GFI2) is to have the students read and respond to chapter review questions during class time. Gudmund often tells his students that "we are building a brick wall and are laying the bottom bricks now, and if they don't come to class or haven't studied they are going to have gaps" (GFI2).

When I asked Gudmund to define what it means to be an effective statistics teacher, Gudmund said, "well, certainly it's a person who makes it possible for students to learn and also to remember" (GII2). While end-of-semester evaluations of teaching become "student popularity quizzes" (GII2), Gudmund believes that effective teaching could be shown in the following manner:

It seems to me what you really ought to do is to order back the student ten years later and see if they remember anything. And that's going to be the criteria for

whether they learned anything. I think it's that a successful teacher enables students to understand the material, and in a way that makes sense to them, thereby they can remember it. (GII2)

So is Gudmund an effective teacher of statistics? Gudmund told me "I'd like to think so, because my students certainly light up and understand things" (GII2). In addition, Gudmund does indeed "talk to [the students] when they come back years later, and it's amazing what they can still remember" (GII2). Gudmund also receives feedback on his effectiveness from colleagues:

I have colleagues telling me that students who come out of my course understand all of the statistical issues, while students who take econometrics have no idea what it's all about. They can do it, but they don't understand it. My students are just running circles around the econometrics students. So I must be doing something right. (GII2)

The introductory statistics course that Gudmund teaches, Statistics 1, is a concepts-based course, where "we're trying to train the students so they can read a newspaper, a news magazine, or an academic journal—how to understand statistics" (GII4). Topics discussed during the course include "statistical significance, ... relationships between variables, causality if we get that far, or lack thereof, and problems of data collection" (GII4). The intention of Statistics 1 is the "understanding of statistics—no formulas" (GII4). So, while students are "not going to be able to do very much after they finish, but they will understand" (GII4).

Statistics 1 was developed specifically for the understanding of, rather than the doing of, statistics. There was a mathematical statistics course that the students used to take, but Gudmund found that:

There were students in there who were very uncomfortable. ... When they were asked to derive the formula for some expression for the t variable they would just

cringe, because they didn't understand. ... And it didn't seem to me that that should be enough to keep them from knowing something about statistical thoughts and ideas. (GII4)

As a result, Gudmund "simply redesigned [the course] and created this new course. Now it's being taken by almost a third of all the students at the college" (GII4). Statistics 1 was created "to provide an overview of the field without getting all bogged down in technical issues" (GII6-7).

What does it mean for students to learn in Gudmund's class? To Gudmund, learning:

Creates a familiarity with some material, something they didn't have before. Enable them to think in a different way and maybe to do things in a new and different way. Certainly something is implanted in them that wasn't there before. (GII5)

And students learn through a combination of "the fact that I know material and can talk to them about it ... reading the textbook ... doing exercises" (GII5). Lecture, reading, and doing exercises, in combination, "means that this material becomes part of them in a way that it was not before" (GII5).

While Gudmund is aware of "all these new ways with group projects and class participation that somehow I haven't quite been convinced I can do it" (GII5). Instead, Gudmund teaches by doing "what comes natural to me, what I feel comfortable with" (GFI3). What comes natural to Gudmund is "being able to explain what can be explained in a very bad way, I can explain these things in simple words and voice for people to understand them" (GFI3). Gudmund does want his students:

To know my way. You know I think I've worked enough with the material so I know it better than they do. So I just want them to learn it the way I think it

should be learned. I guess I'm more authoritarian than perhaps others, but that may come because of my age. I don't know. (GF13)

Instructional Strategies

Gudmund's instructional strategies do support his comment about wanting the students to know his way of doing statistics. At the same time, Gudmund's probing questions in class illustrated Gudmund's desire for his students to understand the concepts. The following paragraphs are filled with examples of Gudmund's instructional strategies.

During my two class visits, there was some information that Gudmund just told the students. For example, much of class on Tuesday was spent with Gudmund showing the students how to read the tables of the standard normal, t, Chi-squared, and F distributions. Gudmund spent this time telling the students how to use the tables because "they've got to do it. You know if they struggle they can't make sense out of it" (GF11). Other examples of transmission of information from Gudmund to his students came in the forms of summaries of concepts that had already been discussed and statements of 'simple facts.'

Gudmund used summaries of prior information to remind the students what they had been talking about in class. The following is an example of one of Gudmund's summaries of prior information:

So we're in Chapter 4, talking about data analysis. So we have selected our data, collected our data, rather, and we're doing some analysis. And so we either make a picture or we make a table or we compute something or we do all of the above. ... So we talked about how we're interested in characterizing our data by some single value rather than listing the data. ... if you look on page 154. On the

previous page, we looked at the previous page not long ago, and there the data were taken into a picture. Here on page 154, those data points, I think about 30, 30 different countries, get replaced by a single number, and that's the number in the middle. And of course there's the mean, 19.2.

Great simplification, but loss of information. So trying to balance those two things is difficult. And so what we've done then is we've settled for something in the middle, and here we've got the median, or we have the mean. That's in the middle of the data. That's a very useful thing.

But then we decided that that wasn't quite enough, because we could have different data points, we can have different situations. So we're interested in how spread out the data are. Are the observations close to the middle or are they spread out? And that makes a big difference. And so here then is where we talked about the range. We talked about the middle 50%. And we're talking now about the standard deviation. And so letter s is the standard deviation. (GFCM1-2)

A few examples of statements of 'simple facts' that Gudmund told his students about occurred during Thursday's class meeting. On Thursday, the topic of the hour was probability. In the following examples, Gudmund stated the 'simple facts' to his students:

- And one probability, the probability of a girl for example is 1 minus the probability of a boy. So the probabilities add up so that the probability of a girl plus the probability of a boy is equal to 1. So what do we get when we add two probabilities? Well, you can see here a particular birth has to be a girl or a boy, so this plus then takes the place of "or." One or the other. And if that's the case, then we add the probabilities. (GSCM2)
- And this histogram then tells us a lot about the z variable. It tells us it's symmetric, so half of the numbers in this barrel are negative and half are positive. And this is about 1 right here, 2 right here, -1 and -2... (GSCM4)
- So we have to know how to read these tables. There are different tables in the book, and we have to know how to read them. (GSCM4)

But, as mentioned earlier on page 162 in the section on Gudmund's teaching philosophy, Gudmund's expositions did make many ideas sound easy and matter of fact, thus making them not foreboding. In the following examples, Gudmund's words take hard concepts and make them sound manageable. In the following exchange between Gudmund and a student, Gudmund makes probability seem simple:

- (Gudmund) So Chapter 5 on probability. We already talked about that ever so briefly. And so what is a probability?
- (Student) A number between zero and one that tells you how often ...
- (Gudmund) Right, right. Probability is nothing but a number. It doesn't help to say it's a likelihood, it doesn't help to say it's a chance of anything, it's simply a number. Between 0 and 1. And what does it do? It tells us how often things happen. If the probability, that number, is close to zero, then it doesn't happen very often. If the number is close to one, then it happens often. That's all it does. There's nothing more mysterious with probability than this number that tells us how often something happens. (GFCM12)

When talking about the probability of the union of two simple events, Gudmund said:

It's not very surprising that we add the probabilities in this case, because we clearly want something that's larger than what we started with, because we're allowing for this thing or that thing. So these two probabilities together will have more probability than either one of them. (GSCM2)

The probability of intersections of two events also sounded quite sensible when

Gudmund talked about it:

There's the "and" that's coming in, we're looking at both things happening at the same time. And that's a more restrictive event and it shouldn't come as any great surprise that this is going to be multiplied. (GSCM2)

One last example of Gudmund's ability to take what could be difficult concepts and make them seem easy was when Gudmund described the standard normal distribution:

Let's start with the z variable. One way to think about this is to imagine a whole barrel full of numbers. Imagine a 55-gallon jar full of little pieces of paper, on each little piece of paper is a number. In other words, the values of this variable. And then all these numbers together make up the z variable. In principle, it's really infinitely many, but a large barrel will suffice.

So we have all these numbers and those are values of the variable. Just like here for all the students at the college we've got all their ages, a bunch of numbers, 1300 numbers. So here we have millions and millions of numbers of the z variable, not of the age variable.

So we just rattle around in this and we pick up a number and it may say -0.87. Put it back and pick up another one, it may say 1.43. In other words, we get a whole bunch of different numbers. So we can make a histogram of those things. So here's the z variable. It turns out that the numbers pretty much range

between -3 and +3. [drew the normal curve] Oh, you'll find an occasional outlier, but most of them are between -2 and +2. (GSCM3)

Gudmund does believe that interaction between the students and himself is important "up to a point" (GII3). Gudmund thinks that interaction can be time consuming and warns, "if students are just left to ramble on, I don't think that's good use of the time" (GII3). However, Gudmund has found that "it certainly helps to have them participate and ask questions and even answer questions" (GII3).

Gudmund has also found that the number of students in the class has influenced the amount of interaction that was possible in his class. In the following excerpt,

Gudmund discussed class size:

One time I taught [Statistics 1] and actually let in everyone who wanted to, and it had 125 students. And that was, I think, in some ways quite successful as well. I'm not sure 25 is such an optimal size. 15 or 20 is about the most difficult size, 25 or 30 makes it a little more lively, and in a small class of 5 or 6 or 7 students which I also have had makes it possible.

You know, the group has to be big enough to be a group that you can play on the emotions of the group. Fifteen is a very difficult number. If it's very small, of course, we'll all work together. So I think that 25 to 30 is a nice size in the sense that there's an audience for anything you do. (GII3)

Although Gudmund described his 125-student class as "quite successful," Gudmund said, "there clearly was much less class participation... it was much more just straight lecturing" (GII3).

One type of interaction that went on between Gudmund and his students occurred when students read and answered chapter review problems from the textbook. Gudmund has found that the students in Statistics 1 were "quickly learning that they have to" (GII7)

be prepared for the review problems, because "it's a bit embarrassing when they read what basically are very simple questions and have to admit that they don't know the answer" (GII7).

The following are examples of the exchanges that went on between Gudmund and his students during the class meetings I attended:

Excerpt 1 (about the standard deviation when all values are the same):

- (Gudmund) Suppose we have some observations that are all the same. Suppose we are counting something or measuring something and we have five observations, and they're all equal to nine. What's the standard deviation of these numbers? Yes.
- (Student) Zero.
- (Gudmund) Zero, he says. s is equal to zero. Why is that? Tell me.
- (Student) Oh, because there's no variation. I mean you can't go to the left or right of nine and find any other values.
- (Gudmund) There's no variation, there are no distances. All the distances to the mean, the mean is obviously equal to nine, and all the distances from the observations to the mean... they're all equal to zero. And the average of all the zeroes is zero. So the standard deviation of those numbers is zero. (GFCM3)

Excerpt 2 (about the conversion to the standard normal distribution):

- (Gudmund) Why is this new scale so useful? What's going to be the values, the range of values, approximately for the new numbers? How large are they going to be and how small are they going to be? If we find all 30 of them and look at them, what are we going to find? Yes.
- (Student) They'd be from negative 2 to 2.
- (Gudmund) Negative 2 to positive 2, exactly. (GFCM4)

Excerpt 3 (continuing the discussion of the standard normal distribution):

- (Gudmund) What do you think the mean of these new numbers is?
- (Student) Zero.
- (Gudmund) Very good guess. Or maybe you even knew where you could do it or something. Thank you. So the mean is zero. What do you think the standard deviation is?
- (Student) One.
- (Gudmund) You're right. The standard deviation is 6.6, which is 1 [in our new scale]. So these new numbers turn out to have a very nice feature: mean of zero, standard deviation of one. (GFCM4-5)

Excerpt 4 (about the standard error of the sample mean):

- (Gudmund) Would we expect those numbers to be identically the same? No, why are you shaking your head back there?
- (Student) Because everyone wouldn't have the same pulse.
- (Gudmund) Because everyone doesn't have the same pulse rate and so from the randomness of selecting one group as opposed to another group you get a different number. So we're going to have a whole bunch of different x -bars. How can we find out how different they are from each other?
- (Student) Standard deviation.
- (Gudmund) Ah, the standard deviation. We can find the standard deviation. Not just the standard deviation of a bunch of observation, but in this case the standard deviation of a bunch of means. Do you think it's going to be smaller or larger than 6.6, which was our standard deviation for our sample?
- (Student) Smaller.
- (Gudmund) So why do you say smaller?
- (Student) Because you'll probably see like, within each group of observations you're going to see relatively similar means, so they'll all be closer together. (GFCM5)

Another form of interaction between Gudmund and his students was an invitation from Gudmund to his students to question anything that Gudmund said without a reason for saying it. One instance of such an invitation occurred when Gudmund told his students the standard error for a certain sample mean. Gudmund said to his students:

- (Gudmund) Where'd I get that number from? Don't let me get away with things. I'm just throwing this out and walking around like it's... Where'd I get this number 1.18 from? Well, you know it helps to have a Ph.D. in statistics, I guess. (class laughter) You don't really know, do you? And so when I just throw things out, don't let me get away with it. Holler and say "wait a minute, wait a minute, wait a minute, where'd that come from?"
- (Student) It's just sort of a guess, but...to take some formula in the back.
- (Gudmund, with a chuckle) You're right. He's already peeked in the back. There's a formula in the back that makes it possible to find that number even though I don't have means for a whole bunch of different classes, it turns out there's still a way around that issue and that's what's so nice about it. Don't let me get away with these things that somehow just come out of the blue. (GFCM6)

During interactions with his students, Gudmund was supportive of his students' answers, correct or incorrect. After a student answered one of the chapter review

problems, Gudmund would typically respond with a comment like "that's a good way to put it. Um hmm" (GFCM7) or "um hmm. Very nice" (GFCM8).

Even when a student was clearly not prepared to answer the chapter review problem, Gudmund was supportively pushed the student to think about the problem. In the following scenario, the student was to find a variable for which it would be useful to find the mean instead of looking at the entire data set. The example given in the book was the number of words per page. Here is the exchange after the student sat in silence for a bit:

- (Gudmund) So we need another variable when it might be useful to find the mean.... Or the median for that matter.... Just really any old variable.
- (Student) All right.
- (Gudmund) Just any old variable really.
- (Student) I mean what about the number of words per page?
- (Gudmund) Well that's just an example. You know just count up on each page and we get a different number each time and so we have a variable, number of words per page. And we have a lot of data, six/seven hundred different values of that variable. So just think of another variable.
- (Student) I don't know. You could find height for everybody in the room.
- (Gudmund) Sure. Height of everybody in the room, a useful thing to have, an average height. For one thing, you can make new furniture for the new building that's to come right here if you knew how large we are. (GFCM8)

Gudmund also pushed his students for more than just a formulaic answer to a problem. Consider the following dialogue about the mean of a set of data:

- (Student) The mean is the computed average, all the values added up and then you divide it by...
- (Gudmund) Yeah, but you see that doesn't tell me anything. I don't understand, I mean I can do it, but so what? What does it mean? You need to get beyond how you find it. How do we think about the mean?
- (Student) It's like a balance point?
- (Gudmund) The center of gravity in the seesaw. That's right. If we put the observations onto the seesaw accordingly to the magnitudes and the scale, it would balance right there. And that tells me so much more than just the fact that we add up all the numbers and divide by n . (GFCM7)

During the two class meetings I observed, Gudmund associated new concepts with previous concepts. For example, Gudmund related arithmetic with probabilities to arithmetic with numbers, an experience the students had in their 'pre-statistics lives':

A probability p is just a number from 0 to 1. And so the question is what can we do with these numbers? And, of course, like other numbers, we can add them up, we can multiply them, we can subtract them, we can divide them. And so they do different things for us. (GSCM1-2)

Similarly, when introducing the t -distribution, Gudmund made comparisons between the t -distribution and the standard normal z , a variable with which the students had already worked. Gudmund used his barrel analogy (considering all of the values of the standard normal z as numbers in a barrel) to introduce the t -distribution. With the t -distribution, Gudmund said:

It turns out that there isn't just one t variable. Again we have a barrel full of numbers. There are several of them, a whole family of t 's. So how do you keep them separate, how do you keep track of them? You could give them names if you wanted to, that's how we refer to ourselves. But that's a little hard to do, so we give them numbers. They're just numbered. So instead of having just one barrel we have a bunch of them. ...

So, how do these t numbers compare to the z numbers? Well they look like they're a little bigger. Of course all the z 's are between -1.96 and 1.96 . Here, in order to have all the t 's, we have to go out to plus or minus 2.23 . So they're just a bit bigger. Otherwise it's nice and symmetric, the mean is zero. Standard deviation is a little different, but... There it is. The biggest question is how to know which one. (GSCM7)

During both class meetings that I observed, Gudmund set up his students for hypothesis testing. During Tuesday's class meeting, Gudmund told his students that data values will typically fall within two standard deviations of their mean:

And that is a very important fact. So here's minus 2 down here, plus 2 up here, so the range is typically going to be from minus 2 to plus 2. Approximately. There

could be some larger ones, could be above plus 2 or under minus 2, could be less than that. But overall that's going to be the range.

Now then, why is this so important? Well, later on, in a couple of chapters, we're going to take our data... we're going to compute one of these numbers from our data. And then we're going to look at that number and see where it is. Sometimes it's more than plus or minus 2. It could be plus 3 or it could be minus 15 or plus 12. When we find such a number, we know right away that it's outside of the range of minus 2 to plus 2, so there must be something unusual about that number.

So that's the purpose of introducing these new numbers. We're going to compute some of these numbers as we go. Most of the time we are going to call them a value of t . So t could be equal to 5. Well if t is equal to 5, and it's supposed to be in a range from minus 2 to plus 2, then we've found an unusual value of t . And we're going to sit up, take notice, and we're going to do certain things if that's the case. If we had another data [point] and we found t and it's equal to minus 1.3, well there's nothing unusual about that. So we just nod our heads and say, "yep, nothing unusual about that." But sometimes we find extreme values and we take note of that and sometimes the values of t that we're going to be computing are not very unusual. (GFCM4)

Gudmund used two standard deviations from the mean as a typical range because he was:

Trying to anticipate things, as I am sure you can see, so the fact that we reject the null hypothesis if t is more than 2 makes it natural to say 2 or 3 classes before that that plus or minus 2 is big. (GFI1)

Also during Tuesday's class meeting, Gudmund alluded to the idea of a p -value in

hypothesis testing:

We're going to be using probabilities to find probabilities of getting some data results. And typically we will talk about getting the data we got or something more extreme. ... If that probability is large, then of course there's nothing unusual about our data. If that probability is small, then we're going to sit up and take notice. "Hmm that's very unusual to get data like that because the probability of getting those kinds of data is very small." (GFCM13)

Part of Gudmund's set up of hypothesis testing included tossing a 'fair' coin multiple times. The following dialogue is the exchange between Gudmund and his students when Gudmund tossed a 'fair' coin 10 times:

- (Gudmund) I'm going to show you a little bit on how we may do some probabilities. Here's a nickel and I'm going to toss it ten times. [Gudmund tossed it 10 times and seemed surprised to get 10 heads. The class got suspicious.]
- (Gudmund) How about that? [class laughed] We have HHHHHHHHHH. So this is the world. This coin is our world, and we now wonder about this coin. Let's see that coin. And we wonder. And the question becomes is this a fair coin? Let's see if we can use some statistics and conclude something without looking at the actual coin. So the question is: Is this a fair coin?
- (Gudmund) All probabilities are based on certain assumptions. So here, assuming that this is a fair coin... There are always assumptions floating around. Assume fair coin. What's the probability of the data? Well if this is a fair coin, what's the probability of getting a head? A half. And a half for the second one. We multiply and get half... So this is $1/2$ to the 10^{th} which is 1024. So now what do we have? If this is a fair coin, then the probability of our data is 1 in 1024. In other words, if I repeat... If I have a fair coin in my hand and did this thing 1000 times over, only once would I get 10 heads in a row. So, now we have to make a conclusion. We have to say something about this assumption. Now if I assume this is a fair coin, what do you think about this assumption? Do you think it's correct or should we throw it out?
- (Student) It's pushing it.
- (Gudmund) It's pushing it, he says. That's right. Because if this is a fair coin, then you observed something very, very unusual. If it's not a fair coin, then of course the probability of getting this is 1. So now we have to make a choice. Is it a fair coin or is it a coin with 2 heads? Based on these 2 probabilities. If it's 2 heads, then the probability of the data is 1; if it's a fair coin, then the probability of the data is 1 in 1024.
- (Student) Stranger things have happened.
- (Gudmund, with a chuckle) Stranger things have happened.
- (Student) I don't think with just that alone that you can throw the coin out and say it's not fair.
- (Gudmund) All right. Anybody else have an opinion about that?
- (Student) I think you have to do it again...
- (Gudmund) No no no no no no no no. You cannot do it again. No no no. (class laughed)
- (Student) Throw it out.
- (Gudmund) He says throw it out.
- (Student) Yeah, I'd throw it out.
- (Student) I bet you weren't surprised.
- (Gudmund) (class laughed) All right, who wants to see the coin? You can tell them.
- (Student) Yeah. You're a cheat. (class laughed) You've got a coin with 2 heads.

- (Gudmund) This is actually a nickel with 2 heads. My brother-in-law who does strange things gave me this. I said, "great I'm going to take that to class!" Now I'd better not get it mixed up with the rest of my coins... (GSCM9-10)

Following this shared classroom experience, Gudmund told his students the basic set up of hypothesis testing:

So, anyway, so here is a typical situation. We assume something about the world, we collect the data, we compute the probability, and based on the magnitude of those probabilities we either keep that assumption or we throw it out. And here, if the assumption is true, then the probability is as small as 1 in 1024. But that's so small, that hardly ever happens, so the best explanation for this must be that the assumption was wrong. It's not a fair coin. But this is the kind of thing you want to do. (GSCM10)

After a few more examples of computing probabilities in similar situations, Gudmund said:

So what's going to happen is that in the next couple of chapters we're going to formalize this a little bit. I've just sort of given you a taste of what's coming, and we're going to formalize a bit. (GSCM12)

During our interview after my observations, Gudmund and I talked about his anticipation of upcoming topics, and he confirmed that "even today we obviously did hypothesis testing without mention of the word" (GFI1).

In addition to providing links to previous mathematical concepts and anticipating for upcoming statistical concepts, Gudmund linked ideas in statistics to ideas from students' everyday lives. For example, when introducing standardizing a random variable by transforming the variable into the standard normal, Gudmund linked this notion to the idea of temperature:

You know we're used to Fahrenheit degrees, and so today it's about 65 degrees out there. If we go to Europe, the same temperature is not measured in Fahrenheit, it's measured in Centigrade. So 65 Fahrenheit is about, what, 16 or 17 degrees

Celsius? It doesn't change the temperature, it's just a different number we attach to how warm it is. The same thing here with this new scale. (GFCM3)

Like both Paul and David, Gudmund used story telling and jokes about statistics in his classroom. One story that Gudmund told his students traced the history of probabilities:

Probabilities can be traced far back. There is actually mention of probabilities back in the Old Testament when they are talking about tossing and deciding things by randomness. There is a mention in an old description of some of the Vikings trying to determine the border between Norway and Sweden. And so the Viking king of Norway and the Viking king of Sweden got together, they disagreed as to where the border should run between the two countries. And so they had this chunk of land. They decided then to simply toss a coin to decide whether that piece of land should belong to Sweden or it should belong to Norway. So they had some sense of randomness even a thousand years ago, and the Old Testament which is even older. (GFCM13)

Gudmund also told his students about the significance of the number 1.96 in statistics. During our follow up interview, I told Gudmund that the story had to make it into my dissertation somewhere, so here it is:

Now, so 1.96 is a magic number in statistics. It is something that you should always keep in mind and it will always be with you. And for one particularly good reason.

Eventually most of you, and perhaps even all of you, will graduate from this college. ... And you will go out in the real world. You'll get some internships...

But anyway you will do your internships in Washington or New York or Boston or something like that. And on Friday night, you've done it for the week, and so you want to go out on the town and you want just to keep your eyes open, you know, because who knows who you are going to meet. So you're at this bar and you're old enough to drink and so you have a drink. And then you see this other person down there. And you say "Wow, that is something, that looks very promising." [students chuckled] So you mosey down next to this person and then...

See here's my advice to you. You say, you look this person straight in the face and you say 1.96. That's what you say, 1.96. Now one of two things will happen. Either the person will look at you and think you're about as strange as you probably are or [students chuckled] the person will say "oh, yes, so you took

a statistics course also." And you'll say "yes, wasn't it great?" And the other person says "ah, it wasn't too great, but I did it." So now you've found a soul mate. [students laughed]

When you come back for your 10th reunion with your soul mate and perhaps little ones behind you, seek me out and tell me "thank you for having alerted me to this fact about life." Your parents probably never told you about this. So 1.96 is the magic number. It always works. Anybody who's ever taken a statistics course knows that number. So it's the magic number. All right, that's probably enough about the z values and now you've learned more of the facts of life. (GSCM6)

One final instructional strategy that Gudmund employed was assessment, both informal and formal. Gudmund informally assesses his students through eye contact: "sometimes I think I can just see it in their faces, you know that 'ah, yes that's the way it is'" (GII6). Gudmund's mentioned that his formal assessments also reflect student learning:

If [the students] can do homework, if they can do questions on a midterm or a final, and can write—they write two papers in this course—if they can write these things down, it must show something has happened to them. (GII6)

The exams that Gudmund writes are:

Mostly open-ended... No multiple choice, so in that sense all open ended. Some real essay questions, some asking for more technical definitions. Trying to see connections between one chapter and another chapter. Of course those are difficult questions to create, but that's my hope. I have to get something that cuts through several different things. (GII6)

Gudmund assigns papers to his students because at Swarthmore College, there has been an effort to "increase the writing across the curriculum... So this presented itself very naturally as a course where this could happen" (GII6). During my site visit, Gudmund gave his Statistics 1 students their first paper assignment. This is what Gudmund had to say about this first paper:

So the first time around, the paper's due in two weeks, and of course [the students] don't know much yet. We talked about data collection, we talked about statistical graphs, we talked about ethical issues in experimentation on people, done some computation of means and standard deviations and stuff... So I send them to *Chance* magazine and the *International Encyclopedia of Statistics* and whatever else... And just deal with some issue and write to me, write a paper about it so I can see that they can manipulate some of the concepts. You know, how to draw a sample for a survey or what the important issues are. The need for control groups in experiments. You know, it's fine if they're just repeating things they've learned, I'm not looking for new deep insights, to be able to see them explain these things in their own words. (GII6)

Use of Technology

Technology did not play a large role in Gudmund's classroom. Students did have access to campus computers, and Gudmund was able to use a computer in the classroom if he wanted to. As far as using the computer in the classroom goes, Gudmund reported that:

I probably bring it to class three or four times over the semester. The first time around just to show them how to do it. And basically I just tell them "if you want to do it, just go out and do it." And usually they're brave enough and smart enough so they figure out or they get help, so they do it. (GII5)

The data analysis package that Gudmund's students use is *Data Desk*. During the two class meetings that I visited, Gudmund mentioned *Data Desk* as a helpful tool for his students. During Tuesday's class, Gudmund told his students that "*Data Desk* is very good at finding standard deviations for us, and so we don't really need to worry much about how to do the computation" (GFCM3). On Thursday, Gudmund told his students that the textbook's table for the t-distribution "is not detailed enough for us to tell" (GSCM8) the exact value for a p-value, but that "*Data Desk* will tell us directly" (GSCM8).

By using *Data Desk* for computations, Gudmund had his students concentrate on understanding statistical concepts. Gudmund's employment of technology is primarily "to save them the drudgery of having them do the numerical work" (GII5). For example, Gudmund talked about using the computer to calculate the least squares regression line:

You know when you find a regression line, I think they understand the idea without being able to find one themselves. You know, the least sum of squares seems to make sense to them. That uniquely determines a line, and then it's just a matter of some formulas they don't have to use. (GII5)

Interaction With Students

As mentioned on page 157 of this chapter, Gudmund almost flunked his first course in statistics. This is a fact that Gudmund shares with his students: "I always tell my students that. They're delighted to hear that one" (GII1). Gudmund had a hard time in his first statistics course because:

I just didn't get the idea, the basic underlying ideas... you know, like "we have n random variables." It just didn't make any sense—what does it mean n random variables? And all of a sudden we talked about a sample of size n , and what did that have to do with—I thought it was just one variable. You know, so there were just things like that that never... I didn't catch on to in the beginning. And so it was all very confusing, but I liked the applications that I saw and the examples that I saw, so I pursued it and finally, you know, sort of understood more of it. I probably never fully understood the very detailed mathematics part of some of it, because I just wasn't that interested. (GII1-2)

Statistics 1 was designed with student understanding in mind (see page 161-162). And Gudmund makes himself available to his students so that they will understand the concepts in the course. For example, during my visit the students were assigned one of two papers for the course. Gudmund invited the students to come see him about getting started on the papers:

I'm certainly more than willing and able to help you get started if you somehow feel that you've only been in this course for, what, two or three weeks and how can you write a paper about anything? (GFCM1)

Gudmund also holds office hours to which his students come. He has found, however, that many of his students in Statistics 1 see the course grader for help instead of seeing Gudmund for help—as Gudmund said with a chuckle, "Well, I'm probably sort of tall and forbidding in many ways. I try to smile, but sometimes I guess I just look sort of scary" (GII4). Gudmund said that during office hours "usually people show up wanting to just talk about the material and I explain it and answer their questions" (GII4).

One important aspect of interacting with his students is for Gudmund to learn the students' names. My site visit was still toward the beginning of the term, and Gudmund was still learning the students' names. When Gudmund handed back homework on Tuesday, he took the time to hand it back individually and apologized to the students: "I'm sorry this takes a while, but at least I get to work on names" (GFCM1). On Thursday Gudmund said, "let me work on some names today" (GSCM1) and called roll. When I asked Gudmund why it is important for him to learn the students' names, he responded:

Oh, because the class small enough, and I see them outside of class as well as during class, I should be able to address them when they have a question. But also when they come by. And, of course, in the end when I assign grades to them it's nice to be able to attach their faces to those grades. And it just seems like the human thing to do. (GF11)

In addition to his own desire to be 'human,' Gudmund was able to tell a story about Sir Ronald Fisher that made Fisher, a famous statistician, seem like just a regular guy. While David's story about Fisher was connected to experimental design (see pages

149-150), Gudmund's story about Fisher explained the origin of critical values in

hypothesis testing:

So that gives you 2.5% on each side so there's 95% in the middle. That's right. And the origin of that, the 2.5% on each side which adds to 5%, is that...

Go back to Fisher, Sir Ronald Fisher, the great English statistician. At one time, he was interested in genetics also. But he was at the mecca of statistics. Didn't know statistics had a mecca, did you? It's in England at a place called Rothamsted. And Rothamsted is an experimental station, an agricultural experimental station, where they had been growing stuff on these different pieces of land for a long, long time so they know that a certain type of fertilizer gets a certain yield, another type of fertilizer got this much. They kept track of these numbers for years and years and years and they used different experimental set-ups. So the place is full of data. Fisher was there, eyeing to be a statistician.

And so he sat around and drunk tea one afternoon and said... he was inventing all this stuff we were doing... In 1920 they were inventing all this stuff and now we teach it in a first introductory statistics course. So you can see what happened. Anyhow, so there's Fisher, inventing this stuff and he says "I need to answer that guy's question, I need to figure out where's the cut off between small and large."

So he sort of mulls this over, drinks a little tea, and he says to himself: He strokes his beard and says, "I think 1 in 20 is small." So he figures that's 5%, that's 95%, so that's 2.5%. So that's where it came from: Fisher having tea one afternoon, stroking his beard, and asking himself what's a small number.

The irony of course is that that number has taken on magic proportions. And if you are a poor, young assistant professor in some of the empirical sciences and you want to get published so you can get tenure, you'd better collect data that has a p less than 0.025. Because otherwise the editor will say that does not provide far enough sufficient criteria for us to accept your paper. So this number has made and broken careers for the last 80 years.

And there are many reasons why your p may not be particularly small: maybe you didn't have enough data; maybe you didn't quite run it. So there are all these things that were not published that have been discovered, but the p wasn't small enough so it never got published. Disaster. So that's what it is. But anyway, it's a very crucial question and I was trying to sort of jump around it for a while, but you put me to the spot. (GSCM12)

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Beth Chance at California Polytechnic State University

This is the story of Beth Chance at California Polytechnic State University.

During my visit to CalPoly, Beth's class was discussing inference (confidence intervals and hypothesis testing). Like the other three tales in this chapter, this story discusses Beth's teaching and her students' learning of inference and centers around the four themes that emerged from the data of all four participants. The following four themes are explored in this story: Beth's teaching philosophy; Beth's instructional strategies; Beth's interaction with students; and Beth's use of technology in her introductory statistics classroom. Again, the analysis of the data that constitute this story is reserved for Chapter 5 of this document.

Teaching Philosophy

This section of Beth's tale addresses Beth's teaching philosophy. The following paragraphs talk about Beth's teaching philosophy through four sub-themes: Beth's own teaching; effective teaching in general; the purpose of the course; and, Beth's knowledge of learning theories. Recall that Beth is the one participant who has some formal background in learning theories.

Beth Chance "grew up wanting to be a teacher" (BEQ1). Beth was frustrated when her friends hated mathematics and "thought it was only because they didn't have some of the great teachers I did" (BEQ1). During her undergraduate years, Beth "discovered psychology and became very interested in how people learn and how to

promote 'meaningful' learning" (BEQ1). After graduating from college, Beth entered a doctoral program so that she could teach at the college level after earning her Ph.D.

Beth was a graduate teaching assistant while she was in graduate school. After earning her doctorate, Beth taught for five years as an assistant professor of statistics at the University of the Pacific [UOP] before taking an assistant professorship at California Polytechnic State University²³ [CalPoly]. About college teaching, Beth said:

I am amazed that college professors are not required to take any education courses and somehow it's felt that knowing the highest levels of the subject matter is sufficient for you to be qualified to teach. I am very grateful for my courses in cognitive psychology, curriculum design, social psychology, and math education. (BEQ2-3)

In addition to her experience in cognitive psychology, curriculum design, social psychology, and math education, courses Beth feels that she has "a good understanding of currently recommended pedagogical practices for introductory statistics and am constantly striving to incorporate them into my course" (BEQ2).

With respect to her own teaching, Beth reported:

I feel I am very reflective of my teaching and am constantly trying to improve what occurs in the classroom every day. I am very committed to providing the highest quality of instruction possible... I do feel my background influences my pedagogy and I'm constantly striving to find a better way to teach my students. (BEQ1)

Later on in the same questionnaire Beth added:

I love explaining things to people and helping them understand. I felt too often students were turned off to mathematics and statistics because they weren't shown the applications of the material, nor sufficient multiple representations to have a fair chance of understanding the material. (BEQ3)

²³ As mentioned earlier in this document, data collection occurred during Beth's first semester at CalPoly.

Beth defined the effectiveness of a statistics teacher from the point of view of what the teacher's students are able to do:

Students know what to use, when to use it, and they can explain what they're doing. So part of it's the calculation, but also just understanding it and being able to explain it to somebody else. (BII1)

Despite her love for teaching, in terms of her own effectiveness Beth mentioned that:

I am not a very good motivator. So if a student really doesn't want to be there, then I'm probably not very effective with them. But I think there are some students who do seem to get it, and I think I do... have expectations, so that if they meet those expectations it's been effective. (BII1)

Since Beth feels that she is not a good motivator, she does:

Try as many examples from a lot of different disciplines and a lot of activities about [the students] themselves and stuff to try to get them interested. And sometimes it works and sometimes it doesn't. And I finally accepted that there are some students that there is not much you can do. (BII1)

Even so, Beth said, "I wish I had a little bit more command of other examples sometimes to reach out to more students" (BII1). At the same time, Beth does not "think I should have to be an entertainer, but I do think it is good to help them see the relevance in their lives" (BII1).

Beth gets feedback on her own effectiveness in the introductory statistics classroom through "follow up questionnaires and that type of stuff" (BII1). In addition to follow up questionnaires, Beth believes that she is effective in the classroom "because I think a lot of them come in knowing nothing, and some of them do demonstrate to me that they now know something" (BII1). And, just like the other participants in this study, Beth mentioned:

After a few years you start to get students coming back saying "Oh, now I understand that" and "I'm seeing other students struggle, but I think you really

helped make it interesting" and "I'm doing much better now in my follow-up courses because of these things you made me do." So even if they didn't appreciate it at the time, I think later they do start to see some of the benefits. (BII1)

In order to continue her own growth as a statistics educator, Beth is "always trying new examples, finding out what other people are doing to try to convey different concepts, just trying to stay very current with the literature" (BII1). Beth finds out about what other statistics educators are doing in their classrooms "mostly on the internet" (BII1), which includes "checking out JSE, Chance News, AP Stat list²⁴, talking to other instructors at conferences or by email" (BII1).

Beth believes that students "learn almost everything...through the debates and the discussions that they have with each other" (BII2). In fact, Beth encourages group work in her classroom "because I think all learning takes places when they debate with each other" (BFI4). Beth supported this belief about student learning with the following comment:

I even feel that I think I can tell them, but until [the students] try it themselves and work it out themselves, it hasn't really been taken in to their minds. Whereas if they kind of have to struggle with it and work it out, I think they learn a lot more. (BII2)

When I asked Beth if she would call the above experience 'discovery' or what word she would put on the experience she had just described, she responded:

²⁴ JSE stands for the *Journal of Statistics Education*, an on-line publication of the American Statistical Association. The internet site for JSE is <http://www.amstat.org/publications/jse/index.html>. *Chance News*, a monthly publication of the CHANCE Project, contains abstracts of recent articles from newspapers and magazines and suggestions for pedagogical use. For more information on *Chance News*, visit the following internet site <http://www.dartmouth.edu/~chance>. The AP Stat list is the listserv for those educators involved with the Advanced Placement Statistics courses offered in high schools. For more information on AP Statistics, visit the following internet site http://www.bbn.org/us/math/ap_stats/.

Just internalizing it... I mean I guess that kind of goes back to motivation too. I've found discovery's hard and a lot of times students are very reluctant to discover and they just give up. But at the same time, if I tell it to them, I'm going to be telling it to them again two days later. And it's really hard for them to get it that way as well. (BII2)

When I asked Beth to define learning, her response was:

I get jumbled up with all the models I learned about in psychology, but I do think that you can form a connection with other information in your mind. And I think... A lot of times I think if you can't say it in your own words, you don't really understand it. Or if you can't do it backwards or apply it to new problems, you don't really understand it. So I do think there is a big difference between rote memorization and deep levels of understanding. (BII4-5)

There is no one particular psychological theory of learning in which she believes, but Beth has "always played with the term 'meaningful learning.' I think you can know things without really understanding them" (BII5).

In order to assess student learning, Beth said:

I try to do a lot of different things, but also some performance assessment. A lot of giving [the students] novel problems that they haven't seen before to see if they can apply it, and asking them things that they haven't strictly seen before. And asking a lot of explanations. You know, not just can you do it, but can you explain it to somebody in your own words. (BII5)

During our follow-up interview, Beth again mentioned that she knows that students have learned:

When they can say it in their own words, when they're not just kind of repeating something, but it really is their own words and their own expressions. And also when they can apply it to new problems. But also when they can explain it to somebody else. (BFI1)

In addition, "sometimes [students] have a different perspective than I do and that may help get through to another student" (BFI4). In fact, during Wednesday's class meeting,

when Beth "wasn't really understanding [a] student's question—another student was able to step in and try and clarify where she thought that was going" (BFI4).

Another way that Beth knows her students have learned is:

When they come up with a question, they can kind of figure it out themselves. They've learned how to answer the question themselves: how to start; how to kind of piece things together themselves. That's something I'm always trying to shoot for, when they learn how to answer their own questions. (BFI1)

This long-term process of students answering their own questions is something that Beth told me I was not able to see during my time at CalPoly. About the class meetings that I witnessed, Beth said:

The lectures you saw were a lot more lecture-based than some of the other ones. And so I was also doing a lot of reflecting. And I think I do kind of like the idea of kind of forcing them to struggle with it a little bit and then kind of coming back and clearing up things. I think if I say that to them it's in one ear and out the other, but if they have to struggle with it and then explain something and then they say, "Oh, now I understand it." It's just kind of unfortunate the way it's set up now, a lot of times their struggle means they're not getting as high homework scores. And I think that's frustrating for them. You know, "Well if you told me this before the homework I would have understood it." So I'm kind of still trying to find that balance. (BFI1)

Also, after two days of reflecting on my earlier question about which educational theories she believes, Beth recalled a course she had taken on curriculum development.

In Beth's words:

And then you asked what kind of educational theories I abide by. And one course I was remembering was this course on curriculum development. And you kind of had to decide which type you believed in. And I found myself falling partly in the experiential side, you know, that students should really learn by doing. But then also on the disciplinary or I can't remember the term...but the side where you kind of need to understand the principles of the discipline, the background information, in order to kind of put that together and understand even the basics. And so I used to do a lot more "Where does this come from?" and kind of explanation of the background and some of the more formal proofs. And that's

actually something I've gotten a little bit more away from I think over the years, not necessarily by choice but partly by time. And I would do differently with a statistics student than a non-major. (BF11)

While Beth does not abide by any one particular learning theory, she does "believe that you need to pay attention to kind of the students' development in that you don't want to try and teach things to them before they're ready" (BF16). When I asked Beth how she can tell whether or not her students are ready to learn certain concepts, Beth responded:

It varies from semester to semester. But part of the reason I teach regression later in the course instead of early in the course is I think it tends to freak [the students] out, and they're kind of not comfortable with the course yet and realize that the course isn't all about formulas. Because I think sometimes if you do regression early they focus too much on those formulas. So some of how the ordering I put material in the course is trying to kind of teach them things when they're ready [for] it... Another thing you can't see in two days is I try and do a lot of kind of linking together and seeing the same relationship over and over again so kind of the spiral pattern, you know kind of coming back to the same idea and adding to it a little bit. (BF16)

To Beth, the word 'constructivism' means "students are more responsible for constructing their own knowledge" (BF16). When I asked Beth if she believes in constructivism as a theory of learning, she said:

I think so. Do I think it's a valid theory? Or do I think it's the right answer? ... I think it's definitely got a lot of merit. I don't think I necessarily execute it so well. But like I was saying, I agree with the idea of making [the students] struggle, so when you do talk to them you're talking to them at a much higher level I think. (BF16)

Beth's beliefs about constructivism impact her teaching because:

I think I try and do a little bit more of a Socratic method as well. When students ask for help, I try and get them to answer the questions instead of me just telling them. Sometimes they get frustrated by that. ... And so I do, I try and do a lot of getting them to lead themselves through the problem. I try. And even in class

trying to get some of the participation and having them kind of help me build the lecture instead of me just telling them the same thing every time. (BF17)

I mentioned to Beth that I had just that day been reminded through my reading that constructivist theory is only one theory for learning (Schaffner, 1997). With this in mind, using instructional strategies that support student construction of knowledge is good for students who can construct their own knowledge or who will construct their own knowledge. I told Beth that one of my beliefs has been that if you help students construct their own knowledge, you're actually helping all students, that construction of knowledge should be good for everybody. When I asked Beth to comment on that idea, she said:

I probably wouldn't be a hundred percent convinced. I do think different students learn differently. I don't think you can come up with one method that'll work for all students. Because some students, in particular with constructivism, they just give up way too quickly. And so maybe I need to spend more time at the beginning getting them comfortable with that mode. But I think you also are fighting 12 years of education prior to when they come to you. They're so used to that lecture mode; it's so hard to get them out of that.

One thing I thought I would be good at as a teacher was being able to kind of adapt to individual students and to be able to say, "Okay, that explanation didn't work for you, let's try another explanation," and being able to try and look at some of these different perspectives. And I really think it's important to give students multiple ways of looking at information. So the visual, the verbal, all the different things. But that's why it's so frustrating with me when students don't come to my office hours, because they don't give me that opportunity to try and give them a different explanation.

And I just think constructivism, it's just hard. I don't think... I think I also realize a lot more on the teacher. And that's the main thing I'm learning this quarter is I'm not all that good at it yet. And I think the students are resistant to it to begin with, and so when I do things to make it harder... And it's also hard to find... You know I try to say, "Yes, I think they can do this on their own." And so there's a lot of you need to know whether students can do it on their own or not. And I'm doing a very good job of overestimating or underestimating how long a lot of this stuff takes. (BF17-8)

Based on her knowledge of learning theories and her experience teaching statistics, Beth gave the following as a description of her ideal undergraduate introductory statistics classroom:

Thirty students, each student at a computer, which is loaded with several statistical packages and visualization tools, but also the ability to lecture (students facing a common board) and have classroom discussions. All students are there because they want to be. Students work through materials on their own (e.g., the Workshop Statistics approach) but ask a lot of questions of me and other students to clear up their understanding. Students do all of the homework assigned, come to office hours with questions, and have ridiculously easy access to the computer software outside of class as well. Students share results with each other and solve sample problems for each other (e.g., mini presentations). Lots of data collection and analysis of that data. Lots of "hands on" activities. A semester-long course or less material in a quarter course so students have time to practice and reflect and apply their knowledge. A final "projects day" where students from all sections present their term project reports to the other students and faculty from other departments. Students are assessed through a combination of exams, activities, homeworks, presentations, and other feedback mechanisms. Oh, and I've have 5 graders and teaching assistants who would grade everything as anally as I with tons and tons of written comments for the students, returning the work the next day. I also feel there should be more coordination among instructors of different sections of the same course. This could include jointly written and graded exams. (BEQ3-4)

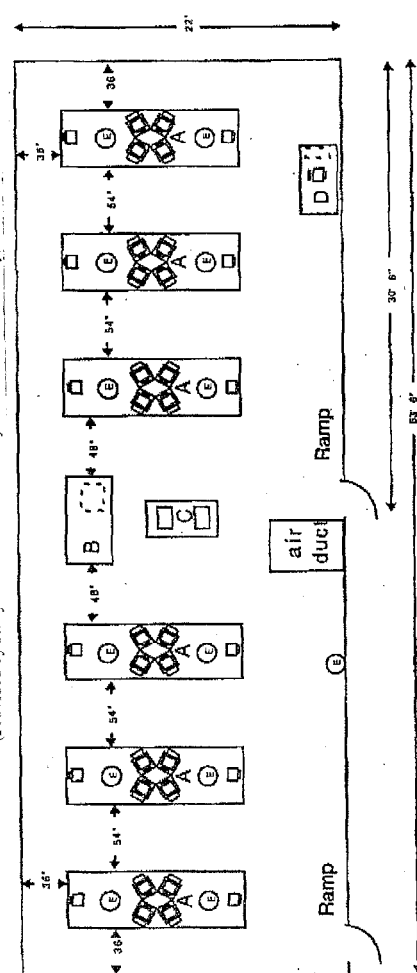
The reason that Beth posited the above environment as her ideal undergraduate introductory statistics classroom is because:

It's a positive learning environment that maximizes what students can learn from the course. I do believe in students constructing their own knowledge as I feel this increases motivation, retention, and understanding. Students should also learn from each other and feel pride in their work. The facilities I have now are almost perfect but I do feel they hamper group discussion too severely. The above dream also lets the material be the focus, not the computer. (BEQ4)

Instructional Strategies

Statistics 217, the class that Beth teaches at California Polytechnic State University, meets twice a week for two hours at a time in a studio classroom. Statistics 217 has a cap of 48 students per section. Figure 4.2 is an illustration of the studio classroom in which Statistics 217 is taught.

Statistics Lab – Proposed Furniture/Computer Layout
(Provided by Roxy Peck of California Polytechnic State University)



A = Student Work Tables (48" X 144") – (4) Workstations, (2) extra monitors at ends of tables for extra Robotel Monitors, (2) extra ether drops/table for laptop plug-ins (see "E" below)
B = Faculty Work Station (36" X 72") – (1) Workstation with Robotel control module
C = Printer Table (30" X 60") – (2) printers
D = Server Table (30" X 60") – (1) server
E = Additional ether drops

Note: Floor is raised 3", all com lines, Robotel, and electrical will be under floor

Figure 4.2: The Studio Classroom in Which Beth Teaches

Beth has found that the two-hour class meetings "can be a long time. Even when you're mixing up the lecture and the activity, it's still a long time" (BFI3). However, Beth added:

But one hour a meeting wouldn't be enough because you wouldn't be able to get as deeply involved in the activities. So 80 minutes is what I used to have at UOP—that might be okay. (BFI3)

Beth mentioned that, while the students do pretty well during the two-hour class meetings, "they definitely get off task. They definitely can't listen to me lecture for two hours" (BFI3). Taking some responsibility for her students being off task, Beth said, "partly I'm not doing a good enough job keeping them on task" (BFI8), an issue that she has discussed with a colleague:

[My colleague is] convinced in a class of, say, 30 there's a lot more peer pressure, a lot more interaction with the instructor, they stay on task a lot more. Where with 50 when I can be behind a wall sometimes, it's too easy for them to get distracted. (BFI8)

When Beth was at UOP, there were approximately 45 students in her class, "but it was a little bit more lecture oriented, so it was a little bit easier to kind of control where [the students] were at and what they were learning at different times" (BII2). At CalPoly, Beth has "switched over to trying to do a lot more activities, a lot more of them on their own" (BII2). With 50 students in Statistics 217, Beth has found that "50 is kind of large for me to be able to visit everybody and make sure they're staying on task" (BII2). Even so, Beth added the following about the number of students in an introductory statistics class:

If it's too small you can't always collect data in class and see any kind of pattern to the data. But I want it to be small enough where they feel comfortable asking questions and working together and sharing information. (BII2)

During the two class meetings I observed, Beth did lecture a bit. Her 'straight lecturing' took on the form of reviews and summaries. The following excerpt from the first class meeting I visited is an example of one such review:

Okay, then I wanted to spend a few minutes going over what we did with confidence intervals. So I'd like to hit on some of the activities you were working on. So this would be a good time to ask any questions that you still have about margin of error, things like that. So by the end of last time we pretty much got into this formula and we said this is the confidence interval for the population proportion. So I'm trying to estimate theta. And I'm going to do that based on the limited information I have in \hat{p} . Hopefully, and we saw this through a lot of simulations, \hat{p} -hat's close to theta. So I'm going to take \hat{p} -hat, I'm going to go a distance in either direction, and hopefully I'm near theta. So when I'm done with this interval, when I get those two numbers, that tells me the values of theta, or the population parameter, that I think are plausible based on what I observed in the sample. So I'm trying to contain the population parameter in this interval. (BFCM2-3)

In addition to reviews and summaries, Beth introduced the idea of practical versus statistical significance in a lecture format:

Statistical significance is not the same thing as practical significance. What does that mean? [pause] So what does statistical significance tell you? [pause] All it looks at is this distribution and tells you whether or not a result like this could have just happened by chance. So it's just saying, "Could this have happened only because of the sampling variability?" It doesn't tell you [if it is] important. It doesn't tell you if it's a big difference. It just tells you "could it have happened by chance?" So I may end up deciding it's not 0.5, but is it 0.45? 0.4? 0.3? Is it a big difference to me personally?

So you'll see that in the shopping data. We may say yes the stores are statistically significantly different, but maybe it's only 5 cents. Maybe it's not worth the extra cost in gas to go to the store that's further away. So is it different to you in a practical sense? Okay? You may find out it's not 0.3, but if it's 0.29 am I really lying to you to say it's 0.30? Is it really a difference in the practical sense, just talking between you and me? Okay?

So statistical significance doesn't tell you much about importance or even how big the difference is. The confidence interval can tell you kind of how big the difference is, how far away it is. So a lot of times we follow up our test of

significance with a confidence interval. And we say it's not 0.5, well what is it? Well the confidence interval tells you what range of values seems to be a plausible value for the parameter. (BSCM5)

The instructional strategy that I saw Beth use most often was more of an 'interactive lecture.' The following excerpts from the class meeting transcripts serve as examples of Beth's interactive lecture:

Excerpt 1 (about $z=1.96$ in the confidence interval formula):

- (student 1) Where did the 1.96 come from?
- (Beth) All right, so where did this 1.96 come from?
- (student 2) It came from your 95%.
- (Beth) So I said, well I know that if I was to do the sampling distribution of a bunch of \hat{p} -hat values, they should be centered at?
- (student 3) Theta.
- (Beth) Theta, whatever theta may be. And we know it should be following a normal distribution. Is our sample size bigger than 30? Yeah. So it should be following a normal distribution. So then if I want 95% in between, okay? So I want to find the minus z^* and the z^* that give me 95% in between. But the table doesn't come in that format. The table doesn't talk about between. The table talks about one point and all the way down. So if there's 95% in here, what's all the way down? ... If there's 95% in here, what's not in there?
- (student 1) 5%
- (Beth) 5%. And half of that has to be up here and half of it down below. So what's half of 5%?
- (student 1) 2.5%
- (Beth) 2.5%. So 97.5% all the way down. So now go to this part of the table and look for something close to .9750. And from that you should be able to read off the z -value. ... (BFCM4)

Excerpt 2 (about using the normal distribution for confidence intervals):

- (Beth) Now what two things must be true for all of this to work? And so that's the technical assumptions that your book refers to.
- (student) Sample size greater than 30.
- (Beth) Sample size has to be greater than 30 so I can draw that normal picture that we saw. Okay? So I do need at least a certain sample size so things start to look normal. And what else?
- (student) Random sample.
- (Beth) It has to be a random sample. (BFCM5)

Excerpt 3 (about bias in sampling):

- [The problem posed is that an alien lands on Earth and notices that there are two sexes of the human species. The alien wants to estimate the proportion of all humans who are female and uses members of the 1997 Senate as a sample, where he found that there were 9 women and 91 men. The resulting confidence interval from the alien's calculation is that the alien is 95% confident that between 3.4% and 14.6% of all humans are female.]
- (Beth) Are you happy with that calculation? Are you happy with that conclusion? What's wrong with the conclusion? [pause] You don't think there's 3.4% to 14.6% females?
- (student) No, there's...
- (Beth) Probably more like 51% females, so why is it so far off?
- (student) Because...it's not based on the population... it's not random...
- (Beth) It's not random. Women and underrepresented in the Senate. This is a very biased sample. Can I plug all the numbers into the formula? [pause] Sure. Does the formula tell me anything about theta, the population parameter? Not really. So I can calculate intervals as often as I like, but you can't forget that simple random sample technical assumption. Without that, all those calculations are meaningless. Well you said the Senate's not a very good example of all women, or of the whole population in the world. So can I say I'm 95% confident that 3.4% to 14.6% of senators are women? [pause]
- (student) No, it's 9%.
- (Beth) Yeah, this is one of those cases where I know theta exactly. Theta in 1997 is just the 9% women. There's no plus or minus there. I know theta exactly. If I go back to the 1997 Senate, there's still going to be only 9 women in there. If I ask them again, now there are still only 9 women. It's not something that varies and so I need to take into account that sampling variation. So you've got to make sure it's a simple random sample. You've also got to make sure it's a sample to begin with and that it's not the whole population. (BFCM10)

Excerpt 4 (about rejecting the null hypothesis at a certain significance level):

- (Beth) Question on that?
- [a student asks a question]
- (Beth) I'm not sure I'm following your question. So it does happen about 10% of the time. Is that less than, say, 5% of the time?
- [another student chimes in to clarify the student question and to answer the question herself]
- (Beth, agreeing with the second student's explanation) Yeah. So if you have a level of significance, which is usually something like 5%, you'll compare your p-value to that level of significance. If your p-value is smaller, then we say yes this result was unusual enough, it happens... it's unlikely enough to happen to convince me it didn't happen just by chance. So if my p-value is less than my level of significance, I say it's significant at that level. (BSCM4)

Although Excerpt 4 represents a discussion among two students involved and

Beth, Beth has found "it a lot harder to have classroom discussions in that type of room" (BII7) because the studio classroom "is very long...and students face four different directions" (BII7). In addition, with the set up of the studio classroom (please refer back to Figure 4.2 on page 190), "half the time the students aren't even looking at you" (BII7). Even though Beth "can control what's on their computer to try and kind of control what they're focusing on" (BII7), she has found that:

Even just getting them to talk to each other, except for the people right around them, it's a lot harder. And so I kind of miss that ability to have [the students] kind of work together as a class and to do a lot more of the question and answer as a class. (BII7)

Beth also mentioned that with the studio classroom set up:

You can't see [the students], the computers are in the way. I wish the computers were down underneath the desks. Or that we could go into a little side room—today we're just going to have discussion, we're not going to be distracted by the computers, we're just going to talk to each other. And I wish there was a room that we could go into sometimes like that. Or having students present homework solutions—I really miss that from what I did at UOP. (BFI3)

During our follow-up interview, Beth talked about establishing a sense of

community in the Statistics 217 classroom:

It takes a while. This quarter's been harder. I don't know why, but somehow meeting every other day or something, it took me a lot longer to learn their names. And I think that helps when I can call them by name and things like that. And the way this room is I feel there are certain students I haven't gotten to know as well. And it's harder to get to every student and establish some kind of rapport. But I do think classes get personalities and relationships with professors. And I think there is some interaction give and take. You know when they can say "that wasn't a very funny joke" back to me and things like that. (BFI5)

Beth's expectations of her students outside of class meetings are intended to support interaction and discussion in the classroom community. For example, Beth had asked her students to look at a particular exercise during the time between the two class meetings I observed. I noticed during the second class meeting that Beth felt she had to go over this exercise more than she had intended to and asked her about it. Beth responded:

I was very frustrated when I was going through it. [The students] were all copying it down for the first time, and so that makes it go a lot slower when I have to wait for them to copy it all down. So it's frustrating for one reason: I never want lecture to be them just copying; I want lecture to be them thinking and reflecting and asking questions.

And so I haven't done a very good job of that. And you saw that the first day when I'm saying, "This is in your book, you don't need to be copying this down." And still, it's really hard to stop doing that. And I think at UOP sometimes I did a better job of saying, "Put your pencils down, just think about this."

So a lot of it is... I do think it's my fault, that's part of the reason I still want to go over it. I did change today a little bit from yesterday [Beth's other section of Statistics 217] that I just kind of shortened it and said, "Look, here's your two-sided p-value, this is what you should have seen."

But, I think that [a colleague] is a good model of... She'll say, "You do this outside of class and that's it," whereas I'm still too easy at saying, "Okay, fine, I'll do it for you if you really ask me to." But I think I am giving them a fair bit to do outside of class. The way the class is going now, since they're not finishing the in-class activities, I give them more of that out of class. Then I feel responsible for going over it, so then we don't go over as many in-class activities. So I think if it worked right, I wouldn't...

And when I give them things to turn in and things to not turn in, they only do what needs to be turned in. And it's a lot harder to do what only needs to be turned in when they haven't done what came before it. So there are a lot of things where the timing's just not working out very well right now. (BF15-6)

Statistics 217 is also a forum in which students can experiment and explore statistical concepts. The project that Beth assigned her students to do outside of class involved hypothesis testing for deciding which of two grocery stores near CalPoly was

more economical. One student mentioned that she thought one of the two stores was more expensive than the other. To this Beth replied:

All right. She thinks one store is more expensive. Remember that. The very first thing you're going to have to do in this lab is you're going to have to make a prediction. And we'll see today why that's kind of important, because that's going to affect how you do the analysis. So if you have a prediction ahead of time... Each of us may have a different prediction. Okay? But be ready to predict one of those stores is cheaper. (BFCM1)

Another exploration of hypothesis testing occurred with a pair of 'fair' dice during class time. The following is the exchange between Beth and her students at the beginning of this exploration of hypothesis testing:

- (Beth) I need a volunteer to help me roll some dice. It won't hurt. Volunteers? [Beth hands the student a pair of dice.] You can stay there. So she's going to roll the dice and she's going to call out the sum of the two dice. So I'd like you to record the sum. So really loud.
- (student) 7...11...7...7 (laughs)...11 (laughs)
- (Beth) What's wrong? Why are you laughing?
- (student) Because it's the same.
- (Beth) It's the same, so? Seven's the most common roll with two die.
- [student looks closely at the dice]
- (Beth, to student volunteer) Why do you think there's something wrong with those dice?
- (student) Oh my G-d.
- (Beth, to class) Why is she now looking at the die and finding out there is something wrong with them? Yeah, one is all 5's the other is all 2's or 6's. Why didn't she look at the die after the first roll? [class chatter] Why didn't she look at the die after the first two rolls? [class chatter] Could this have happened with... What was your assumption when I handed her the die? [class chatter] That they were fair. Do I get a 7 and then 11 with fair die?
- (student) Yeah.
- (Beth) Sure. Do I get three 7's and two 11's in five rolls? [pause] Not usually. Could I?
- (student) Yes.
- (Beth) Yes. Is it unlikely?
- (student) Highly.
- (Beth) Highly unlikely. ... So what did we do here? You had a basic assumption that she had fair die. So we started off thinking they were fair dice. Then she gathered some data. And eventually we decided that data was

just too unlikely to happen by chance alone. So maybe that assumption that they were fair die is false. I want you to try and put that in your own words so you can go back and look at that later and remember this reasoning. So what's the reasoning behind how we started to think they weren't fair dice?

- (student) We started to believe that the dice were not fair after the probability of the rolls got out of line with the actual...
- (Beth) Okay, so we started to believe the dice were unfair. So we started with an assumption that they were fair. The probability just started to make us a little too uncomfortable. And so that gave us some evidence that the dice were not fair. Is that kind of what you're saying here? ... (BFCM11)

Beth also spent time in class providing students with links between new statistical concepts and ideas back to earlier statistical concepts and ideas with which the students were already familiar. The following excerpts from class meeting transcripts contain examples of such links:

Link 1 (linking reasoning about the dice tosses to an earlier activity):

- This is the same reasoning you used back in Activity 14 if you actually want to peek at that again. Remember Activity 14-5 was you had those juries? So you had 12 people and you wanted to know how unlikely it was to only get 2 senior citizens on that jury. Okay?... So basically you're trying to decide if your sample proportion was unusual. So what that activity did is said well what do sample proportions look like? Is this an unusual result of not? Could this happen by chance? To kind of get an idea of the probability of it happening that way. So what you're going to end up doing is kind of standardizing it, like we've been doing before, and asking yourself what's the probability a value like that could happen by chance alone? And then if that probability ends up being too small, maybe what you were using for the parameter, maybe that the initial assumption, or conjecture that you were making, was wrong. ... So you've seen this reasoning before. (BFCM11-12)

Link 2 (linking the test statistic back to standardizing a random variable):

- So that's just standardizing like we did before, but now the term is called a test statistic. So I'm comparing to what I got in the data to what I'm hypothesizing. I call that the test statistic. (BFCM15)

Link 3 (linking rejection of the null hypothesis back to the dice activity):

- Go back to the dice. I assumed the dice were fair. I got data that just doesn't happen—the probability of that data was just too small for me to continue believing the dice were fair. So it could be [one of] those one in a million

samples from that distribution. But instead of thinking I'm that unlucky, I'm going to go and think that the null hypothesis is no longer true. Okay? (BSCM7-8)

Link 4 (linking values of the t-distribution to values of the standard normal):

- What if I'd found a z^* for 95%? [pause] It was 1.96. So the t-values are always a little bit bigger. Okay? I need a little bit wider interval. So, I need a little bit bigger t-value to reflect the fact that I made this additional estimation of the standard deviation as well. So that creates a little bit more uncertainty, a little bit more variability, so I need a little bit wider interval. (BSCM10)

In addition to linking new ideas and concepts to previous statistical ideas and concepts, Beth also linked new material to 'real-life' experiences. The following are examples of these links to 'real life':

Link 1 (linking the meaning of confidence intervals to knowing students' names):

- Because the difference here is what we're considering random or what we're applying the probability statement to. The interval's changing. Sometimes the interval works, sometimes it doesn't. Theta's fixed. It's not like sometimes theta's between .73 and .79 and sometimes it's not, it either is or it isn't. An analogy here is sometimes I know your name and sometimes I don't. There's a different probability every day if I'm going to remember your name. But your name is not changing. It's not like tomorrow David comes in and he has a different name. His name is fixed. I just may or may not give you a very good estimate of what his name is. So there's some probability statement to my estimate. Okay? But it's not like you come in tomorrow with a different name--the parameter is not changing. (BFCM6)

Link 2 (linking hypothesis testing to the trial process):

- In fact speaking of criminal trials, let me give you one more quick analogy. Okay, those are our five steps. Assuming the null hypothesis is true. Well, what do you do in a criminal trial? You assume they're innocent. So you start off with an assumption of innocence. Then you gather some data; you gather some evidence. If that evidence does give you enough evidence against them, against their guilt, you convict them, right? If you have strong enough evidence you convict them. If you don't have strong enough evidence, what do they say, what's the verdict that they read off? [pause] If there's not strong enough evidence... [student: Not guilty.] Not guilty. They don't go around saying they're innocent; they go around saying I didn't have enough evidence to say that they're guilty. So I don't go around saying yes I know for sure the

null hypothesis is true. You just say I didn't have enough evidence to convince me that it's false. And so that's why I like that "fail to reject" phrasing. (BFCM17)

In order to assess her students' understanding of statistics, Beth tries:

To do a lot of different things, but also some performance assessment. A lot of giving them novel problems that they haven't seen before to see if they can apply it, and asking them things that they haven't strictly seen before. And asking a lot of explanations. You know, not just can you do it, but can you explain it to somebody in your own words. (BII5)

The project mentioned above is one such assessment tool that Beth uses. Beth described the project to me:

It's a data collection project, so [the students are] supposed to go out and get the data themselves. I try and leave it as much up to them as possible, so they're supposed to pick a topic that's interesting to them. And they work in a group of about four to collect the data and go on through analysis.

And I do get periodic project reports, so I can say "Well, while you're there why don't you ask them about gender?" Because then I know down the line they'll be able to do a two-sample t-test or something which they may not think of at the beginning. So I do try to make it big enough that they'll have some interesting things at the end. And then I do expect a full test of significance, checking all the technical assumptions and everything by the end. (BII5)

It is Beth's intention to use the project to assess her students' understanding of:

The whole process from beginning to end. So it's a little bit more the process. And to be honest, if their analysis ends up not being beautiful, that's fine. A lot of it's the experience that I want them to have as well. And I think it's also a confidence builder. And a lot of it is just, again, sure I can read all the stuff in the book, but it's not until I actually use it and apply it to something interesting to me... And I'm quoting students on that; that's what they tell me. (BII5)

The projects outside of class are a group effort. Groups are chosen:

However [the students] want to choose them, unless somebody hasn't found somebody, I'll help them find some other people. This year I had them at least kind of brainstorm a little bit about what would be an interesting variable. I thought I'd do more with finding people with common interests. But I do try and make sure they've done some in-class activities and met the people around them and stuff before they have to form groups. (BII6)

Grading for the group project is:

85% group grade and 15% individual grade. And at the end of the term [the students] evaluate each other. And if I find any consistent markdowns of the people, I'll adjust grades that way. And if you do the math, 15% isn't much. But that seems to be enough that I've had a lot less group dynamic problems to deal with than I did initially. So I do try to keep some individual accountability. But again, that's why there's a lot of individual homework and tests as well. (BII6)

In addition to the group project, homework, quizzes, and exams, Beth does try to assess her students' understanding during class time. Beth mentioned that in order to assess understanding in class:

I try and do a lot of probing them or encouraging them to ask me questions that they don't understand, but that isn't always successful. With the workshop approach, I can do a lot more walking around and looking over shoulders and monitoring them that way. And I try to get them to tell me the answer. And I don't do a good enough job of saying, "Okay, she said 17. Bobby, tell me where she got that." And trying to make sure there's more than one person that understands it. But I do try and elicit some of that. And try and get a comfortable enough environment that they'll stop me if I'm going too fast. (BII6)

I asked Beth how her assessments match what she has in mind for her students' learning. Beth responded:

Right now not all that good. But I'm not sure—I'm trying to decide how different that is from previous courses, because this usually is the part of the course when everybody's most unhappy. And usually even that second midterm is a pretty big dip for people in my classes. And I try and put it even kind of early because it forces them to try and learn it instead of waiting three weeks to try and learn it. And so I'm hoping after the midterm... Then, you know, a lot of times they don't start pulling it together until then. And after again they've seen the same concept in the two-sample tests, the same ideas in a chi-squared test, the same ideas in ANOVA, you know, I do think they need to see it for a few times. So I think they're struggling. I think maybe a little bit more that what I'm used to. But that's partly why I'm trying to spend a little bit more time with them right now. (BFI2)

Beth consistently indicated to her students an emphasis of 'process over product' with respect to her assessment of their performance. For example, when talking about showing their work on exams, Beth said to her students:

It's also very, very good to show me this part. Because a lot of you are getting to the point where the numbers are plugged in *correctly*, and then maybe losing a math error here. And a math error takes a lot fewer points off if I see all the numbers plugged in. So I know you had the right idea, and it was just something that the calculator didn't quite get out right. (BFCM4)

Later on during that same class meeting, Beth said, "And again show me the in-between steps, because if I see you set it up right and it's just the algebra that let you down, that's a totally different story" (BFCM8).

Like the other three participants, Beth brings cartoons and stories into her classroom. At the beginning of the first class meeting, Beth posted the quote: "statistics is never having to say you're certain" (BFCM1). At the beginning of the second class meeting, Beth told her students another story:

So our story for today: The Nation Traffic Safety Board recently revealed a plan, a secret plan that they had, where they were covertly sticking black boxes in 4-wheel-drive pick-ups, 'cause they wanted to figure out what was happening right before a car accident. So they're recording the last 15 seconds. And they were surprised to find that in 49 of the 50 states, the last words of the driver in 61.2% of fatal crashes were the same. The one state that was different was Texas, where 89.3% of the final words were "hey, y'all, watch this!" [class laughter] So a few proportions for you to play with. (BSCM1)

I asked Beth about her inclusion of cartoons and stories in her teaching. Beth responded:

Earlier in the course there's a few more cartoons and news articles, and just again showing them all the stuff in the newspaper and all the stuff they can relate to and just trying to show them the lighter side a little bit. And also sometimes I think it's good, not to get them to laugh at other people, but it's the expert on Nightline or the dean who says something really silly, to let them know that they have knowledge that these other people don't have. (BF14)

No matter what instructional strategy she uses, Beth feels that she is "trying to present some information in the most effective way possible" (BF14). Beth added:

But I don't know if I'm supposed to keep them in stitches the whole time either. But I think that helps. And I've been trying a little bit more sometimes to just show a little bit more of my personality and seem a little bit more open and accessible to them instead of just being this person in the front of the class that they only see those four hours a week. And showing that a statistician can actually have a little bit of a personality. (chuckle) (BF14-5)

Use of Technology

Technology plays a "big" (BCI2) role in Statistics 217. Beth reported that "students are expected to work with a computer every lecture and use it for homeworks outside of class as well" (BCI2). The students in Statistics 217 use *Minitab* for data analysis and use "some other software programs for visualization (mostly in class, but also some Java applets)" (BCI2). In addition, "all course notes and handouts are available on the web" (BCI2).

During class time, each of Beth's students sits in front of a computer. The computers are grouped so four students can sit together in a group-like arrangement. While each student is able to work on her/his own computer during class, Beth also has the ability to control the monitors of the computers if she wants the students to look at something she is doing on her own computer or on a particular student's computer.

Beth has found the technology in her classroom to be:

Pretty good. It's a little frustrating that some of the students are very far away and you can't always tell what they're doing. There're a couple glitches with the computers, so then that tends to distract students from what they're doing. Like you can't go into *Minitab* and then open a file, you have to open the file first. It's just a big glitch, but it does distract students. (BF12)

Another 'problem' with the technology in Statistics 217 is that the students are:

Supposed to have access to several labs on campus, and these labs are supposed to have *Minitab* and Netscape. A lot of these students live off campus though, and say it's too inconvenient for them. And some computers, like I think in some of the dorms, aren't in the labs and might not have the same software.

And I was surprised how much [the students] struggled even when I gave them Java applets. Like they didn't even always access to Netscape or they complained that things were in PowerPoint instead of in Word and that's not fair and stuff like that. So even trying to get things off the web has been more of a problem than I expected or was even kind of led to believe at this technology university. And again it's real frustrating when that becomes the focus instead of the learning goal. (BF14)

This is a frustration for Beth because she "can't really rely on [the student] to use the technology outside the class and so that also affects what I can do inside of class versus outside of class" (BF19).

Despite technical problems, technology plays such a large role in her classroom "because I think there are tasks that you can turn over to the computer so the students can concentrate on the concepts instead of on the calculation" (BII4). Beth has found that:

The students I'm working with tend to be very visual learners, and I think there's a lot you can show them visually by using the computer that they can't really understand just through words. And there's a lot I want to be able to play with and see what happens. (BII4)

So, technology in Beth's classroom serves as a computational tool to allow students to spend more time on understanding statistical concepts and as a tool for visualization.

Beth commented:

I do think it's really nice when I can say "look at this"—I can say "here's this idea, now go try it." And they get to use the technology to remove a lot of the computational burden once they get comfortable with the technology. (BF12)

While Beth does want her students "to be able to have the ability to go to a software program and get some output and understand that output" (BII4), she is "not trying to turn [the students] into statisticians" (BII4).

For Beth, technology in Statistics 217 serves "much more as a pedagogical tool" (BII4). Despite the benefits of technology in the classroom, some of Beth's students "just hate the technology at no cost, and they're refusing to work with it" (BF13). However, Beth still feels that using technology can help her students "get to the big picture faster by not spending all their time on the calculator or just doing the individual calculations" (BF13). For example, Beth has her students work with a simulation of confidence intervals where the students are able to change the confidence level. With this simulation Beth's students:

Can say "Oh, well what happens when we change the confidence level?" They change it and "poof!" it grows longer. And so they can really see that right away instead of having to calculate out all these new intervals. (BF13)

One pitfall that Beth tries to avoid when using technology is having the technology turn into a 'black box.' According to Beth:

I think the technology too often can be a black box and so [the students] really need to do [calculations] by hand. And that's something that didn't go that well ... this quarter and part of the reason they're still a little afraid of the technology and not always understanding what they're seeing. So maybe they're still not linking the "by hand" with the "by computer." (BF18)

Interaction With Students

Recall that Beth considers interaction among students to be quite important because she thinks that the students "learn almost everything...through the debates and the discussions that they have with each other" (BII3). While Beth considers interaction

among the students to be very important, she would still like the interaction between her and the students "to be a lot more than there sometimes is" (BII3). In fact, Beth has been:

Surprised at how reluctant some students are to come to office hours. Then they'll say, "I didn't get it" and have never bothered to try to contact me. And I try to make myself very available. Because I'm there all day and I respond to email all night and I'm still disappointed that more students don't take advantage of that. (BII3)

Beth has found that "eventually you start to get [the students] coming, but it can take a while" (BII3).

Beth wants her students to attend office hours and to talk to her about statistics because:

There is a lot in this course that is counter intuitive. Some of it's pretty obvious, but I think there's a lot of it that they can't expect to get on there own without asking questions and getting clarification. (BII3)

One reason that Beth thinks that students do not come to see her is because of the professor/student relationship. According to Beth:

I always wanted to go in and say, "Hi, I'm Susie the TA" and then I think they might be more willing to come in and ask questions. I think they find people like that a lot more approachable. (BII3)

When I asked Beth why she thought students would be more likely to approach her if she were a teaching assistant than as a professor, Beth responded:

I think they just don't want to look stupid in front of somebody. Or [they are] afraid that I'll react to them badly in some way. On Wednesdays I do have a student who helps, and I've seen students ask her questions from material from a couple weeks ago. And I don't think they would have ever dared to ask me about that material. (BII3)

Even though her students did not flock to her office hours, Beth interacted with her students during the class meetings that I attended. Much of the interaction between

Beth and her students was documented in the section on instructional strategies. In addition to those instructional strategies mentioned earlier, while her students were working together in class, Beth spent time wandering around the classroom, asking students probing questions about their work. Beth's 'wandering and questioning' allowed the students to interact with her as well as to interact with each other.

When explaining the project she assigned to her students, Beth told her students why the project write up was structured in the way that it was:

The main reason I'm [assigning this lab with this format] is this is the format I want to see in your final project. So this way you'll get to try it once, get some feedback, and then that final project report is just going to follow that same format and so you'll know exactly how that goes. Okay? Does that sound reasonable? (BFCM2)

Discussing assignments with her students allows Beth the opportunity to explain her reasoning for the assignments as well as the opportunity to get feedback from the students about the assignments, thus letting the students "feel some ownership in the process" (e-mail communication, March 29, 2000).

Questions That Arose During Data Collection (and Answers to These Questions)

During and following my site visits, my head was full of ideas for analysis. I noticed that all of the participants were very interested in and excited about teaching, so I wondered about their preparation for and reflection on class meetings. Paul, David, and Gudmund all mentioned the maturity level of their students, so I wanted to investigate the issue of student maturity a bit further. In addition to maturity level of the students, the issue of teacher as caretaker/performer was raised, so I wanted to probe into this a bit

more. Since all of the participants viewed the introductory statistics classes they taught as 'consumer statistics' courses, I wondered what each participant wanted her/his students to be able to *do* with statistics after the course was over. I also wondered what each participant planned to do in her/his future as a statistics educator. In order to answer these emergent questions, I sent an e-mail to each of the participants posing the following questions:

- About how much time do you spend preparing for each class meeting? What types of activities are included in your preparation for each class meeting?
- About how much time do you spend reflecting on each class meeting?
- Is the environment of your classroom one in which all students can learn?
- What do you want your students to be able to do with statistics after completion of your class?
- Describe for me the maturity level of your students. How does this impact your instruction?
- How do you feel about the issue of teacher as performer?
- How do you feel about the issue of teacher as caretaker?
- Tell me how you imagine your future as a statistics educator²⁵.
 - How many more years do you imagine teaching statistics?
 - With respect to the teaching and learning of statistics, what would you like to do in these remaining years?

Time spent preparing for each class meeting varied across the participants.

Gudmund was the 'outlier' in the group. Gudmund spends only about 15 minutes looking over his notes and planning examples to do in class prior to each class meeting. Paul and Beth each spend about an hour preparing for each class meeting, although Beth mentioned that it takes longer to prepare for each class meeting the first few times she teaches a course. Paul spends his preparation time "reviewing the material, looking over what is in *Data Desk*, selecting homework assignments, and gathering any needed

²⁵ The discussion of the participants' answers to the question about their futures as statistics educators has been reserved for the Epilogue of this document.

materials" (PFE1). Once she is familiar with a course, Beth's preparation time consists of:

Preparing transparencies and notes to myself, preparing an outline for students to supplement during lecture, writing homeworks and solutions, setting up activities... compiling data collected as a class for later analysis, etc. A non-negligible amount of my time is also spent uploading files to the web for student access. (BFE1)

David spends about 2 hours preparing each lecture revising notes, replacing old examples with new examples, previewing and setting up videos, and going over any computer demonstrations, and 2-3 hours per week "preparing quizzes and scripts for TAs" (DFE1).

The participants spend a much shorter amount of time reflecting on each class meeting. Still, Gudmund is the outlier, since he spends "no more than five minutes on my way from the classroom to my office" (CFE1) reflecting on the class meeting. Paul did not specify an amount of time that he spends reflecting on each class meeting, but he did say:

Maintaining the course web site enforces some reflection. I consider whether I need to post additional comments for the students and monitor any comments or questions they've posted. (PFE1)

David reported that he does not spend much time reflecting on a class meeting "if class went OK" (DFE1), but "if not, I make notes for changes in the future" (DFE1), which takes 10-15 minutes. Beth responded, "there is always informal reflection" (BFE1), but that at UOP:

I had a nice system where I tried to spend 10-15 minutes after each class writing notes to myself on what did and did not go well, how time was spent during the lecture, what needs to be looked out for or emphasized harder next time. Though even when I'm grading homeworks, quizzes, labs, etc., I usually make notes on common misconceptions or points I want to make sure to work into upcoming lectures. (BFE1)

As far as learning goes in their classrooms, the participants are split. Beth and Gudmund both think that all students can learn in their classrooms, while Paul and David have doubts about learning in their classrooms. Beth thinks that the environment of her classroom is one in which all students can learn, because she allows and encourages different learning styles (BFE). Gudmund said, "I am not sure what you mean by environment, but if you mean *all* as opposed to *some* students, I think they can all learn" (CFE1). Paul said:

I doubt very much learning takes place in the classroom. But it isn't anything about the environment itself. Lectures just don't help that much in statistics. (PFE1)

David's response was similar to Paul's:

No. A lecture hall seating 470 isn't a great environment. I can cater to those who learn via listening or by watching video. The small recitations allow interaction and serve a majority better. I try to help the TAs make this a good environment. (DFE1)

The participants' feelings about their classrooms being environments in which all students can learn statistics are split by size of the classroom. Both Beth and Gudmund, who teach small classes, feel that students can learn in their classrooms. David does not believe learning happens in his large lecture, but he does think that the small recitations can provide an environment in which more students can learn. Like David, Paul does not believe learning occurs in lecture; to Paul learning takes place as students experience the material through work outside of class with *ActivStats*.

Since the opinions about whether learning goes in classrooms of the participants are split by size of the classroom, the opinions may be a function of the size of the classes

that the participants teach. Perhaps the instructional strategies used by Paul and David in their large lectures are vastly different than the instructional strategies used by these two men in smaller classes. For example, the instructional strategies that David uses with his smaller class of education graduates students differ greatly from the instructional strategies he employs in Statistics 113²⁶. Still, a question arises from this discussion: To what extent does class size impact instruction?

Despite their differing opinions on whether or not all students can learn statistics in their classrooms, all four participants want their students to be informed consumers of statistics. Paul and Beth mentioned that their students might need to interpret statistical results in their future careers. Only Gudmund mentioned his students going on to other courses that need statistics. The following are the participants' descriptions of what they want their students to be able to do with statistics upon completion of the course:

- (Paul) Read uses of statistics intelligently. Not be fooled by misuses. Talk competently with a statistician who might consult with them on their own work. Not be afraid to talk to a statistical consultant about their own work. (PFE1)
- (David) Assess the news critically (observation versus experiment, random sampling versus voluntary response, association versus causation, mean versus median, and so on). Have some sense of how to find trustworthy and relevant data on topics of interest to them. Be more comfortable with simple graphs and calculations (that is, build general quantitative skills without repeating high school). (DFE2)
- (Gudmund) Many of them will go on to graduate school to programs that need statistics, and they will be better prepared for those courses. Almost all of them see the usefulness of statistics and will use what they learned to be critical consumers of statistics. (CFE1)
- (Beth) To be able to understand and critique statistical arguments. To understand the reasoning and logic behind statistical procedures. To know

²⁶ In addition to class size being different, the intentions for and the expectations of the students differ greatly between these two groups of students (graduate students who will need to use statistics in their work versus undergraduate students who will primarily be consumers of statistics).

how and when to ask questions (e.g., they may not be producing their own statistical analysis later but they should know when they need to ask for help and be able to communicate successfully with a statistical consultant). (BFE2)

Recall that the maturity level of the students came up in David's tale. However, the maturity level of the students was an issue that I heard my participants say indirectly, if not directly during my site visits. Because of this, I asked the participants about the maturity level of their students and how student maturity impacts their instruction. Again, Gudmund's situation was different than that of the other three participants. Because Swarthmore College is a highly selective, private, liberal arts college, Gudmund has found that students attending Swarthmore are prepared to work, and, "given their ages, they have a very high level of maturity. Most of them know where they are going with their lives, and they are all exceptionally smart" (CFE1). Because of the maturity level of his students, Gudmund reported that "I can challenge them more than I could with other students I have taught" (CFE1).

Paul's experience with his students at Cornell University has been quite different from Gudmund's experience at Swarthmore College. Paul has found some of the undergraduate students to be "sophomoric" (PFE1). The biggest impact of the immaturity of Paul's students has been on Paul's 'policing' of the students' work outside of class. For example, because Paul "relies on [the students] completing *ActivStats* lessons on their own" (PFE1), Paul has found that, to get his students to do work outside of class, he "sometimes must coerce them with quizzes" (PFE1).

Like Paul's students, David's students are immature. With his students David has found that "lecture attendance is weak, few [students] come to office hours, few come to

exam review sessions. Few are curious about anything, so it's hard to motivate learning" (DFE1). The impact of the students' immaturity on David's instruction is the enforcement of "lots of structure, all information constantly available on-line, weekly short quizzes to force attendance at recitation, emphasis in recitation on getting students to participate" (DFE1-2).

Lastly, Beth commented:

I don't think the students I have been seeing are all that mature. I try not to let it affect my instruction, though it can definitely impact my mood and patience. There are a few things I just have trouble finding funny. Unfortunately sometimes it probably does impact my instruction in that I do feel limited in what I can ask of the students. This includes both the mechanics (e.g., take-home quizzes) and the learning goals. I do feel next quarter here I will include a handout on "how to study" and/or "how to prepare for an exam." Often I feel I spend as much time helping them be better students (the whole high school to real world transition) than learning statistics, but that's part of the nature of a lower division general education course. (BFE1-2)

Another aspect of teaching that came up during my site visits was the notion of 'teacher as performer.' Gudmund happily accepts the role of teacher as performer, while Paul and Beth deal with the role, and David decries the role. In the following paragraphs I investigate the participants' view on the issue of teacher as performer.

When asked "How do you feel about the issue of teacher as performer," Gudmund said:

The instructor is obviously a performer, both in and out of class. Simple things like tone of voice and body language all matter, and an easy joke can improve the setting of the class. I think I have learned from late night talk show hosts [how] to deal with an audience. (CFE1)

Gudmund's light-hearted nature during class reflected his comfort with his role of performer. In fact, during our post-observation interview, Gudmund and I had the following exchange:

- (Jackie) I thought it was very clear during the class, both classes, that you actually enjoy teaching them.
- (Gudmund, chuckling) Yeah, um hmm.
- (Jackie) Do you feel that when you teach?
- (Gudmund) Oh sure. It's probably the secret actor that's hidden in all of us. I think it's great fun. You know, I never tried any acting, I don't think of myself as an actor, but sometimes you feel that you're putting on a show. It's nice to be in charge of that, to have everything under control. So I can see why people get highs on that, like comics just standing up and telling jokes, knowing the audiences are eating out of their hands. (CFI3-4)

Paul's acceptance of the role of teacher as performer was more matter-of-fact than Gudmund's acceptance of this same role. When asked "How do you feel about the issue of teacher as performer," Paul said, "Do I have a choice? I am a performer. That's my job. I'm also a salesman, but I don't see much difference in those roles" (PFE2). During our post-observation interview, I asked Paul to describe his teaching in words. Here is his response:

I try very hard to be dynamic. I'm aware of the fact that it's a performance. That, for a group of that size, all of whom are there because it's a required course, I have some obligation to grab their attention.

I don't think I'd ever go so far as to think I was just an entertainer. I know that there are faculty members who are paying gag writers—this is true—'cause it improves their teaching scores. I don't think I would do that. Nor do I walk in with just *a* joke to tell to start off the hour. I know faculty who do that—there's some in this school who are famous for their jokes. I don't do that.

But I do try to convey the enthusiasm that I genuinely feel for the subject, and I know I succeed in that, because that comment shows up in the course evaluations quite frequently. People will say, "I appreciate the enthusiasm you have for statistics, even though I couldn't muster it." That kind of thing. But it does help, it helps them to stay awake, it helps them to keep interested, and I hope gives them a way of thinking of it as something...

I want them to think of what we're talking about informally as well as formally. I know that they need the structure, they need to know how to think in a structured way about these ideas, but if they think they are in a cubbyhole reserved for "when I am doing a hypothesis test" that's not what I want. I want to change the way they think in everyday life. I want them to understand that they can understand things differently because they understand variance. They can understand things differently when they hear somebody make a claim and they can be skeptical about what test might or might not have been performed. And I want that...I tell them that. So a lot of what I do is to make it colloquial, to try to bring it into everyday discourse.

So, while Paul accepts his role of performer in the class, he tries more so to convey his enthusiasm about statistics than to entertain.

On the issue of teacher as performer, Beth said, "I'm not sure I'm convinced that it's the teacher's job to be able to entertain the students" (BFE2). Even so, Beth recognizes that changing times in the world necessitate more 'performance' from the teacher than was needed for earlier generations of students. Continuing her comment above, Beth said:

However that appears to be becoming more and more of a necessity in the 15 minute time span MTV generation. :) I do think it's important to hold students' interest and motivation and often that takes many different forms. (BFE2)

While Gudmund, Paul, and Beth all accept their roles as performers in the classroom (albeit not happily in the cases of Paul and Beth), David is "not interested" (DFE2) in the role of performer in his classroom. David did add that there are some things he does in the classroom to make it a better learning environment for those students who want to learn, but that he does not 'perform.' David said:

I pay attention to movement, variety with a lecture, trying not to go monotone, and so on, but my business is not to entertain. Some students (not all) are helped to learn by class presentations, and they are my target audience. For others, I work to structure reading, homework, quizzes, and more interactive recitations. (DFE3)

According to David, "that's more helpful for more students (in this large class) than my class performance" (DFE2).

Similar to the issue of 'teacher as performer' is 'teacher as caretaker.' David's view of 'teacher as caretaker' addressed issues of dealing with student problems that arise during the term:

Students have problems and teachers should help and be flexible. I'm happy to give makeup quizzes and exams for any good reason (and usually for not-good reasons also if the student wants another chance). I'm happy to allow alternate exam times for students with work or childcare problems. And so on. This isn't caretaking, but rather response to the fact that students have lives that don't always smoothly fit our set schedules. On the other hand, a student who chooses to miss class regularly, not turn in homework, and so on, gets the consequences. Learning is a student responsibility -- I'll cooperate with wide variation among those who make some effort (even if late and little), but the effort is required. (DFE2-3)

Both Paul and Gudmund referred to the role of caretaker from a therapeutic angle.

Although Paul said, "I'm not a caretaker" (PFE2), he did add, "sometimes I'm a therapist, but that is outside of statistics class" (PFE2). And, even though Gudmund's students at Swarthmore are mature for their ages, Gudmund still reported:

Dealing with young people, there is always some need for a caretaker. Particularly with weaker students or students who have fallen behind in their studies for one reason or another, there is a need for an open ear. I try not to impose myself, but if they want to talk, I am there to listen. (GFE1-2)

Lastly, Beth addressed the issue of 'teacher as caretaker' from the perspective of being a role model:

I do think it's important for an instructor to serve as a role model. Especially as a woman, I feel very proud if I'm at all encouraging other women to think about mathematics or statistics, to not be afraid of being smart, to feel comfortable talking with someone. Often I wish students felt more comfortable approaching me but at the same time I believe it's important to maintain a certain level of

expectation. It's good to be everyone's best friend, but only if you are simultaneously upholding standards and pushing students to work harder. Is this making sense? I don't think a teacher should be a caretaker if that always been giving in to students and helping them use excuses as crutches for doing substandard work. (BFE2)

Summary

The tales of Paul Velleman, David Moore, Gudmund Iversen, and Beth Chance, along with the emergent questions (and their answers), contained in this chapter were my presentation of my data. Now that the tales and questions have been presented and read, I move on to an analysis of the data. Chapter 5 contains this data analysis.

CHAPTER 5

ANALYSIS OF THE DATA

In this chapter I present my data analysis. I answer the two research questions posed in Chapter 1 of this document. In addition to answers to the questions, I provide an analysis of how I see the instructional strategies used in my participants' classroom in relation to constructivism. I then return to the realist tales from Chapter 4 and further analyze the participants' own words for evidence of support of constructivism. After the analysis, I return to the five problems listed on pages 15-16 of this document from Hogg (1992), and address the (lack of) presence of these problems in the participants' classrooms. I then conclude this chapter with a section on the ideal introductory statistics classrooms of my participants and investigate these ideal classrooms with respect to constructivism.

Answering My Research Questions

In Chapter 1, I framed my research questions upon the following premise that, assuming students do indeed construct their own knowledge, teaching must be designed to support such knowledge construction. The global purpose underlying "The Quest for

the Constructivist Statistics Classroom" was: "How do accomplished statistics educators support knowledge construction in their introductory statistics courses?" The two more manageable questions I tackled in my research were:

- What instructional strategies are being used in and around the statistics classroom?
- What are the results of an analysis of these instructional strategies when the analysis is grounded in a constructivist perspective?

In this section I answer the two research questions upon which my study was based, beginning with the instructional strategies used in the participants' classrooms and then analyzing these instructional strategies through the lens of constructivism.

A question that was raised during my analysis was what possible impact my asking the participants about constructivism had on the results that I got. While all four participants knew the title of my dissertation before signing on to participate, no other mention of constructivism was made until the formal questions about constructivism in the post-observation interviews with the participants²⁷.

Instructional Strategies Used in the Participants' Classrooms

The categories of instructional strategies being used in the classrooms of Paul, David, Gudmund, and Beth included: instructional strategies that involved how students come to know statistics; instructional strategies that were technology based; and, instructional strategies used to assess student learning. Figure 5.1 simply lists the instructional strategies used by the participants and indicates which participant(s) used

²⁷ Paul Velleman did broach the subject of constructivism before our post-observation interview, but I told him that we had to wait to discuss constructivism until that time.

each strategy (use of a particular strategy is indicated by '✓'). In Figure 5.1 I have taken a strict view of my first research question and solely identify the instructional strategies that were used in and around the classrooms of the participants. All analysis of the degree to which each participant used each instructional strategy is reserved until later in this chapter.

	Instructional Strategy	Paul	David	Gudmund	Beth
How students come to know statistics	Lecture	✓	✓	✓	✓
	Story telling	✓	✓	✓	✓
	Textbook	✓	✓	✓	✓
	Activities (in and out of class)	✓			✓
	Discussion			✓	✓
Use of technology	For calculations to free more time for discussion of concepts	✓	✓	✓	✓
	For visualization and simulation:				
	Computer demonstrations or simulations	✓	✓		✓
	<i>ActivStats</i>	✓	✓		
	<i>Data Desk, Minitab</i>	✓	✓	✓	✓
	Links to other sites		✓		
	On-line applets		✓		✓
	Video		✓		
	For organization and communication:				
	Course website	✓	✓		
Assessing student learning	E-mail	✓			✓
	Homework	✓	✓	✓	✓
	Exams	✓	✓	✓	✓
	Quizzes		✓		✓
	Papers			✓	
	Projects				✓
	Labs				✓

Figure 5.1: Instructional Strategies Used by the Participants

Analyzing the Instructional Strategies Through the Lens of Constructivism

Because students construct their knowledge in ways that make sense to them and because there are multiple ways of learning, it is important for each instructor to provide multiple resources from which students come to know statistics. As Beth said in our post-observation interview, "I don't think you can come up with one method that'll work for all students. Because some students, in particular with constructivism, they just give up way too quickly" (BFE7). In order to provide an environment in which all students can learn, we need to include multiple instructional strategies in our teaching (Airasian and Walsh, 1997). In the case of the participants in this study, each instructor did indeed provide her/his students with multiple resources for learning statistics. In addition to the resources noted in Figure 5.1, the participants themselves were resources for their students both inside and outside of the classroom. And, Paul and David's students had graduate teaching assistants with whom the students worked in recitations.

My analysis of the instructional strategies used in the participants' classrooms begins with the instructional strategies that involve how students come to know statistics. The analysis continues with my examination of the use of technology in the participants' classrooms, followed by my examination of how the participants assess student learning in their courses.

Instructional Strategies Involving How Students Come to Know Statistics.

Lecture, in its purest form, can be seen as an attempt to directly transmit knowledge from teacher to student. But, transmission of knowledge is never pure,

because the receiver of the transmission interweaves the new knowledge with her/his existing knowledge. Originally, I would have argued that lecture in its purest form does not support the construction of knowledge. However, during discussions with many people over the 1.5 years spent immersed in my research, I now recognize that lecture can be used by the learner in order to construct her/his knowledge *if* the learner puts the information from the lecture together in a way that makes sense to him/her.

A more direct way that lecture can be used to support knowledge construction is when the instructor uses lecture to put pieces of the material together in different ways for the students. For example, Paul uses *ActivStats* as a tool for student discovery outside of class and reinforces this learning during lecture time.

Across all four participants, none of the 'lectures' that I observed were pure transmission of knowledge. Instead, 'lectures' were used as forums for multiple instructional strategies. David incorporated videos, demonstrations, and simulations into lecture time. Gudmund engaged his students in the lecture through questions and answers. Beth spent lecture time posing questions to her students, gathering data from her students, and allowing her students to work in groups while she walked from group to group posing questions to and answering questions from individual students.

Story telling was another instructional strategy that was employed by all four participants. Paul told his students the story of William Gosset, Guinness Brewery, and Student's t-distribution. David told his students stories about experiments and Fisher.

Gudmund also talked to his students about Sir Ronald Fisher, but from quite a different viewpoint than David's story of Fisher was told. Gudmund also told his story about the number 1.96 as the secret to finding a soul mate.

The stories that Beth told during class were not stories, per se, but rather jokes and witticisms about statistics (e.g., "statistics is never having to say you're certain"). David occasionally begins classes with a cartoon or comic. While I was at Swarthmore, Gudmund invited his students to examine the comics about statistics that were posted on his office door.

What do stories and jokes have to do with statistics? Entertainment value is not their sole benefit. Stories, jokes, witticisms, cartoons, and comic strips all serve to remove the static nature of the content of statistics. With statistics no longer a static content, students can *experience* statistics and the learning of statistics (Dewey, 1938). By providing a way for students to experience the development of statistics, stories and jokes (when used appropriately and in moderation) support student construction of knowledge by inviting students to be participants in their learning.

Another instructional strategy common to all four participants was the use of textbooks. No two participants make use of the same textbook, and each participant utilizes the textbook in her/his own way. The following paragraphs examine how each participant utilizes written textbooks in her/his classroom.

As a supplement to student learning with *ActivStats*, Paul Velleman has his students work with Moore's (1997a) *The Active Practice of Statistics: A Text for Multimedia Learning* (APS). I cannot categorize APS as either a concepts-based book or

a mathematical statistics book, because of its unique nature. *APS* contains exposition, examples, and exercises and is the perfect supplement for *ActivStats*. But, then again, the text was written to accompany *ActivStats*. Some advantages that *APS* adds to *ActivStats* include:

- Large blocks of text are much easier to read and work with in print than on the screen. *APS* complements *ActivStats* by offering detailed explanations, worked examples, and comments on statistical practice that are better presentable in a book.
- A book is more portable than a CD because you don't need a computer on hand. You can study *APS* anywhere.
- Because of its portability and because it is easy to find your way around in a book, a permanent record of what you must know is more convenient in book form. (Moore, 1997a, p. 3)

In tandem, *ActivStats* and *APS* promote student construction of knowledge through discovery and by giving students the opportunity to make such discoveries in their own time and place.

The book that David Moore uses in his class is Moore's (1997b) *Statistics: Concepts and Controversies* (*SCC*). As a "book on statistics as a liberal discipline" (p. x), *SCC* was written for liberal arts students taking (many of them reluctantly) statistics to satisfy a quantitative requirement at their university. Instead of being a book about statistical theory or statistical methods, *SCC* "is a book on statistical ideas and statistical reasoning, and on their relevance to public policy and to the human sciences from medicine to sociology" (p. xi). It was the intention of the author "to invite discussion and even argument rather than mere computation" (p. xi). *SCC* supports knowledge construction by promoting and inviting student questioning of statistical ideas and fits well with David's intentions for his students' learning.

Gudmund Iversen's students use two texts: *Statistics: The Conceptual Approach* (Iversen and Gergen, 1997) and *Statistics: A Guide to the Unknown* (Tanur, Mosteller, Kruskal, Lehmann, Link, Pieters, and Rising, 1989). *Statistics: The Conceptual Approach* "grew out" (GII4) of Gudmund's notes for Statistics 1 and is, therefore, geared specifically to this course and the students at Swarthmore College:

This book grew out of a course designed by Gudmund R. Iversen to meet the challenges created by [a] greater reliance on statistical information. It was one of a series of courses designed at Swarthmore College to fulfill the mission of a liberal arts college to educate its students for the challenges of the twenty-first century. The idea was that students should not become so involved with the intricacies of a single discipline that they lose sight of the big picture. These courses were intended to educate students to understand how the major ideas of a field relate to the world. In many respects statistics seemed an ideal subject for one such course. While statistics could be a mystifying, self-aggrandized, and esoteric discipline, it could also be a key to understanding many other disciplines. The course, Stat 1: Statistical Thinking, was created to produce this understanding. The course proved to be very popular, and each year it grew in size. Over time the lecture notes for the course became more refined and extensive, and eventually the course material served as the basis for this book. (Iversen and Gergen, 1997, p. vi)

By relating the major ideas of statistics to the world, this text supports constructivist theory by providing a link between the new knowledge (statistics) and old knowledge (knowledge of the world that students bring into the class with them).

The tone present throughout the text reflects Gudmund's zeal for teaching introductory statistics, inviting students to join him on a journey to discover statistics. Since the students are a part of this journey with Gudmund, they experience statistics. The joint navigation by Gudmund and his students through statistics does not allow the content to be static. As such, students experience statistics, thus again supporting constructivist theory.

Although *Statistics: The Conceptual Approach* grew out of Gudmund's own notes, the text is intended for a larger audience. The beginning paragraph of the Preface to *Statistics: The Conceptual Approach* clearly explains the intentions of the book:

This statistics textbook is unique in its design and execution. It was created to fill a growing but previously unmet need to provide today's students with a sophisticated grasp of the nature of statistical information. It is a response to teachers who want their students to become statistically literate citizens, not (often hopelessly) amateur statisticians. (p. v)

In addition to using *Statistics: The Conceptual Approach*, Gudmund's students also read *Statistics: A Guide to the Unknown* (Tanur et al., 1989). Gudmund told me how he discovered *Statistics: A Guide to the Unknown*: "I just ran across that and I read it and I thought it was great" (GII4). Gudmund added, "I just thought it was well written and had interesting examples, much better than anything I could come up with, so I just tell my students to read it" (GII4). Gudmund's experience with having his students read this book is that "they read it and they all tell me they love it" (GII4). Because of its connections to the 'real world,' it could be argued that Gudmund's use of *Statistics: A Guide to the Unknown* supports constructivist theory²⁸.

Beth Chance's students use *Workshop Statistics: Discovery with Data and Minitab* (Rossman and Chance, 1998). The opening of the Preface for *Workshop Statistics* clearly explains the intentions of the book:

This book contains activities that guide students to discover statistical concepts, explore statistical principles, and apply statistical techniques. Students work toward these goals through the analysis of genuine data and through interaction with one another, with their instructor, and with technology. Providing a one-semester introduction of fundamental ideas of statistics for college and advanced

²⁸ Please refer to page 92 in Chapter 3 of this document for a short discussion about how almost all instructional strategies can be used to foster constructivist learning.

high school students, *Workshop Statistics* is designed for courses that employ an interactive learning environment by replacing lectures with hands-on activities. The text contains enough expository material to stand alone, but it can also be used to supplement a more traditional textbook.

Some distinguishing features of *Workshop Statistics* are its emphases on active learning, conceptual understanding, genuine data, and the use of technology. (Rossman and Chance, 1998).

Beth utilizes *Workshop Statistics* as a stand-alone text in Statistics 217. Students in Statistics 217 do activities from *Workshop Statistics* both in and out of class. Beth collects data from the students for some of the work that the students do with *Workshop Statistics*. One advantage of the workshop approach for Beth is that she "can do a lot more walking around and looking over shoulders and monitoring [the students] that way" (BII6). The emphasis of *Workshop Statistics* on active learning together with Beth's encouragement does indeed support constructivist theory.

The effect of student access to resources when the instructor is the author of the materials used in class can be looked at from two different angles. First, materials used in class can be accessed at any time a student needs them. If the student's instructor is the author of the course materials, the student has access to her/his instructor whenever s/he needs it. This is a benefit. However, if the student does not understand the information provided by the instructor, having materials written by the same instructor may not provide an alternate explanation for the confusing material²⁹.

²⁹ During my research I saw only the benefits of instructor as author of class materials. In addition, I did not hear any concerns from the instructor/authors about students not feeling comfortable enough to approach them with questions. This is not to say that drawbacks did not exist. However, because of the natures, personalities, and genuine interests in teaching of the instructor/authors I encountered in this research, I do not believe that drawbacks of the instructor/author arrangement were wide spread in the classrooms of these participants.

Take, for example, Paul Velleman and *ActivStats*. As its creator, Paul designed *ActivStats* to provide a form of interaction with his students, albeit between computer and student, that just could not happen in a classroom of 300 students³⁰. Paul's students are, in essence, able to access their instructor at any time of the day or night and from anywhere they can use the *ActivStats* CD. Paul's intention for *ActivStats* was to give a student the impression that he (Paul) is standing over her/his shoulder: taking the material at any pace the student needs/wants; discussing a statistical concept in as much depth as the student desires; and patiently re-explaining anything the student needs to hear/see again. By not simply re-doing in class what the students have done on their own outside of class and instead referring to what the students have done as a reference, Paul uses *ActivStats* to enhance the instruction he provides in the classroom (or uses classroom instruction to enhance the student work with *ActivStats*).

Paul, David, and Beth employed activities³¹, during and/or outside of classroom time. Paul has his students work with the activities in *ActivStats* outside of class time so that the students learn by discovery and not by pure transmission. Both David and Beth have their students visit on-line applets because of the ability the on-line applets give students to interact with statistical concepts. In addition to working with on-line applets, Beth's students are constantly involved with activities (both in and out of the classroom) in *Workshop Statistics*. By providing students opportunities to interact

³⁰ In fact, when I asked Paul if this was the reason he decided to use his own voice in *Data Desk*, his response was "absolutely" (PIIS).

³¹ For the purpose of this analysis and discussion, I did not include homework as an activity, since homework will be addressed in the section on assessment.

with and discover statistical concepts, the ways that Paul, David, and Beth have their students use activities support constructivist theory.

The final instructional strategy used by the participants to help students come to know statistics was discussion. Only Gudmund and Beth were able to successfully employ discussion themselves in their classrooms. Although Beth mentioned that the set-up of her classroom made discussion difficult, she was still able to use discussion as an instructional strategy in Statistics 217. Both Paul and David told me that the enormity of their classes, both in the number of students and in the size of the room, prohibits discussion in their courses. However, Paul's students were able to participate in discussions during section meetings, and David's students were able to participate in discussions (outlined by David for the graduate teaching assistants) during recitations. As a shared, negotiated process that allows students to develop or question concepts over time, discussion supports student construction of knowledge.

An Analysis of the Use of Technology in the Participants' Classrooms.

All four participants use technology in their classrooms primarily as a learning tool. Both Paul and David did mention that it is nice for the students to use technology to do statistics because practicing statisticians use technology to do statistics, however, the two men use technology in the classroom for pedagogical reasons. Gudmund and Beth did not mention the use of technology by practicing statisticians as a reason that they have students use technology in the classroom.

The primary use for technology (including *ActivStats*, *Data Desk*, *Minitab*, and calculators) across participants was as a calculation tool to allow more time for the discussion of concepts. None of the four participants expect the students in the classes I observed to be direct users of statistics; all four participants expect these students to be consumers of statistics. As such, it was much more important to the participants to spend time discussing concepts with the students than to spend time doing calculations.

The participants' use of technology varied both during and outside of class time. Gudmund used technology least of all. Gudmund told me that he might bring the computer into the classroom three or four times over the semester to show the students how to do specific procedures with *Data Desk*. Outside of class time, Gudmund's students use *Data Desk* to do calculations. As mentioned in Chapter 4 of this document, Gudmund has his students use technology "to save [the students] the drudgery of having them do the numerical work" (GII5), thereby allowing the students more time to concentrate on understanding the concepts in statistics.

Paul, David, and Beth each used technology during class meetings and had their students use technology outside of class meetings. The following paragraphs discuss the use of technology by these three participants.

As a prelude to the discussion of Paul and David's use of *ActivStats* in the classroom, the following is a concise description of *ActivStats* and its capabilities³². Student work in *ActivStats* is built around the idea of a 'Lesson Book' that changes to

³² The quotations about *ActivStats* that follow come from the *ActivStats* website located at <http://www.activstats.com/ActivStats/>

reflect the work the student has done as s/he works through the semester. Each lesson "presents a single concept or method taking full advantage of the multimedia abilities of the computer." The 'multimedia abilities' include the integration of "video, simulation, animation, narration, text, interactive experiments, web access, and *ActivStats* into a rich learning environment." As mentioned in Chapter 2 of this document, the opportunity for students to interact with statistical concepts and to actively participate in their learning of statistics supports the construction of knowledge.

Paul used *ActivStats* during class time to do simulations and visualizations of statistical concepts, as well as to connect what his students had done outside of class time with what he was talking about during class time. Paul's students work with *ActivStats* on their own, outside of class time. As mentioned in Paul's tale in Chapter 4 of this document, the activities in *ActivStats* provide Paul's students the opportunity to 'discover' such concepts as the p-value in hypothesis testing. Something that Paul did not mention during our interviews is that *ActivStats* also gives students the opportunity to work through statistical concepts at their own pace and in a way that makes sense to them (travelling through the concepts in a linear or non-linear manner). For all of these attributes and more, *ActivStats* is a technology that supports the knowledge construction of individual students.

David also uses *ActivStats* during class time for simulations and visualizations³³. Although David's students do not use *ActivStats* on their own outside of class time, they do benefit from the simulations and visualizations that *ActivStats* provides. Simulations and visualizations do, I believe, support student construction of knowledge, particularly if they are used as links to existing knowledge that the student has or if they are used as springboards to new knowledge.

All homework assignments for David's course include on-line components. David has the students visit websites like the *New England Journal of Medicine* in order to see statistical results in actual medical studies. The use of links to other websites may be minimally supportive of constructivism by linking statistical knowledge to knowledge of the outside world. David also has students use on-line applets since he believes that the interactive nature of the on-line applets is effective for learning statistics. As mentioned in Chapter 4 of this document, David uses on-line applets as a substitution for not using software in the course. At the same time, David has found that the on-line applets are more interactive than typical statistical software. Because students can interact with statistical concepts through the use of on-line applets, I believe that the use of on-line applets supports student construction of knowledge. Unfortunately, David reported, the students are resentful of the time that it takes to work with the on-line

³³ David did not use *Data Desk* during the two class meetings I attended, but he talked to me about his use of *Data Desk*.

applets, since these on-line activities are not things that they can do right before they turn in their homework. As such, the students may not be taking advantage of the benefits of these interactive on-line applets.

The video that David showed during class was a clip from *Statistics: Decisions Through Data* (Moore, 1992) about experimental design. Material can be presented in a much more meaningful and powerful way through video than it can be conveyed through plain speech (Velleman and Moore, 1996). This attribute of video is the primary reason David uses video in the classroom. In addition, the video shown during class time provided a common foundation upon which knowledge could be built for all students in attendance. David helped his students' construction their understanding of experimental design by using the students' common foundation of experimental design (from the video) as the basis for his discussion of experimental design.

Both Paul and David have elaborate websites for their courses³⁴. Each website is primarily used as a source of information and organization for the students. The course syllabus, all course assignments, and announcements are among the information that students can access from the course website. David's students can access their grades from the course website. For now, neither of the websites directly supports student construction of knowledge, but they do serve as excellent organizational tools for the instructors and for the students (as reported to the instructors through course evaluation feedback).

³⁴ While Beth did not formally mention a website for the course, she did mention that "all course notes and handouts are available on the web" (BC12).

During my visit to Purdue University, David mentioned that it is important to spend a lot of time 'running the big machine' that is Statistics 113 and stressed that organization plays a large role in making sure the machine runs smoothly. While Paul did not refer to his course in the same terms, dealing with his 300-student class must also be like running a big machine. The course websites for these two classes help with the organization of handling such a large group of students all taking the same course.

Rounding out the technology section of this analysis is e-mail. Paul was the only participant who mentioned e-mail as an important part of communication with his students, although Beth briefly mentioned e-mail as a medium through which her students can contact her. E-mail, while it enables students to ask and get answers to questions, does not directly support student construction of knowledge. Rather, it serves primarily as a tool for communication. However, e-mail does have the potential to support knowledge construction if either Paul or Beth (or any instructor) responds to student questions in such a way to stimulate such construction.

An Analysis of the Participants' Assessment of Student Learning.

Among them, the four participants use homework, exams, quizzes, papers, projects, and labs as formal tools for the assessment of student learning. In addition to these formal methods of assessment, all four participants informally assess their students' understanding during class time. The following paragraphs address assessment of student learning in the classrooms of Paul, David, Gudmund, and Beth.

Students of all four participants do weekly homework assignments. The homework assignments that Paul's students do are all units and activities in *ActivStats*. As mentioned on pages 230-232 of this chapter, student work with *ActivStats* supports student construction of knowledge. The homework assigned by David consists of exercises from SCC, visits to websites, and interactions with on-line applets. As mentioned in Chapter 4, David's intention for the homework he assigns to his students is to support student learning through their own activities. Gudmund's homework assignments are made up of problems from the textbook and are more traditional in nature. However, Gudmund believes that, by working through the assigned problems, students do have the opportunity to practice using statistical concepts. Finally, Beth's homework assignments are activities from *Workshop Statistics*. Like Paul's students' experiences with *ActivStats*, Beth's students' experiences with activities in *Workshop Statistics* help students to construct their knowledge of statistics through interaction with the course material.

Another assessment tool common to all four participants is the use of exams. In addition to exams, David writes weekly quizzes for his students (intended as learning tools), and Beth writes periodic quizzes for her students. As mentioned in Chapter 4, on an exam Paul might analyze a set of real data and ask the students to tell him what the analysis means. David's exams are primarily multiple-choice, however, the quizzes include open-ended questions. Gudmund and Beth also write open-ended questions for their students to work through on their exams.

Again, the issue of class size becomes noticeable when you examine the types of exams given by the participants. For example, Paul would like the students to use technology during exams, but managing the technology use is difficult in a class of 300 students (see page 121 in Chapter 4 for related discussion). And David abandoned the use of open-ended and essay questions once the size of Statistics 113 exceeded 250 students (see page 147). Beth mentioned that with a large class it would be hard to constantly be aware of how students are doing on homeworks, projects, and exams (BII2).

Gudmund's students write two papers over the course of the semester. One intention of these papers is to support a desire of Swarthmore College for writing across the curriculum. Gudmund's own intention for the papers he assigns is to assess how his students are able to "manipulate some of the concepts" (GII6) and to "explain these things in their own words" (GII6).

Beth's students do labs and projects over the course of the semester in Statistics 217. The labs serve as preparation for doing and writing up the term project, allowing students to work on individual parts of the process of statistical analysis. With the project, it is Beth's intention for the students to experience "the whole [data analysis] process from beginning to end" (BII5) and to use and apply statistical concepts to something in which the students have ownership. By actively working together on the data analysis process with data that they have a vested interest in, Beth's students have the opportunity to construct their knowledge of statistics.

Above all, assessment has both formative and summative purposes. Through the assessments discussed above, Paul, David, Gudmund, and Beth are indeed able to evaluate student understanding of statistics. The homework assignments, papers, labs, and projects all serve as formative tools for learning and understanding statistics, as occasions for students to interact with the statistical concepts they are studying, and as opportunities for student construction of knowledge. And, in their own way, the exams and quizzes are also meant to be learning tools for the students as well.

Analyzing the Participants' Words Through the Constructivist Lens

The presence of the participants' support of student construction of knowledge went beyond the two research questions posed in this document. In this section I return to the participants' words within the realist tales and pull out examples of the participants supporting students' knowledge construction.

Paul's Constructivist Allusions

The following quote from Paul (originally found on page 105 of this document) is a nice example of an allusion to student construction of knowledge:

I do tell all of my students that I don't stop being their teacher just because the term has ended and that they are invited to come back and talk to me about any projects that have a statistical component if they want, or about anything else. But, in particular they're invited to use me as a resource and as a consultant. (PII3)

In addition to highlighting the responsibility that Paul feels towards his students, Paul's comment brings attention to Paul's belief that learning about statistics continues

throughout students' lives as students encounter new situations in which they need to develop further understanding of statistics. Through his words it is clear that Paul recognizes that he can serve as a 'more knowledgeable other' for former students when they encounter new statistical concepts.

During our discussion of learning theories and constructivism (part of which can be found in Chapter 4 on page 111-112), Paul said:

Oh, I firmly believe that you don't learn anything until you have constructed the learning for yourself in some sense. You, at the very least, have to paraphrase it for yourself and rephrase it to fit it into your understanding of things, to fit it into your worldview. And if you can discover it for yourself even, then you're much more likely to fit it into your worldview. Just being told something is not a very good way to learn. (PFI5)

Even during our first interview Paul mentioned that "when the students can discover a concept for themselves, it's really lasting" (PII13). Paul's use of *ActivStats* to have students 'discover' what a p-value is in hypothesis testing is a very clear example that supports Paul's words above. In fact, Paul told me that "part of the design of *ActivStats* was to put students in that sort of situation where they were free to construct their own knowledge" (PFI5). The following comment, made by Paul to his students during class, supports these comments to me about the importance of knowledge construction and discovery learning:

Doing the experiments yourselves on the computer should give you far greater insight than anything I can do up in front of the room. So, I can't stress enough that you do those lessons and work through the simulations and get the understanding from that. There's nothing I can do up here that would have comparable impact and would let you learn the material as well. (PSCM1)

In Chapter 4 we learned that Paul tries to make statistics "colloquial, to try to bring it into everyday discourse" (PFI4). The examples that Paul provided for this were

about bringing current events into the classroom. I would argue that bringing current events into the classroom does not just make statistics colloquial, but also provides a link between issues with which the students are familiar and new statistical ideas and concepts, thus aiding students' construction of statistical knowledge and understanding.

David's Constructivist Allusions

When talking about effective teaching, David said, "any teacher who's honest will always recognize that the students do the learning" (DII5). David also commented that effective teaching is defined through helping students learn (see pages 129-131 for the section of David's tale that addresses effective teaching). Commenting that "students do the learning" implies David's belief that students are the ones who construct their own knowledge and that a teacher cannot just give her/his students knowledge.

The classroom setting created by a statistics educator is important to providing a forum for learning about statistics. During our first interview, David mentioned that "whether we can effectively help [students] learn varies with our setting" (DII4), adding that he's not "convinced, for example, that much of anything I do in our 400-student lecture is a great help" (DII4). However, when talking about his education graduate students (see page 130) who "didn't think they'd have a setting in which hard work would lead to learning" (DII5), David said, "I do know how to create such a setting" (DII5). The setting in which the education graduate students learn is more supportive of constructivism than the setting for Statistics 113. David's support of student construction of knowledge is shown through his preference for such a setting.

Although the setting in which Statistics 113 is not ideal, David believes that he is responsible for teaching students in Statistics how to be "intelligent consumers of information which has a statistical component" (DII9; see page 133). David tries to teach students in Statistics 113 how to question all of the information they are presented with and "find what's relevant in it" (DII12). I believe that encouraging students to question what they see supports constructivism through having them think critically about new information.

Also mentioned in David's tale is his desire to help his Statistics 113 students see how the pieces of statistics fit together (see page 134). By providing organization in the course, David supports students construct their emergent webs of statistical understanding. In addition to providing organization, David provides opportunities for students to learn by continued interaction with the material through homework and quizzes. This interaction with the material is part of what David's thinks about making learning operational (DFI7) and supports student construction of knowledge and understanding.

Gudmund's Constructivist Allusions

Recall the following statement from Gudmund's tale:

To know my way. You know I think I've worked enough with the material so I know it better than they do. So I just want them to learn it the way I think it should be learned. I guess I'm more authoritarian than perhaps others, but that may come because of my age. I don't know. (GFI3)

This statement implies more support for a transmission model of education than for a model of education that supports constructivism. However, Gudmund's own educational

background is based upon a "European model of education, just lectures and people being motivated and studying on their own" (GII7). Even so, there is a slight allusion to constructing knowledge about statistics in phrases like the following: "we are building a brick wall and are laying the bottom bricks now" (GFI2).

Gudmund also mentioned the importance of participation and questions and answers on student understanding (see page 166). And, with student questions and answers, Gudmund probes for a sense of student understanding rather than rote answers. To me, this extends beyond the transmission model of education and begins to enter a model of education that supports constructivism.

It was clear to me that Gudmund was the least constructivist in his teaching (among the four participants). But, as mentioned in Gudmund's tale, Gudmund is fine with his teaching methods and it is clear that his teaching is successful at Swarthmore. Perhaps there is something about the type of student who attends Swarthmore (Gudmund mentioned the brightness of Swarthmore students several times during our interviews) that does not necessitate more support of knowledge construction because the Swarthmore students find ways to construct their knowledge on their own.

Beth's Constructivist Allusions

Beth believes that "all learning takes place when [the students] debate with each other" (BFI4). Because of her belief, Beth provides opportunities for the students to work together in groups both in and out of class meetings. And, while students are working together during class time, Beth wanders around her classroom in order to pose

questions to the students and to monitor the discussions going on in the groups. It is important to Beth that her students have opportunities to struggle with the material and to work out their own understandings. (see pages 183-186). This internalization through struggle supports the accommodation aspect of Piaget's equilibration and also acknowledges student construction of knowledge as an individualized process.

Beth also provides opportunities for students to answer the questions of other students in her classroom. Although she misses having students present homework solutions like she did at UOP, Beth does encourage students to answer others' questions because "sometimes [students] have a different perspective than I do and that may help get through to another student" (BF14). Additionally, Beth attempts to have students "kind of help me build the lecture instead of me just telling them the same thing every time" (BF17). By encouraging students to act as 'more knowledgeable others' for each other, Beth supports Vygotsky's zone of proximal development and constructivism.

Like David, Beth wants students to understand how the pieces of statistics fit together. Beth helps the students put these pieces together in ways that are meaningful to them through the project she assigns in class. By doing the project, Beth's students experience "the whole process from beginning to end" (BI15). By emphasizing process, both through the project and through encouraging students in class and on exams, Beth supports student construction of knowledge about statistics.

The (Lack of) Presence of Hogg's (1992) Problems in Introductory Statistics Courses

Recall five issues in introductory statistics courses raised by statistics educators in Hogg (1992) as listed in Chapter 1 of this document:

- Statistics teaching is often stagnant; statistics teachers resist change. The most popular introductory texts have evolved slowly over the decades. There is a tendency to present the same subjects, the same way, from the same books year after year. Meanwhile statistical methods are progressing rapidly.
- Techniques are often taught in isolation, with inadequate motivation and with no connection to the philosophy that connects them to real events; students often fail to see the personal relevance of statistics because interesting and relevant applications are rare in many statistics courses. The applications, if any, are often contrived, even "phoney." ... The open-ended nature of statistical investigations and the sequential nature of statistical inquiry are not brought out. The students are not pushed to question their environment and seek answers through investigations.
- Teachers are often unimaginative in their methods of delivery, relying almost exclusively on traditional lecture/discussion. They fail to take into account the different ways in which students may learn, both individually and in groups, or the many possible modalities of teaching. They also fail to use the wide variety of simulations, experiments and individual or group projects which can make statistics come alive while simultaneously enhancing student understanding.
- Many teachers have inadequate backgrounds: in knowledge of the subject, in experience applying the techniques, and in the ability to communicate in English. The word "statistics" has itself acquired bad connotations.
- Statisticians may put their subject in a bad light for the students. They often fail to see any need to convey a sense of excitement. (p. 6)

Statistics teaching is often stagnant; statistics teachers resist change... It is my belief that none of the participants in "The Quest for the Constructivist Statistics Classroom" can be accused of this problem. Well, Gudmund did mention that he was pretty much set in his ways of doing things, but he did write the book he uses *for* his students and he does remain a participant in discussions about the teaching and learning of statistics. During our initial interview, Gudmund said "it may be too late" (GI15) for

him to make changes in his teaching. I countered by telling him that it is never too late, and he did agree.

Techniques are often taught in isolation, with inadequate motivation and with no connection to the philosophy that connects them to real events; students often fail to see the personal relevance of statistics because interesting and relevant applications are rare in many statistics courses. I've come back to this problem again and again and cannot make up my mind whether or not this problem was present with my participants. I observed the participants trying to connect statistical ideas and concepts to bits and pieces of the students' lives, and it is true that all four participants talked about real examples in their classes. For example, David talked about the Physicians' Health Study, and Gudmund used an example with real data collected about houses very near Swarthmore that were for sale. Assuming that the class meetings I observed were typical for the participants, I could conjecture that the participants used 'interesting and relevant examples' throughout the course. At the same time, I know that this problem is one that plagues many introductory statistics classrooms, so it very well might be a part of my participants' classrooms as well.

Teachers are often unimaginative in their methods of delivery, relying almost exclusively on traditional lecture/discussion. They fail to take into account the different ways in which students may learn, both individually and in groups, or the many possible modalities of teaching... All four participants recognize the different learning styles that their students have as well as the many instructional strategies that are available for teaching statistics. I think that both Paul and David would like to do more

with their students in terms of getting the students actively involved in the learning process, however Paul and David believe the enormity of the lecture portion of their classes prohibits such active involvement. As David said (from Chapter 4):

In principle you can try to get the students to form groups of 3 or 4. And pose problems for them and give them several minutes to work on them in their groups to try to come up with a reasonable resolution. Now what you do after that if you've got 400 students is not so clear, because again it's going to be hard for the groups... You can at least get them working with each other and try to concentrate their minds on the problem before you bring them back together and talk. And I have never done that in a very big class. I do that in the classes of 50 or 60 also. (DII8)

Again, Gudmund is the most traditional one in terms of his teaching style, basing class meetings mostly on lecture and discussion. However, for Gudmund and his students, this more traditional method seems to work. It may be something about the students at Swarthmore College, or it may be something about Gudmund, but Gudmund's methods seem to work fine for him.

Many teachers have inadequate backgrounds: in knowledge of the subject, in experience applying the techniques, and in the ability to communicate in English...

This problem as posed by Hogg (1992) appears to center around knowledge of content, rather than knowledge of teaching. As far as statistics content goes, each of the participants has a solid background. With respect to teaching, none of the participants has had any formal training in education, with the exception of Beth's courses in learning theories. In my opinion, all people who teach should learn how to teach—mastery in content does not imply an ability to teach. However, in the cases of Paul, David, Gudmund, and Beth, these four participants have taught themselves how to teach statistics by investing time and energy into the education process. Their passion for

teaching statistics, which has made them recognizable forces in statistics education, has helped them to become better teachers as well.

Statisticians may put their subject in a bad light for the students. They often fail to see any need to convey a sense of excitement. I don't think this was an issue at all. One striking thing I noticed with all the participants was their sense of excitement about statistics and about teaching statistics. I only hope that I was able to preserve that excitement in the tales of the participants in Chapter 4.

Investigating the Participants' Ideal Introductory Statistics Classrooms

One of the questions posed in the e-mail questionnaire (Appendix D) that was sent to the participants was: "What does your ideal undergraduate introductory statistics classroom look like (e.g., environment, size, pedagogy, knowledge acquisition, interaction, technology, and/or assessment)?" In addition to a description of an ideal introductory statistics classroom, I asked each participant to explain why s/he found this classroom ideal. Figure 5.2 contains the participants' descriptions of these ideal classrooms along with their support of the 'ideal-ness' of these classrooms:

Participant	Description of Ideal Classroom	Reason for 'Ideal-ness'
Paul Velleman	I'd want a small room (30 student limit), plenty of board space, computer projection that I can turn to briefly several times during the class. I'd rather talk to students than lecture at them, so I'd like a feeling of intimacy about the room. (PEQ2)	It works well with my style. Might not be ideal for others. (PEQ2)
David Moore	I like to teach from examples, and I like to involve students. So my favorite environment has a workstation for each student; examples are done collectively, with "what next?" always up for discussion. My machine is projected for those who get lost. Exams use the same environment so students can be asked realistic problems and automate details. Perhaps 20 to 40 students (often working in pairs). One can't imagine an environment farther from this than Statistics 113. For these liberal arts students, a group of about 15 meeting regularly in an ordinary room with most time devoted to discussion would be great. (DEQ2-3)	Continuous teacher-student and student-student interaction, in ways appropriate for the type of course. Small enough that I can discuss.... Small enough to change course in response to student interests and reaction (within the frame of what must be learned: I know this and the students don't). (DEQ3)
Gudmund Iversen	The ideal would be a small group of around 8 students with access to computers where they could analyze data sets with some help from me. Through group discussions and guidance from me they could invent most statistical data analyses on their own. (GEQ2)	Students learn best when they are motivated, and I think this setup would serve that purpose. (GEQ2)
Beth Chance	Thirty students, each student at a computer, which is loaded with several statistical packages and visualization tools, but also the ability to lecture (students facing a common board) and have classroom discussions. All students are there because they want to be. Students work through materials on their own (e.g. the Workshop Statistics approach) but ask a lot of questions of me and other students to clear up their understanding. Students do all of the homework assigned, come to office hours with questions, and have ridiculously easy access to the computer software outside of class as well. Students share results with each other and solve sample problems for each other (e.g. mini presentations). Lots of data collection and analysis of that data. Lots of "hands on" activities. A semester-long course or less material in a quarter course so students have time to practice and reflect and apply their knowledge. A final "projects day" where students from all sections present their term project report to the other students and faculty from other departments. Students are assessed through a combination of exams, activities, homeworks, presentations, and other feedback mechanisms. Oh, and I've have 5 graders and teaching assistants who would grade everything as anal as I with tons and tons of written comments for the students, returning the work the next day. I also feel there should be more coordination among instructors of different sections of the same course. This could include jointly written and graded exams. (BEQ3-4)	It's a positive learning environment that maximizes what students can learn from the course. I do believe in students constructing their own knowledge as I feel this increases motivation, retention, and understanding. Students should also learn from each other and feel pride in their work. The facilities I have now are almost perfect but I do feel they hamper group discussion too severely. The above dream also lets the material be the focus, not the computer. (BEQ4)

Figure 5.2: The Participants' Ideal Classrooms

The descriptions of the participants' ideal undergraduate introductory statistics classrooms vary in both size and detail, however, one noticeable similarity among the descriptions is that each participant's ideal classroom has a small number of students. Paul who taught a 300-student lecture would want a 30-student limit for his ideal class. Similarly, David would reduce his 480-student lecture to a class with "20 to 40 students (often working in pairs)" (DEQ2). Beth, who currently teaches in a room with a limit of 48 students, would want only 30 students in her ideal class. Finally, Gudmund, who teaches a section of only 25 students, would want a "small group of around 8 students" (GEQ2).

Computer access was another common thread among the descriptions of the participants' ideal classrooms. Paul's mention of computers was limited to "computer projection that I can turn to briefly several times during the class" (PEQ2), but I am sure that he would agree with his colleagues' proposed uses of computers. Both David and Beth would want each student to have a computer in the classroom. David's proposed use of computers included collective solution of examples "with 'What next?' always up for discussion" (DEQ2) and his screen projected for all of the students to view in case they got lost. David's proposed computer use is similar to what can be done in the studio classroom that Beth currently has. While Beth did not specify how the students would use the computers during class time, she did say that each computer would be "loaded with several statistical packages and visualization tools" (BEQ3). Finally, Gudmund

would want his students to have access to computers so that "through group discussions and guidance from me [the students] could invent most statistical data analyses on their own" (GEQ2).

In terms of working with the students David and Gudmund would work with the students during class time to do examples and statistical analyses, as mentioned above. Paul would "rather talk to students than lecture to them" (PEQ2) during class time. Both Paul and Beth would have their students work through materials on their own (Paul outside of class and Beth during class time), but, as Beth said, the students would be able to "ask a lot of questions of me and other students to clear up their understanding" (BEQ3).

Three of the four participants (David, Gudmund, and Beth) supported the 'ideal-ness' of their ideal classrooms through the issue of student learning. Paul, the exception, said that the reason his proposed classroom would be ideal was because "it works well for my style" (PEQ2). Both David and Beth mentioned "continuous teacher-student and student-student interaction" (DEQ3) when supporting their proposed classrooms. David added that his ideal classroom would be "small enough to change course in response to student interests and reaction" (DEQ3), while sticking to concepts that needed to be addressed in an introductory statistics course. To Beth, her ideal classroom is "a positive learning environment that maximizes what students can learn from the course" (BEQ4). By providing atmospheres in which their students are engaged in learning statistics, each participant provides an atmosphere for intrinsic motivation of her/his students. And, as Gudmund said, "students learn best when they are motivated" (GEQ2).

Do the ideal undergraduate introductory statistics classrooms of the participants support student construction of knowledge? I say yes. Combining the atmosphere of talking to his students in an intimate setting with the work Paul already has his students do with *ActivStats*, Paul's ideal classroom is an environment that supports student construction of knowledge. Through working examples with the students "with 'What next?' always up for discussion" (DEQ2), supporting teacher-student and student-student interaction, and allowing for changes in the schedule based on student needs and interests, David creates an environment for student construction of knowledge in his ideal classroom. Student construction of knowledge is clear in Gudmund's ideal classroom, since students would "invent most statistical analyses on their own" (GEQ2). Finally, Beth said the following about her ideal classroom:

It's a positive learning environment that maximizes what students can learn from the course. I do believe in students constructing their own knowledge as I feel this increases motivation, retention, and understanding. Students should also learn from each other and feel pride in their work.... The above dream also lets the material be the focus, not the computer. (BEQ4)

Summary

Paul, David, Gudmund, and Beth are all accomplished statistics educators, as established both in Chapter 3 and through their tales in Chapter 4. Each participant uses a blend of instructional strategies in her/his classroom that has been addressed in this chapter. While none of the participants is teaching in what s/he would describe as her/his ideal classroom, each still does something special in the classroom—I saw that 'magic' myself. Each participant agrees that students do construct knowledge for themselves and, to some degree, each does indeed foster such knowledge construction.

CHAPTER 6

CONCLUSIONS, DISCUSSION, IMPLICATIONS, AND DIRECTIONS FOR FUTURE STUDY

Introduction

In this chapter I address the conclusions of, discussion about, and implications of "The Quest for the Constructivist Statistics Classroom." In the 'Conclusions' section I present a brief summary of the answers to my research questions and transition into the 'Discussion' section where I address the thought process behind several questions that arose during my research. In the 'Implications' section of this chapter I attempt to realize the impact of "The Quest for the Constructivist Statistics Classroom" on the teaching and learning of introductory statistics. Following these three sections, I address 'Directions for Future Study,' centering on suggestions in the areas of theory, practice, and methodology.

Conclusions

This is the part of the document where the reader should be able to turn for some answers to the questions posed way back in Chapter 1 of this document. The simple answers are as follows:

- The categories of instructional strategies that were being used in the classrooms of my participants include: strategies for knowing statistics (lecture, story telling, textbooks, activities, and discussion); the use of technology (for calculations to free up time for discussion of concepts, for visualization and simulation, for organization and communication); and assessment of student learning (homework, exams, quizzes, papers, projects, and labs).
- An analysis through the lens of constructivism revealed that each participant support student construction of knowledge to varying degrees.

So, that's it—those are the simple answers. However, so much more is going on here.

Each of the participants was selected because s/he has been identified as accomplished statistics educators. Each participant has received praise at her/his institutions for teaching. I went into this research project wondering to what degree the participants support student construction of knowledge about statistics and have come out with more questions than answers. These questions are addressed in the following 'Discussion' section of this chapter.

Discussion

This section provides an opportunity to discuss some of the issues and questions that arose during research for "The Quest for the Constructivist Statistics Classroom." First, I discuss my perceived impact of class size on the teaching of my participants.

Following this discussion of class size, I address the "effect of the Ivy League" on my participants. I conclude this section with some of the questions that arose during this research.

The Issue of Class Size

The size of their classes certainly impacted the instructional strategies each participant employed in the classroom. Both Paul and David taught large classes and felt that the size of their classes prohibited them from interacting with their students as much as they would have liked. The size of Beth's class was bordering on too large to do some of the more involved projects that she would have liked to give the students. Even Gudmund, who had a class of 25 students, would opt for fewer students in his classroom in order to increase the interaction that he and the students could have.

The size of Paul's class limits his ability to provide opportunities for his students to construct knowledge and understanding about statistics. Paul mentioned that if he had a smaller class he could "get more interaction... assign projects and have students work on things more on their own" (PII4). Having interaction during class helps Paul determine how to adjust his teaching to meet the needs of the students (PII12).

David spoke similarly about the challenges of including the "interpersonal aspects of teaching" (DII4) in Statistics 113. For example, one interpersonal aspect of teaching that is difficult for David in his large class is achieving the interaction necessary to provide a rich learning environment for his students. In addition, David mentioned that

students are anonymous in large classes and thus are not as accountable for their engagement in the classroom as they are in smaller classes.

Recall from David's tale that he often made comparisons between Statistics 113 (his 480-student undergraduate introductory statistics class) and the statistics course he taught to graduate students in education (about 50 students in size). It was evident to me during my time with David that he was much happier with both his teaching and his students' learning in the course for education graduate students than he was with the teaching and learning in Statistics 113.

As mentioned earlier in this chapter, class size impacts the types of assessments that can be used in the introductory statistics classroom. In his tale, David talks about his shift from short-answer and essay questions on exams to multiple-choice questions on exams. With fewer students in their classes, Gudmund and Beth are able to include more open-ended assessments, although Beth mentioned that having even 48 students in Statistics 217 limits her ability to include as many individualized assessments as she would like.

The Effect of the Ivy League

What effect did Ivy League schools have on my participants? The impact of the Ivy League on my participants was something that I did not think about during the research process until a committee member mentioned that all four participants were schooled in the Ivy League. Paul did his undergraduate work at Dartmouth and his graduate work at Princeton. David did his undergraduate work at Princeton and his

graduate work at Cornell. Gudmund Iversen did his undergraduate work at the University of Oslo and graduate work at the University of Michigan and at Harvard. And, Beth Chance did her undergraduate work at Harvey Mudd College and her graduate work at Cornell.

There was a clear distinction between the participants who were more supportive of constructivism (Paul, David, and Beth) and the 'outlier' of the group who was not as supportive of constructivism (Gudmund). From Gudmund's tale we learn that, while Gudmund acknowledges the importance of discovery on student learning, he could not imagine using class time to have the students "sit down in groups and discover the stuff for themselves, when I'm in the room and I know it, I learned it, and so on" (GFI4) (see page 159). Gudmund would prefer that students 'know his way' (see page 162). Paul, David, and Beth, on the other hand, emphasized the importance of interaction in the classroom as well as the importance of discovery learning, active learning, and knowledge construction.

Despite this division in the support of constructivism, all four participants are accomplished statistics educators. What is the implication of their Ivy League schooling on their successes as statistics educators? Perhaps Ivy League schools recruit certain types of thinkers, students who will naturally excel in their fields. Or, perhaps Ivy League schools educate their students in such a way that graduates of Ivy League schools excel in their fields. Of course, I need to recognize the potential interaction of the recruitment of certain types of thinkers and then the education of these thinkers in such a way that these four Ivy League students are accomplished statistics educators.

In any case, what are the implications of any of these above lines of thought? What biases enter into this research by my working only with Ivy League graduates? Now, this discussion is based on the observation of the schooling of only the four participants in this research. Statisticians might argue that such discussion based on a sample size of 4 is meaningless. For example, there are certainly people who have not attended Ivy League schools but who are accomplished statistics educators. Even so, the effect of the Ivy League on the accomplishment of these statistics educators is an interesting issue to address through more extensive study in the future.

More Questions Than Answers

I finish this document with more questions than I have answers. In this section I share the thought process behind the questions that arose during my research. These questions are fairly general, but are all related in some way to "The Quest for the Constructivist Statistics Classroom."

At one point in time I had thought about researching what it means to be an effective teacher of introductory statistics. There is much research about 'good teaching' and 'effective teaching' in the literature, some of which I had read in preparation for the research I planned to do on what it means to be an effective introductory statistics teacher. Many times during my research for "The Quest for the Constructivist Statistics Classroom" I wondered whether what I was seeing in the teaching of Paul, David, Gudmund, and Beth was simply evidence of 'good teaching.' And, since the four

participants support student construction of knowledge to different degrees, is 'good teaching' something different than supporting student construction of knowledge and understanding?

I was certainly not surprised that Paul, David, Gudmund, and Beth are all good teachers, nor was I surprised that they were excited and enthusiastic about statistics and the teaching of introductory statistics. I was not even surprised that none of the four of them had any formal training in teaching, and that only Beth has some formal education in learning theories. A few questions grew out of an internal discussion about these issues: How does a statistics educator with no formal training in teaching learn to be a teacher? In what ways does how a teacher comes to learn and understand statistics impact her/his teaching of statistics? Is teaching something the teacher constructs in a way that makes sense to her/him? In light of the issue that many teachers of introductory statistics have not have formal training in teaching, how and where can we provide opportunities for these statistics teachers to learn about teaching and learning? What types of opportunities need to be provided?

Assume that we provide opportunities to statistics teachers to learn about teaching and learning and assume that student learning and understanding is enhanced by instructional strategies that support construction of knowledge. If an introductory statistics teacher is not teaching in such a way that is supportive of student construction of knowledge, can we still expect that the students are constructing their knowledge and

understanding about statistics? Do we care? Assuming that we do care, what can be done to support introductory statistics teachers' development in terms of constructivist teaching?

Assume that there is a 'continuum of constructivism' and that various instructional strategies support student construction of knowledge to varying degrees. Is teaching fluid on this continuum? Do teachers employ instructional strategies from *all* ranges of the constructivist continuum or do they tend to employ instructional strategies from only *certain* ranges of the constructivist continuum? Is there a 'concept dependence' that requires certain statistical ideas and concepts to be taught in particular ways? If so, which instructional strategies are best used for which ideas and concepts in statistics? And, if certain statistical ideas and concepts are better taught in certain ways, how are multiple ways of learning taken into account?

Does it really matter how constructivist a teacher is if her/his students truly understand the material? How do we measure that understanding? Despite the instructional strategies are being employed in the introductory statistics classroom, how do students in introductory statistics courses actually come to know and understanding the material?

All four of this study's participants view the students in their introductory statistics courses as consumers of statistics and not users of statistics. However, there are many statistics methods courses for practitioners (users of statistics) who need to know how to correctly use statistics in their own fields of study. How much conceptual understanding of statistics do these practitioners need to have in order to correctly use

statistical methods in their fields? On a related note, how much meaning do practitioners have to *construct* in order to correctly use statistical methods in their fields? And, if it is not necessary for practitioners to construct their understanding of statistics in order to correctly employ statistical methods, what is it about statistics that would allow them to just learn the methodology without constructing their own understanding?

As addressed in the paragraph above (as well as on page 10 of this document), many people use statistics as a methodology discipline, either by employing statistical methods themselves or using statistical results in their everyday lives. This issue raises a couple of questions in my mind: Are we teaching statistics just so people can use it? Is statistics solely a methodology discipline, a means to an end, to be used by other disciplines for grander things? Or, instead of being purely a means to an end, is there something about the process involved with learning and making sense of statistics that matters to those of us who teach statistics? Or, is there just some aesthetic pleasure to statistics that is part of learning statistics?

Many of the questions above came out of my research in "The Quest for the Constructivist Statistics Classroom" but relate to statistics as a discipline rather than to my interaction with my participants. While watching them teach, I felt like there was something magical going on in the classrooms of Paul, David, Gudmund, and Beth. This 'something' is a quality I have encountered before in the classrooms of good teachers. How can I define the 'magic' that goes on in the classroom of a good teacher?³⁵

³⁵ What is the implication of the 'magic' on distance learning and/or computer-based learning?

Implications

What impact will "The Quest for the Constructivist Statistics Classroom" have on the teaching and learning of introductory statistics? I wanted to see what was working in the classrooms of accomplished statistics educators. The instructional strategies employed by the four participants are all strategies that each of us could use in our own classrooms. What was most evident to me was that Paul, David, Gudmund, and Beth are four excellent teachers who are excited about and interested in their subject matter and teaching that subject matter to students. That excitement and interest was evident in both my discussions with these people and my observations of their classes. In their tales, I hope to have conveyed this excitement and interest. I hope that you have experienced what truly 'neat' individuals Paul, David, Gudmund, and Beth are.

My intention has always been that someone somewhere will pick up this dissertation, read it, and think critically about what s/he does in her/his introductory statistics classroom. Maybe someone will try new instructional strategies in her/his classroom as a result of reading this document.

However, I can be a realist here too. A colleague of mine recently asked me if I really thought anyone would read my dissertation. Instead of implying "Will anyone read *my* dissertation?", his comment was meant more as "Does anyone really read any dissertation?" Yes, I've heard the joke that only two people read your dissertation, your advisor and your mother—and your mother lied. All jokes aside, in order for me to make people aware of the implications of this work, the onus is on me. I need to get "The

Quest for the Constructivist Statistics Classroom" out to forums where more people can be challenged to think critically about their own teaching and to dare to try new things in the classroom.

Directions for Future Study

During data analysis it was difficult for me to make decisions about whether or not an instructional strategy used by a participant supported knowledge construction. Because the process of knowledge construction is such an individualized process that occurs internally, I could only make conjectures on whether or not an instructional strategy actually supported knowledge construction. These conjectures were based on my working definition of constructivism and on my own experience. There is much research about constructivism and the use of constructivist theory in the classroom, but I propose that the literature address how to identify instructional strategies as supporting (or not supporting) constructivist theory.

Also, Garfield (1995) mentioned that students sometimes leave the statistics classroom knowing how and when to do statistical procedures without really understanding what they are doing. This brings to light two issues for future study. First, what is it about statistics that would allow students to be able to use statistical procedures without actually understanding what is going on with those procedures?³⁶ And, if

³⁶ This question is related to a question about practitioners' use of statistics posed on pages 259-260 in the 'Discussion' section of this chapter.

students know how and when to use statistical procedures, how does their lack of understanding impact the application of and the results of these procedures?

Assuming again that construction of knowledge by a student enhances her/his learning and understanding of a concept, let us promote student construction of knowledge in our classrooms. But, activities that promote the construction of knowledge tend to take more time than instructional strategies that rely on transmission of knowledge. With this in mind, we need to determine which concepts in introductory statistics are better taught through constructivist methods, and which concepts in introductory statistics courses can be taught in more traditional ways. In order to move towards statistics classrooms that support student construction of knowledge, I suggest that readers of this document try to incorporate new instructional strategies into their teaching of introductory statistics. I am suggesting a period of evolution and not revolution in the introductory statistics classroom, that we gradually change over time, introducing different instructional strategies one at a time and deciding their worth (Garfield, in Moore et al., 1995).

Methodologically, I found my discussions with and observations of Paul, David, Gudmund, and Beth to fit my needs for this study. However, I propose that future research be done in the classrooms of these (or other) statistics educators in the form of a case study, spending more time immersed in the field.

In addition to spending more time in the field, I propose that data be collected to determine how well introductory statistics students in the classroom understand statistics. The investigation of student understanding of statistics could be done on a longitudinal

basis, examining understanding at different points in time, including: prior to the introduction of the material; after the introduction of the material; at the end of the term; and, at some designated time following completion of the course. As the participants mentioned, introductory statistics students tend to need statistics at some point later in their lives, and it would be instructive to learn about their understanding of statistics at these various points in time. This research could also address how students come to learn statistics, by talking to students about how they construct their knowledge and understanding of statistics.

Summary

Here we are at the last few paragraphs of six years of study and one and a half years of research in "The Quest for the Constructivist Statistics Classroom." It is my belief/hope that all teachers of introductory statistics want their students to understand statistics as well as to enjoy statistics as much as they do. What we need to keep in mind is that students learn in many different ways and that we need to reach *all* students with our teaching.

By getting students involved in their learning of statistics, we promote student ownership of their learning. For some teachers this may be a daunting task, because promoting student ownership of learning implies giving up some degree of control over the students' learning. But, in reality, we do not control *how* our students learn, so the control teachers try to assert over student learning is false anyway. With this in mind, we might as well promote student ownership of learning.

Instructional strategies that support student construction of knowledge promote student ownership of learning by getting the students involved in the learning process. Each of the participants in "The Quest for the Constructivist Statistics Classroom" employed multiple instructional strategies to involve the students in the learning process. As accomplished statistics educators, Paul, David, Gudmund, and Beth serve as exemplars from which other teachers of introductory statistics may glean ideas for their own teaching.

"The Quest for the Constructivist Statistics Classroom" is not over. It began for me when I first encountered constructivist theory and will continue throughout my career. In my own classroom, I consistently try to incorporate ways to involve the students in their learning of statistics. I think that the next step in "The Quest" needs to investigate how students come to learn and understand statistics. From there the quest will continue. Stay tuned for future chapters in "The Quest for the Constructivist Statistics Classroom: Viewing Practice Through Constructivist Theory."

EPILOGUE

THE PARTICIPANTS' PLANS FOR THE FUTURE

The Participants' Plans for the Future

Since each of the participants has contributed to the field of statistics education thus far in their careers and each continues to be interested in the teaching and learning of statistics, I wondered how each participant imagined her/his future as a statistics educator. For Gudmund and David, retirement is approaching in the not-so-distant future. Paul has a good many years left as a statistics educator, and Beth is, in some ways, just beginning her career as a statistics educator. The following paragraph contains each of the participants' visions for their futures.

Gudmund is the participant who is closest to retiring, and he said of his future as a statistics educator:

The future is getting shorter! I expect to quit after another couple of years, and I have no radical plans for the remaining time. I think the best thing for the students is that I continue to do what I do best, explaining statistical concepts and the role of statistics in the world outside the classroom. (GFE2)

David, who is about 5 years from retirement, imagined the following in his future:

I'd like to find a way to use technology to (a) replace me lecturing to 400 students, and (b) update our mastery-learning, self-directed version of the core methods course. The latter works for responsible students—I like the mastery learning principle—but is out of date because there is no software use. There are lots of logistical problems in both (a) and (b) that make promising ideas hard to implement. (DFE3)

Paul imagines teaching statistics "as long as I can. I also expect to be learning statistics throughout that time. Can't do one very well without the other" (PFE2). During this time, Paul hopes to "develop more materials" (PFE2) and "dreams of having the leisure to

write some books on the subject" (PFE2). Beth had the following to say about her remaining time as a statistics educator:

I'm still very excited about learning how students learn and trying to find ways of helping them learn, including on a large-scale level. I would like to have an impact. Part of me wants to retire and be an educational consultant (a large part). But I do feel that it's crucial for such a person to also have continuing experience "in the trenches" (i.e., I don't want to be in an ivory tower producing proof of concept, I want to see the student's eyes light up first hand). Still, sometimes I really want to take a weekend off! (BFE2-3)

APPENDIX A
PARTICIPANT SOLICITATION E-MAIL

Participant Solicitation E-Mail

Mime-Version: 1.0
X-Sender: jabmille@pop.service.ohio-state.edu
Date: [date]
To: [participant]
From: Jackie Miller <miller.203@osu.edu>
Subject: Participation in dissertation research?

Dr. [participant],

I am a doctoral candidate in Statistics Education at The Ohio State University. My advisors are Dr. William I. Notz and Dr. Emmalou Norland, with committee members Dr. Douglas A. Wolfe and Dr. Jeffrey P. Smith. I am in the process of developing my proposal for my dissertation research. My dissertation work involves "The Quest for the Constructivist Statistics Classroom." I am interested in looking at the role constructivism does (or does not) play in several undergraduate introductory statistics classrooms.

I am writing you for a few reasons. I have been familiar with your name through my work with Dr. Notz and Dr. Wolfe, as well as through your writing, including teaching from some of your texts. I am excited both about your work and your own excitement in your teaching. I am not sure how constructivism fits into your classroom, but I would certainly like the opportunity to visit your classroom and to interview you about teaching issues.

My data collection will most likely include an interview with you, observation of your class (on a topic of your choice), and perhaps some prompts by email throughout a term. Looking at [school name's] calendar, I believe that I would collect data either later this semester or during your fall semester of 1999.

I am not sure if you are teaching an undergraduate introductory statistics course during either semester, but I hope that you might be interested in participating in my study. My study is exploratory and descriptive in nature and follows my quest for the constructivist statistics classroom.

Thank you for your time and consideration in this matter.

Sincerely,

Jackie Miller
Doctoral Candidate
Statistics Education
The Ohio State University

APPENDIX B
CONSENT FORM - PARTICIPANTS

Consent Form - Participants

Date

Dr. Participant
Department of xxxxxx
College of University Address

Dear Dr. Participant,

I am interested in studying instructional strategies in the undergraduate introductory statistics classroom and analyzing these strategies through the lens of constructivism. My study will be exploratory and descriptive in nature as I look into several undergraduate introductory statistics classrooms. Primarily I am looking at my study from the teaching point of view and am interested in what you, as the teacher, do in the classroom. At this time, I request your participation in the data collection portion of my study entitled "The Quest for the Constructivist Statistics Classroom: Viewing Practice Through Constructivist Theory."

The data collection will be conducted as follows (expected timing in parentheses):

1. Your response to an e-mail addressing background information about you, your teaching, and the undergraduate introductory statistics classroom in general (response time depends on you).
2. A site visit including:
 - a. An initial audiotaped interview investigating issues of teaching and learning in the classroom (1-2 hours).
 - b. An audiotaped interview before observations about the observations (approximately 1/2 hour)
 - c. Observation of 2 class meetings
 - d. An audiotaped interview after observations, including questions about the observations (approximately 1 hour)
3. An e-mail follow-up to the interviews and observations after I have worked on analysis of the interviews (response time depends on you)
4. Document collection - syllabus, project assignments, quizzes/exams

Data collection will be conducted during the months of March through November, 1999.

All data collected will be kept, locked, in the researcher's files indefinitely. Pseudonyms will be used for all participants desiring anonymity in any writing to result from this study. Please understand that your participation in this study is strictly voluntary and that you may withdraw your consent at any time, without prejudice.

Dr. William I. Notz of The Ohio State University is the principal investigator of this study. Dr. Notz is a Professor in the Department of Statistics and may be reached at (614) 292-3154.

William I. Notz
Principal Investigator

Jacqueline B. Miller
Co-Principal Investigator

CONSENT FOR PARTICIPATION IN SOCIAL AND BEHAVIORAL RESEARCH

I consent to participating in research entitled "The Quest for the Constructivist Statistics Classroom: Viewing Practice Through Constructivist Theory."

Dr. William I. Notz or his authorized representative has explained the purpose of the study, the procedures to be followed, and the expected duration of my participation.

I acknowledge that I have had the opportunity to obtain additional information regarding the study and that any questions I have raised have been answered to my full satisfaction. Furthermore, I understand that I am free to withdraw consent at any time and to discontinue participation in the study without prejudice to me.

Finally, I acknowledge that I have read and fully understand the consent form. I sign it freely and voluntarily. A copy has been given to me.

Date: _____ Signed: _____

Signed: _____
(Principal Investigator or his
authorized representative)

Witness: _____

APPENDIX C

CONSENT FORM – TEACHING ASSISTANTS

Consent Form – Teaching Assistants

Date _____

Dear [TA name],

I am interested in studying instructional strategies in the undergraduate introductory statistics classroom and analyzing these strategies through the lens of constructivism. My study will be exploratory and descriptive in nature as I look into several undergraduate introductory statistics classrooms. As a teaching assistant for one of my participants, you are an important part of my data collection. In order to get a sense for the recitation portion of the course, I would like to sit in on your recitation this [day]. With this letter, I formally request your participation in the data collection portion of my study entitled "The Quest for the Constructivist Statistics Classroom: Viewing Practice Through Constructivist Theory."

The data collection from your recitation will include a visit to one recitation. As an observer in your classroom, I will attempt to be non-invasive, participating only to the degree you invite me to participate. I intend mainly to pay close attention to the activities in and environment of your classroom. If you would like, we can talk about your teaching before and/or after your actual class meeting. Data collection will be conducted on [date].

All data collected will be kept, locked, in the researcher's files indefinitely. Pseudonyms will be used for all participants desiring anonymity in any writing to result from this study. Please understand that your participation in this study is strictly voluntary and that you may withdraw your consent at any time, without prejudice.

Dr. William I. Notz of The Ohio State University is the principal investigator of this study. Dr. Notz is a Professor in the Department of Statistics and may be reached at (614) 292-3154.

William I. Notz
Principal Investigator

Jacqueline B. Miller
Co-Principal Investigator

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Dr. William I. Notz or his authorized representative has explained the purpose of the study, the procedures to be followed, and the expected duration of my participation.

I acknowledge that I have had the opportunity to obtain additional information regarding the study and that any questions I have raised have been answered to my full satisfaction. Furthermore, I understand that I am free to withdraw consent at any time and to discontinue participation in the study without prejudice to me.

Finally, I acknowledge that I have read and fully understand the consent form. I sign it freely and voluntarily. A copy has been given to me.

Date: _____ Signed: _____

Signed: _____
(Principal Investigator or his
authorized representative)

Witness: _____

APPENDIX D
E-MAIL QUESTIONNAIRE

E-mail Questionnaire

Mime-Version: 1.0
X-Sender: jabmille@pop.service.ohio-state.edu
Date: [date]
To: [participant]
From: Jackie Miller <miller.203@osu.edu>
Subject: E-mail questionnaire

General Information

- Who are you? Tell me about yourself (e.g., the person, the teacher, the family member, etc.).
- In what ways does who you are impact your classroom instruction?

Perception of Position

- How would you describe your current position at your university?
- How would you describe your current position in the statistics education community?

Teaching and Statistics Background

- What is your background in statistics?
- How did you get interested in statistics?
- What is your background in teaching?
- How did you get interested in teaching?

Personal Memories

- What is your most vivid memory about learning as a student in a statistics classroom?
- What is your most vivid memory as a teacher in a statistics classroom?

The Ideal Classroom

- What does your ideal undergraduate introductory statistics classroom look like (e.g., environment, size, pedagogy, knowledge acquisition, interaction, technology, and/or assessment)?
- Why is the picture you painted above the ideal undergraduate introductory statistics classroom?

Other

- With respect to my writing, what name (your own or otherwise) would you like me to use for both you and your institution?

APPENDIX E

E-MAIL REQUEST FOR COURSE INFORMATION

Email Information About Your Course

Mime-Version: 1.0
X-Sender: jabmille@pop.service.ohio-state.edu
Date: [date]
To: [participant]
From: Jackie Miller <miller.203@osu.edu>
Subject: Information about your course

- How would you (briefly) describe your university?
- How many students per term (and per year) take the course I will be observing?
- What is the structure of the course in terms of meeting times (days and amount of time, lecture, recitation, etc.)?
- How would you describe the "typical" student taking this course?
- What is the make-up of the students in terms of grad/undergrad %, men/women, freshmen/sophomores/juniors/seniors, average/median GPA?
- Approximately what % of students attend lectures/recitation?
- What types of assessments (what formats, what % of the final grade are these) make up the students' grades?
- What role does technology play in the course?
- Is the course coordinated in terms of multiple sections/teachers?

APPENDIX F
GENERAL INTERVIEW PROTOCOL

General Interview Protocol

Initial Interview

Teaching

- Talk to me about what it means to be an effective statistics teacher.
 - Are you an effective statistics teacher?
 - How do you know that you are effective?
 - What instruments do you employ to determine your effectiveness?
- In what ways do you continue your growth as a statistics teacher?
- How does the size of the class impact your instruction?
 - What would you do differently with a small (large) class?
- How important is interaction between instructor and students or students and students during class time?
 - How about interaction outside of class time?
 - In what ways do you think that interaction can be increased in large introductory statistics classes?
- How do you determine which concepts are important to address in this particular course?
- From your writings, I know that technology is important in your classroom.
 - What role does technology play in your statistics classroom?
 - Why do you think technology is so important in the statistics classroom?

Learning

- Talk to me about student learning.
 - How do define student learning?
 - With that in mind, how do you know learning is happening?
- How do you know students understand the concepts in your course?
- How do you assess the conceptual understanding of your students?
 - What form are your assessments?
 - How does the form of assessments help you to identify student understanding?
 - How do you assess understanding during class time?

Students

- Why do students take your course?
- How do you indicate to students what you want them to learn in this course (e.g., syllabus, comments in class)?
- How do your assessments match your intentions for student learning?

Pre-Observation Interview Protocol

About the Observation

- What concept(s) will be discussed during the class meetings I will be observing?
- Is there something particular to this (these) concept(s) in terms of your teaching techniques that I should be looking for?
- What do you expect the interaction between you and your students to be during the class meetings I will be observing?

Post-Observation Interview Protocol

About the Observation

- Talk to me about how you felt about the class meetings I observed.
- Would you consider the instructional strategies I saw in your class to be typical of the type of teaching you do each class period? Why or why not?
- Do you think your students understand the concept(s) discussed during these class meetings? How can you tell whether the students understand or not? Are you ever surprised with your perception of their understanding?

Constructivism

- Upon what learning theories do you base your teaching? Why?
- What does the word "constructivism" mean to you?
- Do you believe in constructivism as a learning theory?
 - How do your beliefs about constructivism impact your teaching? Can you think of any examples?
- In what ways do you allow/encourage students to construct their own knowledge in your classroom?
- Consider the following definitions of constructivism:
 - With that in mind, are there places you see any of this in your teaching?

APPENDIX G

ACTUAL INTERVIEW PROTOCOLS

Actual Interview Protocol – Paul Velleman

Initial and Pre-Observation Interview

- I have a few follow-up questions to the e-mail that you sent to me about yourself. The first thing is that you mentioned that you like to have a casual classroom presence and also that you attempt to convey accessibility to your students. Why are these two things, the casual presence and the accessibility, important to you?
- When the students do come in to your office hours instead of email, do they seem intimidated at that point?
- The other thing is how do these relate to you outside of classroom life? Are you casual outside of the classroom also and try to be accessible?
- Is that something that also carries [over] into your personal life?
- You mentioned that the Dean is opposed to what you do. In what ways do you think the Dean is opposed to what you do?
- One of the things you asked me to come back to in the email was what is your most vivid memory as a teacher in the statistics classroom? I just wanted to see if you remembered that now or if I should come back to that one.
- The first section I want to talk about is teaching issues. Can you talk to me about what it means to you to be an effective statistics teacher?
- When you talked about the citizenship components for, you say, your broad audience, would you look at that... One of the things that I like to tell my students is that it's kind of a "consumer statistics" course... Would you look at it that way as well?
- And do you try to work some of the conceptual understanding into that broader audience as well?
- How do you know that you're effective?
- You mentioned that you can tell in terms of the short term, over the course of a semester that students have gotten things based on their success on exams. Are there other instruments that you do employ or could employ to determine your effectiveness?
- Do you ever do anything with, say, open-ended questions in terms of evaluation?
- In what ways do you continue your growth as a statistics instructor?
- How does the size of the class impact your instruction?
- Even with a class of size 300, how important do you think interaction is between you and your students or among the students during class time?
- In what ways do you think that interaction could be increased in a large statistics classroom?
- Why do you think that the technology is so important for the statistics classroom?
- Do you think that since technology is permuting [sic] the lives of the typical students that it just blends naturally with their other experiences in their own lives?
- Do you think that you're fortunate because you're at this school, whereas at some other schools you might not have similar resources?
- Now I'd like to move over to the learning side of things. How do you define student learning?

- With all that in mind, in terms of wanting them to understand the concepts, how do you know that learning is happening in the classroom or outside of the classroom?
- What form are your assessments in terms of types of questions?
- How do you think that using one or two or three data sets across an exam helps you to identify the student understanding?
- Do you ever have the opportunity to assess their understanding during class time?
- Why do students actually take your course?
- How do you indicate to the students what you want them to learn in the course?
- I had one question that I skipped back in the teaching section. How do you determine which concepts are important to address in this particular course?
- What concept or concepts will be discussed during the two lectures I will be attending?
- Do you think that there's something particular to the concepts of confidence intervals or hypothesis testing in terms of the way that you're going to teach and your instructional strategies that I should be looking for?

Post-Observation Interview

- First of all, can I ask you a few questions about your instructional decision making?
- How did you make the decision to change your flow mid-Tuesday in terms of you going in there deciding to do one thing and then to change?
- What clues do you get from the students?
- What do you think that students get out of the actual lecture time that they couldn't get out, or that they don't get, through *ActivStats* or through the sections?
- One of the things you mentioned the other day was being able to take some of the things that they have heard and just put the pieces together in a different way.... Do you think that that's another advantage of the lecture?
- You told a story about Gosset and Guinness and you told another story the other day. Why do you like to include those stories in the classroom?
- What do you think the ability to quickly draw random samples like you could do the other day or to actually move the tool does in the classroom?
- Would you consider the types of instructional strategies that you used or the way that the class went during the two class periods I saw to be typical or not so?
- Do you think that the students are starting to understand that whole idea of confidence intervals?
- How can you tell whether or not they understand?
- Do you often then ask the TAs to give you feedback?
- Upon what learning theories do you base your teaching?
- Why do you teach the way that you do?
- How would you describe the way you teach? In a typical class. If you had to describe it in words.
- What does the word 'constructivism' mean to you?
- Did your instructors, in the past, just tell you or did they allow you to construct your own knowledge?

- In what ways do you allow or encourage the students of your class to construct their own knowledge?
- What do you think about the room you teach in and how does it affect your instruction?
- Can you think of anything else that I've left out in terms of questions that you think is important as to what I am writing about your teaching and the experience here?

Actual Interview Protocol – David Moore

Initial and Pre-Observation Interview

- The first part that I want to do is a follow up to the email answers you had sent...which has now been a while so I may have to refresh you unless you recall what you sent. One of the interesting things I thought when I asked you who you were... as a person and the other issues, you said well it's not really relevant and also then, and I definitely respected your privacy when you said and not important to people who don't know you. The one thing that you did point out that you thought did come into the picture was your [characteristic left out for anonymity], which is actually something that, in order not to identify you in the dissertation, is probably something I will leave out. Because I think that if I say a accomplished statistics educator then people would pick up on that. And some of the things that a couple of the other participants have shared is marital status, parental status, how many years they've been teaching... and so I was wondering if those were still things that you thought weren't relevant to you...
- So how did you start to learn how to teach then?
- Have you been here for your entire teaching career then?
- One of the other follow-ups I had was from your quote from Andre Soltner about the chef who can't necessarily be an artist... I was wondering what the difference is then between a chef, whom you might think of as the one who creates the recipes, and a cook, who can actually then carry it out... when compared then to teaching.
- Does he also have the ability to be creative, though... in some ways to be the artist?
- A couple of other follow-ups here... One of the things that you said when I asked the question how did you get interested in statistics... You said it was more with Kiefer than statistics, and you said, "I didn't think of statistics as separate until much later." So, my follow-up to that is how do you see statistics as separate from math now?
- One of the other things that you talked about when you were talking about both your parents being teachers is, you said that teaching is a natural companion to learning. I was wondering if you could explain why you personally would define teaching as a natural companion to learning, even though it may seem obvious to you.
- Part of my intention for today is to talk about some general teaching and then some learning issues and then generally about the students and then just do a little bit on what I'll be observing tomorrow. Talk to me about what it means to be an effective statistics teacher. Do you see yourself as effective? How would you define effective? How do you know that you would be effective?
- When you mentioned interpersonal aspects of teaching, you said that those would show more in a class of size 50 than it would in a class of 480. Do you think that in a large classroom like you have you can still show the good attitude and the enthusiasm? Or is it harder to do?
- Would you define yourself to be effective? Do you think that you are?
- How did your students indicate to you or how have they indicated to you your effectiveness?

- One of the things you said when I mentioned that we have classes of size 150 compared to 400 or so. You said there's even a difference between a class of size 150 and a class of 400. How do you see the difference between them?
- Would you also consider class size to be, in addition to the physical barriers and then also with your own [omitted word for anonymity], do you think there are also mental barriers that the students would have as well?
- What would be your ideal interaction between students and instructor or among students in the classroom?
- Do you ask any questions in the large lecture?
- Do you think that there are any ways to increase that interaction in the large classroom?
- What type of interaction do you have with the students outside of class time?
- When you go through which concepts you teach in this class, how do you determine which ones are important for the students and which ones are not?
- Would you say for these students in particular that this course then serves for them as a consumer statistics course?
- Do all teachers of this course believe that the students need to keep up their quantitative skills? Or is that more your personal opinion?
- Why do you think that technology is so important in the classroom?
- I think that's all I have in terms of the teaching. Just to move that into learning which we've been talking about a little bit anyway... How would you define student learning?
- Outside of the exams and the quizzes, when you're actually inside of the classroom, how can you assess whether or not students understand what's being discussed?
- Do you try to watch facial expressions and any other physical indicators?
- You said that pretty much the students all have to take it for a requirement. Do any of the students actually take the course by choice that you know of?
- With respect to the classes I'll be seeing this week, you said that it's going to be design of experiments and observations versus experiments. Will that be the focus of both classes that I see?
- Is there anything particular to these concepts in terms of your teaching that I should look out for? Or do you think that it will be representative of your teaching?

Post-Observation Interview

- I have one question that's not related to the observations but that I didn't ask you the other day. You had mentioned that you had originally thought about going to a small liberal arts college to teach, but then you're advisor said no you have to do a research university. So my question is how come you never made the switch to a small liberal arts college once you came here?
- I have a few questions just based on observations. And some of them may seem a little silly or straight forward, but I still want to ask them. Your greetings to the class at the beginning of class I think are very personal. Why do you greet your students in a personal manner?

- Today I noticed the placebo comic strip that you had put up there... the 12 step program for placebo addicts. And I noticed you didn't say anything about it, it was just up there. But I wondered why you brought that in.
- One thing that I noticed also was that you'll write the main points up for notes for the students, but then you'll also talk besides that... more, I don't know if embellish is the right word, but expand on what you're talking about. So, and I'm not sure if this is the right way to phrase the question... Why do you not write everything down when you talk? Why do you take the time to expand the way you do?
- One of the things I had noted the other day was I was wondering if the students really listened to those little stories and if they realize that what you're saying is actually relevant and important. Because me sitting there as somebody who knows this, I say, "oh that's a cute little story," or I understand why you're saying that.
- Have you ever asked any of the students what they think about the videos that you show and gotten any feedback from them?
- And I also noticed that today you were able to refer back to the video on Tuesday. So it makes it rich because it's not just good for the 10 minutes you show it, but also...
- One of the things from this morning, and I think we talked about this after the meeting with your TAs, but just to get on the tape... Could you explain again or expound on why you think it's important for you to write out the outlines that you do for your recitation instructors?
- Have the TAs gotten back to you on if they think that that works for them? Or that it helps them in terms of leading discussion?
- A couple of things particular to the observation that I did both days, but not coming out of those... First question is: how did you feel about how the classes went that I observed?
- When you said a couple times previously that your attendance usually does drop after your first exam, do you think that that's from the students making this rational choice of "I think I can do this on my own instead of going to class?"
- Would you say that for some of the students who find this beginning material very easy that then they get a false sense of security?
- We talked about this a little bit before in our first interview, but do you think, instructional strategy-wise, that these two days were pretty representative of what you do throughout the course? If so, why, and if not, why?
- This might be a hard question to answer, but do you think that your students understand the concepts that you discussed in the past two days?
- Are there any concepts where you're ever surprised about... where you might think that they understand something very well but yet they show, once recitation comes and the quiz, that they don't really understand it or where you think they don't have a really good understanding but then they seem to, post recitation, understand it real well?
- A little bit different question... Upon what learning theories do you base your teaching?
- If I say the word 'constructivism,' what does that word mean to you?

- In terms of looking at constructivism as a learning theory then, you would say that in a general sense that the learning that students experience...
- So you would buy constructivism as a general statement?
- How do you in your class, and this may come back to some of the stuff you've said earlier, how do you think that you set the students up to learn for themselves?
- Is there a way that you think that we could do that better?
- In a lot of ways you seem much more well read and well informed about the educational learning theories and about what's good teaching-wise, both through your discussions of some of the things that you believe in and also it sounds like your association with some of the educational psychologists... What have you done to learn about all of this? How did you learn all the educational theories that you know?

Actual Interview Protocol – Gudmund Iversen

Initial and Pre-Observation Interview

- First I have a few follow-up questions to the responses that you sent to me. And this starts with when you made a comment that you didn't think you would have received tenure at a large research university. I guess my first question is why do you think you would not have gotten tenure at a large research university?
- So how did you wind up making the change from The University of Michigan to Swarthmore?
- How did Swarthmore find out about you?
- What was it about Swarthmore that made you want to make the move?
- As a follow up to that and also because you mentioned that even when you were a graduate student that you enjoyed teaching...(Um hmm) What is it about teaching that appeals to you?
- Which was also something you mentioned—with having your own difficulties with statistics... (Right) So what was it about statistics that you had difficulty with?
- Did you go back and retake a similar course?
- If you had to define what it means to be an effective statistics teacher, how would you define that concept?
- Do you think by your definition that you would be able to call yourself an effective statistics teacher?
- Are there any formal instruments that you use to determine your effectiveness in terms of course reviews or evaluations?
- Just a lot of anecdotal evidence from your students and other teachers?
- In terms of your own growth as a statistics teacher, in what ways do you continue that growth?
- Since you have such a small class of 25 students, how do you think the size of that class impacts your instruction?
- What, if anything, did you do differently when you taught the group of 125?
- And when you say that if you worked with a small group like 5 or 6 or 7 and that you would all work together, how do you see that being realized?
- How important do you think it is to have interaction between you and your students or among your students during class time?
- And then what is your interaction with students outside of class time as well?
- Do you have a feeling as to why they go to the [undergraduate statistic tutor and grader for the course] more often than come to you in your office hours?
- Suppose that you were teaching a group of even the 125 that you had. How do you think that you could get increased interaction in a class that size?
- When determining the curriculum that you're going to use for your course, how do you determine which concepts are important to address?
- Would you consider the course, then, to be a "consumer statistics..."
- Why did you choose the course materials that you use?
- In what ways [is this book geared] for these types of students?

- You mentioned that the students use, in terms of technology, that they do use *Data Desk* and that it is available on the computers in the labs. How much do you use that in the classroom when you're teaching?
- Do they have a book that's a guide to *Data Desk*?
- Why do you have them work on the technology?
- Do they ever calculate, say the least squares line, by hand?
- How do you define student learning? Of how do you define learning, I guess, would be another way to ask that.
- How do you think that students come about their learning?
- Using your definition of student learning, then how do you know and how do you identify that learning is happening with your students?
- One of the things that I think is unique to your course is that you have them write two papers. Can you talk about the form of those papers and also why you decided to have them write?
- In terms of your midterm and your final exam, what forms are those?
- Just going back to you saying that... it's a natural science distribution requirement. So all of your students take the course because they have to?
- And why do you think the students choose to take statistics?
- In terms of what you're doing this week, what concepts are you going to be discussing that I'll be seeing?
- Probability is one of those things... It's interesting in the literature when people talk about whether or not it should be included (right) or not. Why do you include it?
- Is there anything particular to the concepts that you're teaching this week that I should look out for?
- What do you expect the interaction to be between you and the students?
- Do you find that all of your students actually do their work outside of class?
- Because this is a highly selective school do you think that the students are more interested in learning?

Post-Observation Interview

- The first question that I have is just one from today. Why do you take the time to learn the students' names?
- What is the math background that the students in the class have?
- I did notice, however, that they didn't question you on what you did. (Oh no.) And some of them seemed to know calculus. (Sure, right.) But it was definitely different to see them not question the simple math.
- Are all the classes an hour and fifteen minutes?
- Why did you choose that?
- A couple things just from class... On Tuesday, why did you choose to use the plus or minus 2 as a guide for almost all the data fall in between plus or minus 2 standard deviations instead of the plus or minus 3?
- Is it that same anticipation of things for which you brought up the idea of standard error of means last time?

- Why did you spend so much time today investing the time in how to actually read the tables?
- So to get the mechanics out of the way then it's easier for them to... (Right.) concentrate on the concepts?
- Also, from Tuesday. In the section where you had the students read and respond to the review questions, why do you make that an important part of the class meeting?
- Although I did notice that they seem rather willing to participate and also to ask questions. (Oh yeah.) Why do you think that that is?
- This is one I had a hard time wording here, but the question is how do you think you do with making things that could be hard seem very simple? For example, today you said "well z is just another variable, just like age or height or weight." So how do you think you do with making things that may be difficult seem simple?
- How did you actually feel about the two class meetings that I observed?
- Just typical for each of your classes then?
- You just touched on this, but do you think that the students understand the concepts talked about both Tuesday and today?
- Are you ever surprised with your perception of their understanding?
- Now we get to the theoretical part. Upon what learning theories do you base your own teaching?
- Can you describe what feels natural or comes naturally to you?
- Now somewhere in the dissertation title and certainly in my methodology chapter and in the theoretical part, I have this word 'constructivism' floating around. What does that word 'constructivism' mean to you?
- If I talk about constructivism as a theory where students bring in their own beliefs and understandings and experiences into the classroom... So that exists, you don't assume that they're blank slates. But then you also allow them to construct their own knowledge in their own way...
- Do you think that your background from your undergraduate experience...
- Is that true with the secondary schooling as well in Europe?
Now one of the things that I noticed in the classroom is I felt as if it were more of a lecture type (um hmm) of a class. However, the students weren't frantically writing notes. So it's not that you were bombarding them with information. How are you so successful in allowing them to actually listen to what's going on, to talk about concepts, as opposed to bombard them?
- Was it different when you were using a [different] book?
- I thought it was very clear during the class, both classes, that you actually enjoy teaching them. (chuckle - yeah, um hmm) Do you feel that when you teach?
- Can you think of anything that I haven't asked you that you would want to add with respect to your teaching?
- But are you totally okay with what you do?
- Do you feel like you can be included in discussions about new teaching techniques?
- Anything else that you can think of?

Actual Interview Protocol – Beth Chance

Initial and Pre-Observation Interview

- Talk to me about what it means to be an effective statistics teacher.
- Do you think that you're an effective statistics teacher?
- What do you mean by sometimes?
- Now one of the things that I noticed in the comments you wrote back to me is that in your ideal classroom you would have people who actually wanted to be there. So does that take care of your motivation... that since you say you're not a good motivator, would that then...
- And do you think it's important to be a good motivator for the students?
- How do you know that you're effective for those students who are already motivated?
- Do you employ any instruments to determine your effectiveness?
- In what ways do you continue your growth as a statistics teacher?
- In what ways do you find out about what other people are doing?
- How do you think the size of the class impacts your instruction?
- So what was the size of the class when you were at UOP (The University of the Pacific)?
- What other things do you think you'd do differently if you had a large class?
- How important do you think it is to have interaction between instructor and students or among the students during class time?
- And why do you think that that's the way that they learn the best?
- Would you put a word like 'discovery' with that? Or what type of word would you put with that?
- Do you think if a student does give up you have the ability to motivate them to try again?
- What about interaction outside of class time?
- And was that true at UOP too?
- And then how about here at CalPoly?
- Why do you think that they would be more likely to come up to you if you were a TA than if you were the full instructor?
- Now when the students interact between themselves during class and they have these debates, do you think that they're more likely to ask each other questions as well?
- Now suppose that you had a large introductory stat class. How do you think that interaction could be increased there?
- And what do you think about the model where there's an instructor who teaches the large lecture and then you have different people in the recitation? What do you think about that?
- And then when you were at Cornell did you do recitations?
- When you think about the concepts that are important for the class, how do you determine which concepts your introductory stat students need?
- And so does that have everything in it that you would like? Do you use all of that? Do you supplement it?

- You mentioned in the class that you'd want to construct if you could construct your own classroom that the computer would play a big role in it. And the computer does play a big role in your classroom now. Why do you think it's so important to have technology in the statistics classroom?
- Do you treat the computer then more as a tool to help the students visualize than as saying well this is really the way that statistics is done, with a computer?
- Switch over from teaching into learning. How do you define student learning? If you had to define learning in general, because someone said to me well what other kind of learning is there?
- Is there a particular psychological theory of learning that you believe in?
- Keeping your definition of learning in mind, how do you know that learning happens in your classroom for your students?
- So would that be the way that you ensure that the students are understanding the concepts as well?
- Can you talk to me about the term-long project that you use with them?
- And do you like the project then to cover or at least address all of the issues?
- Is it then that they work in groups?
- And so they turn in a group project?
- How do you determine grades for individuals?
- How do they choose their groups?
- During class time how do you assess student understanding of what's going on?
- Do you find that the students will stop you [if you are going too fast]?
- How do you think your assessments match what you have in mind for your students in terms of learning?
- A little bit about this week as to what I'll see. What concepts will you be discussing during the class meetings that I'll see?
- Do you do testing for means with the z at all or do you just use the t?
- Do you think there's anything particular to these concepts in terms of what you're doing that I should particularly key into?
- And then the second day will be more of a balance? Or it depends on how the first day goes?
- Is there anything else that you think I should be thinking of before I go into the class?

Post-Observation Interview

- Is there anything you'd like to add from the other day?
- A couple things that I have about the actual observation... Talk to me about how you felt about the class meetings that I actually observed.
- Now one of the things I noticed today was you had two t distributions in 7-6. (Um hmm.) I was assuming those were t distributions. (Um hmm.) Why did you choose to each of the groups and talk about that instead of maybe pulling them back together to talk about that?
- How do you think the students' understanding is of the concepts that you talked about?

- A couple things about the format of the class. What do you think about the teaching technology in that room?
- So if you could talk about how does it help or hinder the students? The technology.
- Which particular applets or technologies do you use for that?
- So are these applets from what's on the web then?
- What do you think about the format of two hours times two days?
- How do you think the students hold up over that two-hour period?
- And when you did that did you have them present on the board?
- Do you think that you could do that and use the technology of the projection system?
- What kind of access do the students have to the computers outside of the classroom or outside of class time?
- Switching a little bit over to your teaching... Why do you start class with a quote or a story or a joke?
- Why do you encourage the students to work in groups?
- One of the things you mentioned the other night was that with your teaching you're not an entertainer. (Um hmm...) In what ways do you or would you compare teaching to performing?
- How long does it take for you to get a sense of community in the classroom?
- How about setting up expectations for the students? One of the things you mentioned, not during the interview, is that it's hard to set those expectations.
- Just a little on the students. What's their math background?
- What are your expectations of the students outside of class? And I phrase that from... For example, with the spinning of the penny... That's something that you asked them to take a look at before today, I thought. (Um hmm.) But yet my assumption was that you felt you had to go through that more.
- One of the things that I noticed with some of the students is that there's space in the book to write these things, but yet they're taking all of the notes down on paper. Why do you think that is?
- That was all kind of based on my observations, and now we get to that constructivism word. So you already talked to me about what learning theories you base your teaching on. Do you have any more to add to that?
- And how do you know, how can you tell whether or not the students are ready?
- If I use the word 'constructivism' what does that word mean to you?
- Do you believe in constructivism as a learning theory?
- And how do you think any of your beliefs about constructivism impact your teaching?
- One of the things that I was reading today, in Andrew's dissertation actually, mentioned that constructivist theory is only one theory for learning and so what you're doing is you're doing a really good job for students who can construct their own knowledge or who will construct their own knowledge. And one of my beliefs has been that if you help students construct their own knowledge, you're actually helping all students. Construction of knowledge should be good for everybody is my thought. (Um hmm.) What are your feelings on that?

- Is there anything that I haven't brought up or that I haven't talked about that you'd like to discuss?
- So in terms of kind of always starting with doing things by hand and then moving into the technology...
- Anything else you can think of?
- Do you think that that's something you might bring in more next quarter?
- Anything else? ... Now if you happen to think of anything in the next couple of days you can always email, because that would work too...

APPENDIX H
FOLLOW-UP E-MAIL

Follow-Up E-mail

Mime-Version: 1.0
X-Sender: jabmille@pop.service.ohio-state.edu
Date: [date]
To: [participant]
From: Jackie Miller <miller.203@osu.edu>
Subject: Dissertation data collection: follow-up e-mail

- About how much time do you spend preparing for each class meeting?
What types of activities are included in your preparation for each class meeting?
- About how much time do you spend reflecting on each class meeting?
- Is the environment of your classroom one in which all students can learn?
- Describe for me the maturity level of your students. How does this impact your instruction?
- What do you want your students to be able to do with statistics after completion of your class?
- How do you feel about the issue of teacher as performer?
- How do you feel about the issue of teacher as caretaker?
- Tell me how you imagine your future as a statistics educator.
 - How many more years do you imagine teaching statistics?
 - With respect to the teaching and learning of statistics, what would you like to do in these remaining years?

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