The Dissertation Committee for Michael Jeffrey Elliott certifies that this is the approved version of the following dissertation:

On the Role of the Laboratory in Learning Chemistry

Committee:

J. J. Lagowski, Supervisor

Kent K. Stewart

Jennifer Brodbelt

Raymond E. Davis

Marilla Svinicki

On the Role of the Laboratory in Learning Chemistry

by

Michael Jeffrey Elliott, B.A.; M.A.T.

Dissertation

Presented to the Faculty of the Graduate School of

The University of Texas at Austin

in Partial Fulfillment

of the Requirements

for the Degree of

Doctor of Philosophy

The University of Texas at Austin

May 2006

Dedication

To P.A.K.

Acknowledgements

I would like to thank the entire faculty of the Department of Physical Sciences at Barry University in Miami Shores, Florida, for their encouragement and support in my returning to graduate school to work on my Ph.D. In particular, I want to recognize Dr. Mary Ann Jungbauer and Sister Marie Joannes O'Donnell, O.P., Ph.D., both retired from Barry University, for acting as my mentors as I began my teaching career.

To my fellow Chemical Educators in the Collaborative for Chemical Education at The University of Texas at Austin, I owe a debt of thanks for their many stimulating and insightful discussions of all things "Chem Ed." Special thanks go to Dr. J. J. Lagowski for his admonishments to "press on, regardless" and "keep the faith" and for his patience, suggestions, and guidance through my years here at The University. A note of gratitude is extended to Dr. Kent K. Stewart, my "partner in reform", for his insight and mentorship. Rita Wilkinson has been a great friend and supporter not only to me, but to all of the Collaborative for Chemical Education, as we sought to achieve our individual and collective goals.

Finally, I acknowledge Paul Kamarauskas for the sacrifices he made during my time in graduate school. Without his support, my lifelong dream of completing the Ph.D. may never have been realized.

On the Role of the Laboratory in Learning Chemistry

Publication No._____________

Michael Jeffrey Elliott, Ph.D.

The University of Texas at Austin, 2006

Supervisor: J. J. Lagowski

Chemistry is a laboratory science; hence, no instruction in chemistry would be complete without some laboratory component. But in a discipline as wide-reaching as chemistry is, the natural questions of *what* should be taught and *how* it should be taught are not trivial. Indeed, these questions have been on the minds of chemical educators for many years.

Current instructional models in chemistry laboratories can be grouped under several broad descriptions. *Expository laboratories* are intended to illustrate important chemical principles. While these laboratories offer the benefit of reinforcing lecture-based instruction, students often know the outcome of such experiments in advance, and this model of instruction does not accurately depict the process of accumulating scientific knowledge. To address this apparent shortcoming, inquiry models have been developed. *Discovery (or, Guided inquiry) laboratories* focus primarily on the scientific method, providing students with some instruction towards addressing the problem at hand, but also requiring students to develop some decision-making processes of their own. *Inquiry (or, Open inquiry) laboratories* provide less assistance to the students, effectively

obligating them to develop complete procedures for themselves. The difficulty with these models is that content almost becomes irrelevant; the focus is on the process of obtaining scientific information. Even then, these models still do not accurately reflect the nature of scientific work; scientific inquiry always begins from some knowledge base, which these models do not presuppose.

Feeling that none of these models adequately addresses the needs of chemistry students, at The University of Texas at Austin we have developed a new General Chemistry laboratory course based on the idea of introducing students to chemical research. As a model, we employed Cognitive Apprenticeship theory, which is based on traditional craft apprenticeships but is adapted to cognitive domains. It appears to be suitable as a model for laboratory instruction because it assumes that content matters, that the sequence for that content is important, and interaction between the instructor/ mentor and the student/ apprentice is essential. Both the immediate and longitudinal effects of the research-based course on introductory students are compared to those of a standard Expository laboratory course.

Table of Contents

List of Tables xii

List of Figures xxi

Chapter 1: Introduction 1

Overview 1

Literature Review 2

Expository Laboratories 9

Discovery Laboratories 9

Inquiry Laboratories 10

Problem-Based Laboratories 11

What We Know about Laboratory Instruction 11

Do Laboratory Courses Help Reinforce Concepts? 12

Do Laboratory Courses Improve Laboratory Skills? 13

Do Laboratory Courses Convey Scientific Processes? 13

Do Students Acquire Positive Attitudes towards Science as a Result of Laboratory Instruction? 14

Do Students Learn Facts about the Nature of Chemistry as a Result of Laboratory Instruction? 14

Summary of What We Know and its Implications 15

A Concurrent Thread 16

Cognitive Apprenticeship Theory 18

Chapter 2: Experimental 21

Steps Towards a New General Chemistry Laboratory Course 22

Applying Cognitive Apprenticeship Theory to the New Course 27

Structure of the New Course 31

Data Collection 38

Chapter 3: Data Analysis 40

Spring 1998 40

Survey Data 40

Student Persistence 43
Interviews 44
Overview of the Analysis From Fall 1998 Through Spring 2001 44
Survey Data 45
Drop and Withdraw Data 46
Longitudinal Studies 47
Enrollment in Research Courses 47
Retention in Science and Engineering Majors 48
Fall 1998 51
Survey Data 52
Drop and Withdraw Data 64
Longitudinal Studies 66
Enrollment in Research Courses 67
Retention in Science and Engineering Majors 71
Control Versus Experimental For Spring 1999, Fall 1999, Spring 2000, And Spring 2001 75
Survey Data 76
Drop and Withdraw Data 91
Longitudinal Studies 96
Enrollment in Research Courses 98
Retention in Science and Engineering Majors 106
Evaluation of The Effect of the Teaching Assistant 115
Survey Data 115
Drop and Withdraw Data 126
Longitudinal Studies 126
Enrollment in Research Courses 127
Retention in Science and Engineering Majors 131
Effect of a Different Instructor on the Experimental Course 135
Survey Data 135
Drop and Withdraw Data 148
Longitudinal Studies 150
Enrollment in Research Courses 151

Retention in Science and Engineering Majors 155
Effect of the Experimental Course on an At-Risk Student Group 158
Survey Data..159
Drop and Withdraw Data 170
Longitudinal Studies 172
Enrollment in Research Courses 174
Retention in Science and Engineering Majors 181
Summary of Findings..188
Survey Data..189
Drop-Withdraw Data 190
Enrollment in Subsequent Chemistry and Biology Research Courses 190
Enrollment in Subsequent Natural Sciences Upper Division Research Courses..191
Retention in Science and Engineering Majors 192
Chapter 4: Discussion 194
Group Comparisons 194
Fall 1998: Control versus Experimental when the Groupings are Truly Random 194
Spring 1999 Onward: Control versus Experimental...................................195
Does the Teaching Assistant Make the Difference? Control versus Experimental when the Same TA Teaches Both Courses 199
The Effect of the Instructor: Control versus Experimental when a Different Instructor Teaches the Experimental Course 200
The Effect of the Experimental Course on an At-Risk Student Group..........202
Overall Conclusions...205
Interest in Science 205
Confidence in Success 207
Enrollment in Research Courses 210
Persistence as Science Majors 210
Suggestions for Future Work 211
Summary 214

Appendix A: Spring 1998 and Fall 1998 Survey 218

Appendix B: Spring 1999 Survey 226

Appendix C: Fall 1999, Spring 2000, and Fall 2000 Survey 233

Appendix D: Spring 2001 Survey 238

Appendix E: Statements on the Survey 244

Appendix F: Survey Responses, Fall 1998 253

Appendix G: Survey Responses, Spring 1999 262

Appendix H: Survey Responses, Fall 1999 270

Appendix I: Survey Responses, Spring 2000 274

Appendix J: Survey Responses, Fall 2000 282

Appendix K: Survey Responses, Spring 2001 290

References 298

Vita 301

List of Tables

Table 1: Relative Importance of Laboratory Goals 8

Table 2: Common Chemistry Techniques Used in Life Science Laboratories.................24

Table 3: Enrollment History of CH 204 AV..26

Table 4: Comparison of the Structures of the Control and Experimental Courses...........37

Table 5: Survey Form Used, per Semester 38

Table 6: Student Self-Reported Confidence in Ability, Spring 1998 41

Table 7: Student Self-Reported Interest, Spring 1998 42

Table 8: Spring 1998 Grades 43

Table 9: Variations of the Experimental Course from Fall 1998 to Spring 2001.............50

Table 10: Common Questions from Survey for Control versus Experimental, Fall 1998..52

Table 11: Overall MANOVA on Survey Data, Fall 1998 56

Table 12: MANOVA Survey Results, Fall 1998 57

Table 13: Drops and Withdraws, Fall 1998 64

Table 14: Drop-Withdraw Cases, Fall 1998 65

Table 15: Drop – Withdraw Count, Fall 1998 65

Table 16: χ^2 analysis on Drop – Withdraw Data, Fall 1998 66

Table 17: Final Course Grades, Fall 1998 67

Table 18: Biology and Chemistry Research Enrollment, Fall 1998 67

Table 19: Biology and Chemistry Research Course Enrollment, Fall 1998.....................68

Table 20: χ^2 analysis on Biology and Chemistry Research Course Enrollment, Fall 1998..69

Table 21: Natural Sciences Research Enrollment, Fall 1998 69

Table 22: Upper Division Natural Sciences Research Course Enrollment, Fall 1998 70

Table 23: χ^2 analysis on Upper Division Natural Sciences Research Course Enrollment, Fall 1998 71
Table 24: Enrollment by College, Fall 1998....72
Table 25: Natural Sciences Retention, Fall 1998....73
Table 26: Engineering Retention, Fall 1998....73
Table 27: Total Natural Sciences and Engineering Retention, Fall 1998....73
Table 28: Summary of Retention Data, Fall 1998....74
Table 29: χ^2 analysis on Retention Data, Fall 1998....75
Table 30: Merger of Survey Responses for Control versus Experimental....76
Table 31: Box's Test on Survey Data, Control versus Experimental....79
Table 32: Levene's Test of Equality of Error Variances, Control versus Experimental...80
Table 33: Overall MANOVA on Survey Data for Control versus Experimental....82
Table 34: MANOVA Survey Results, Control versus Experimental....83
Table 35: Drops and Withdraws, Spring 1999....92
Table 36: Drops and Withdraws, Fall 1999....92
Table 37: Drops and Withdraws, Spring 2000....93
Table 38: Drops and Withdraws, Spring 2001....93
Table 39: Total Drops and Withdraws for Control versus Experimental Comparison.....94
Table 40: Drop-Withdraw Cases, Control versus Experimental....94
Table 41: Drop – Withdraw Count, Control versus Experimental....95
Table 42: χ^2 analysis on Drop – Withdraw Data, Control versus Experimental....95
Table 43: Final Course Grades, Spring 1999....96
Table 44: Final Course Grades, Fall 1999....96
Table 45: Final Course Grades for Sections without the Common TA, Spring 2000......97
Table 46: Final Course Grades, Spring 2001....97

Table 47: Final Course Grades, Control versus Experimental 98
Table 48: Biology and Chemistry Research Enrollment, Spring 1999............................98
Table 49: Biology and Chemistry Research Enrollment, Fall 1999 99
Table 50: Biology and Chemistry Research Enrollment for Sections without the Common TA, Spring 2000..99
Table 51: Biology and Chemistry Research Enrollment, Spring 2001..........................100
Table 52: Biology and Chemistry Research Enrollment for Control versus Experimental..100
Table 53: Biology and Chemistry Research Course Enrollment, Control versus Experimental..101
Table 54: χ^2 analysis on Biology and Chemistry Research Course Enrollment, Control versus Experimental...101
Table 55: Upper Division Research Enrollment for Control versus Experimental, Spring 1999...102
Table 56: Upper Division Research Enrollment for Control versus Experimental, Fall 1999...102
Table 57: Upper Division Research Enrollment for Control versus Experimental, Spring 2000...103
Table 58: Upper Division Research Enrollment for Control versus Experimental, Spring 2001...103
Table 59: Natural Sciences Research Enrollment for Control versus Experimental......104
Table 60: Upper Division Natural Sciences Research Course Enrollment for Control versus Experimental..105
Table 61: χ^2 analysis on Upper Division Natural Sciences Research Course Enrollment for Control versus Experimental..105

Table 62: Enrollment by College, Spring 1999 106

Table 63: Enrollment by College, Fall 1999....107

Table 64: Enrollment by College, Spring 2000 108

Table 65: Spring 2001 Enrollment by College 109

Table 66: Enrollment by College for Control versus Experimental 110

Table 67: Natural Sciences Retention in the Control Group 111

Table 68: Engineering Retention in the Control Group....111

Table 69: Total Natural Sciences and Engineering Retention for the Control Group....112

Table 70: Natural Sciences Retention in the Experimental Group....112

Table 71: Engineering Retention in the Experimental Group 113

Table 72: Total Natural Sciences and Engineering Retention for the Experimental Group 113

Table 73: Summary of Retention Data for Control versus Experimental....114

Table 74: χ^2 analysis on Retention Data for Control versus Experimental....114

Table 75: Survey Data for Control versus Experimental....115

Table 76: Overall MANOVA for Sections with the Common TA, Spring 2000 118

Table 77: MANOVA Survey Results for Sections with the Common TA, Spring 2000....119

Table 78: Final Course Grades for Sections with the Common TA, Spring 2000 127

Table 79: Biology and Chemistry Research Enrollment in Sections with the Common TA 127

Table 80: Biology and Chemistry Research Course Enrollment in Sections with the Common TA 128

Table 81: χ^2 analysis on Biology and Chemistry Research Course Enrollment in Sections with the Common TA, Spring 2000 129

Table 82: Natural Sciences Research Enrollment in Sections without the Common TA, Spring 2000 130
Table 83: Upper Division Natural Sciences Research Course Enrollment in Sections with the Common TA 130
Table 84: χ^2 analysis on Upper Division Natural Sciences Research Course Enrollment in Sections with the Common TA, Spring 2000 131
Table 85: Enrollment by College, Spring 2000 132
Table 86: Natural Sciences Retention in Sections with the Common TA 132
Table 87: Engineering Retention in Sections with the Common TA 133
Table 88: Total Natural Sciences and Engineering Retention in Sections with the Common TA, Spring 2000 133
Table 89: Summary of Retention Data in Sections with the Common TA, Spring 2000 134
Table 90: χ^2 analysis on Retention Data in Sections with the Common TA 134
Table 91: Survey Data for Control versus Experimental 135
Table 92: Overall MANOVA on Survey Data for Sections with the Different Instructor 139
Table 93: MANOVA Survey Results, Different Instructor 140
Table 94: Drops and Withdraws, Different Instructor 148
Table 95: Drop-Withdraw Cases for the Control and Experimental Groups, Fall 2000 148
Table 96: Drop – Withdraw Count for the Control and Experimental Groups, Different Instructor 149
Table 97: χ^2 analysis on Drop – Withdraw Data for the Control and Experimental Groups, Different Instructor 150
Table 98: Final Course Grades, Different Instructor 150

Table 99: Biology and Chemistry Research Enrollment for the Control and Experimental Groups, Different Instructor 151
Table 100: Biology and Chemistry Research Course Enrollment in the Control and Experimental Groups, Different Instructor 152
Table 101: χ^2 analysis on Biology and Chemistry Research Course Enrollment in the Control and Experimental Groups, Different Instructor 152
Table 102: Natural Sciences Research Enrollment, Different Instructor 153
Table 103: Upper Division Natural Sciences Research Course Enrollment in the Control and Experimental Groups, Different Instructor 154
Table 104: χ^2 analysis on Upper Division Natural Sciences Research Course Enrollment in the Control and Experimental Groups, Different Instructor 154
Table 105: Enrollment by College, Different Instructor....155
Table 106: Natural Sciences Retention, Fall 2000....156
Table 107: Engineering Retention, Different Instructor 156
Table 108: Total Natural Sciences and Engineering Retention, Different Instructor....157
Table 109: Summary of Retention Data in the Control and Experimental Groups, Different Instructor 157
Table 110: χ^2 analysis on Retention Data in the Control and Experimental Groups, Different Instructor 158
Table 111: Survey Data for Experimental versus PENS 159
Table 112: Overall MANOVA, Experimental versus PENS....162
Table 113: Survey Results, Experimental versus PENS....163
Table 114: Drops and Withdraws, Fall 2000 171
Table 115: Drops and Withdraws, Spring 2001....171
Table 116: Drops and Withdraws, Experimental versus PENS....171

Table 117: χ^2 analysis on Drop – Withdraw Data for the Control and Experimental Groups, Experimental versus PENS 172
Table 118: Final Course Grades, Fall 2000 173
Table 119: Final Course Grades, Spring 2001 173
Table 120: Final Course Grades, Experimental versus PENS 174
Table 121: Biology and Chemistry Research Enrollment for Experimental versus PENS, Fall 2000...174
Table 122: Biology and Chemistry Research Enrollment for Experimental versus PENS, Spring 2001 175
Table 123: Biology and Chemistry Research Enrollment, Experimental versus PENS.175
Table 124: Biology and Chemistry Research Course Enrollment, Experimental versus PENS..176
Table 125: χ^2 analysis on Biology and Chemistry Research Course Enrollment, Experimental versus PENS 177
Table 126: Upper Division Research Enrollment for Experimental versus PENS, Fall 2000...178
Table 127: Upper Division Research Enrollment for Experimental versus PENS, Spring 2001 178
Table 128: Natural Sciences Research Enrollment for Experimental versus PENS 179
Table 129: Upper Division Natural Sciences Research Course Enrollment for Experimental versus PENS 180
Table 130: χ^2 analysis on Upper Division Natural Sciences Research Course Enrollment for Experimental versus PENS 180
Table 131: Enrollment by College, Fall 2000...182
Table 132: Spring 2001 Enrollment by College 183

Table 133: Enrollment by College, Experimental versus PENS 184
Table 134: Natural Sciences Retention, Fall 2000...185
Table 135: Engineering Retention, Fall 2000 185
Table 136: Total Natural Sciences and Engineering Retention, Fall 2000 185
Table 137: Natural Sciences Retention, Spring 2001 186
Table 138: Engineering Retention, Spring 2001..186
Table 139: Total Natural Sciences and Engineering Retention, Spring 2001 186
Table 140: Total Natural Sciences and Engineering Retention, Experimental versus PENS 187
Table 141: Summary of Retention Data, Experimental versus PENS............................187
Table 142: χ^2 analysis on Retention Data, Experimental versus PENS..........................188
Table 143: Summary of Findings 189
Table A1: Statements on the Survey...244
Table A2: Survey Responses for Survey Items 8-55, Fall 1998....................................253
Table A3: Student Self-Reported Confidence in Ability in the Control Group, Fall 1998...256
Table A4: Student Self-Reported Interest in Science Areas in the Control Group, Fall 1998...257
Table A5: Student Self-Reported Confidence in Ability in the Experimental Group, Fall 1998 258
Table A6: Student Self-Reported Interest in Science Areas in the Experimental Group, Fall 1998 259
Table A7: Survey Responses for Survey Items 96-113, Fall 1998................................260
Table A8: Survey Responses for Survey Items 8-55, Spring 1999 262

Table A9: Student Self-Reported Confidence in Ability in the Control Group, Spring 1999 264
Table A10: Student Self-Reported Interest in Science Areas in the Control Group, Spring 1999 265
Table A11: Student Self-Reported Confidence in Ability in the Experimental Group, Spring 1999 266
Table A12: Student Self-Reported Interest in Science Areas in the Experimental Group, Spring 1999 267
Table A13: Survey Responses for Survey Items 71-86, Spring 1999 268
Table A14: Survey Responses, Fall 1999 270
Table A15: Survey Responses for Sections without the common TA, Spring 2000 274
Table A16: Survey Responses for Sections with the common TA, Spring 2000 278
Table A19: Survey Responses for Experimental and Control Groups, Fall 2000 282
Table A18: Survey Responses for Experimental and PENS Groups, Fall 2000 286
Table A19: Survey Responses for Experimental and Control Groups, Spring 2001 290
Table A20: Survey Responses for Experimental and PENS Groups, Spring 2001 294

List of Figures

Figure 1: Mariotte Titration System 34

Figure 2: Histogram of "Would you recommend to a friend?" in Spring 1998 43

Figure 3: Histogram of "Would you recommend this course to a friend?", Control versus Experimental...91

Figure 4: Histogram of "Would You Recommend This Course to a Friend?", Different Instructor 147

Figure 5: Drops and Withdraws, by Group and Semester 190

Figure 6: Enrollment in Subsequent Chemistry and Biology Research Courses............191

Figure 7: Enrollment in Upper Division Research Courses...192

Figure 8: Retention in Science, Engineering, or Pharmacy Majors...............................193

Chapter 1: Introduction

Overview

For as long as chemistry has existed as a discipline, there has been chemistry instruction. And concurrent was the notion that what we were teaching as part of that instruction was incorrect for some reason or another. What made it incorrect was not so much the content being taught, it was the approach that was a part of that instruction. This notion actually drove the father of laboratory instruction, Justus von Liebig, to reform laboratory instruction in the 1820s as he had observed that, in his view, "nobody understood how to teach analysis." [1] Later, in the early 1900s, focus shifted to demonstrations as a time- and cost-effective means for teaching about chemical phenomena. But chemists of the time noticed that there was some value, even if they could not define it, in having students perform experiments for themselves. As the discipline matured and other political and social realities began to impact chemistry instruction, educators began to wonder if the laboratory course might be a vehicle for developing critical thinking skills. And as a result, a whole host of chemistry laboratory courses were developed in the hopes of having students learn how to ask, and answer, questions in the sciences. Still, the success of such approaches is yet to be known. So nearly 200 years after Liebig's establishment of formal laboratory instruction in Giessen, we are still faced with the same fundamental question: what purpose should laboratory instruction serve?

To this end, and in following Liebig's lead two centuries ago, a laboratory course based around the idea that laboratory work was essential to advancing chemical knowledge was developed at The University of Texas at Austin. The natural mechanism by which this happens is through chemical research, so an introductory course designed to introduce beginning chemistry students to chemical research was created. An operational model for such a course was found in Cognitive Apprenticeship theory[2]. Cognitive Apprenticeship resembles traditional craft apprenticeships in that it involves the interaction of an expert and a student, and the student is led through a series of exercises in the expectation that the skill set possessed by the expert will be assimilated by the student; , the skill set in Cognitive Apprenticeship also involves cognitive skills, rather than only physical and manipulative skills as in traditional apprenticeship. A General Chemistry course intended for life science students was designed, taught, and evaluated over the course of several semesters using the framework proposed by Cognitive Apprenticeship, adapted for the realities of the General Chemistry laboratory. This dissertation documents the efforts made in this regard and the results obtained therefrom.

LITERATURE REVIEW

The beginnings of modern chemistry began to emerge in the late 18th century; early chemists recognized the importance of experimental evidence for the advancement of chemical knowledge. Lavoisier's "Chemical Revolution" in the 1770s provided the foundation for experimental methods that would continue to be refined through Dalton's time, and beyond. At the beginning of the 19th century, Dalton formulated his Atomic Theory, which was considered a significant breakthrough in chemical thought. His work was based on careful experimentation and observation, and he was able to establish the relative masses for 17 known elemental substances in 1803. As the body of accepted methods and procedures began to develop, it is only natural that instruction in those methods and procedures would follow.

The practice of chemistry, usually in the laboratory, was the focus of the early discipline and, by association, the focus of formal chemistry instruction. Indeed, many early chemists recognized this condition, particularly Justus von Liebig. Liebig understood the importance of training people to perform the most essential chemistry techniques of the time in order to advance the discipline. Upon arrival at the University of Giessen in 1824, Liebig set out to develop a program of laboratory instruction that ultimately became the model for the chemical world. At the beginning of Liebig's career in Giessen, it was common to have students pay instructors directly for their services, and the costs of instruction were then borne by the instructor, rather than the university. This arrangement ordinarily caused laboratory instruction to be lacking, because such instruction was relatively costly then, as it is now. However, even with his first contract, Liebig had the University of Giessen create a budget for laboratory expenses, even if the sum was not sufficient for all of the expenses. Once Liebig established his reputation, the University of Giessen increased the budget for laboratory instruction such that it eventually covered all of its costs. This model was eventually copied by other German universities, and eventually by other universities throughout the world.

However, it is not in the details of financing laboratory instruction that Liebig would leave his greatest mark on chemical education. Liebig also set out on a course of laboratory instruction that ultimately would be the model for the world. His instruction started students on analyzing known compounds in a set sequence. Once the student made it through the "alphabet" of 100 compounds, he/she was allowed to pursue analyzing new compounds, ones not previously characterized. This method proved useful to students and to Liebig personally; they were able to perform elemental analyses on naturally occurring compounds in the new and developing realm of organic chemistry. Liebig developed a laboratory manual to describe his program; published simultaneously in German and English, it became the standard laboratory program throughout Europe.

Perhaps the most remarkable feature about Liebig's model of laboratory instruction was that it had a very practical goal; it was designed to develop chemists capable of performing analyses using the best equipment available to chemists at the time. It was his observation that "nobody understood how to teach analysis" that caused him to establish what many consider to be the first systematic laboratory instruction in his labs at Giessen[1]. However, laboratory work had been offered to students prior to Liebig's time. Friedrich Stromeyer first began offering laboratory work to students in Göttingen in 1806, J. N. von Fuchs followed at Landshut in 1807, Döbereiner at Jena after 1811, and N.W. Fischer at Breslau after 1820.[3] Even then, outside Germany, laboratory instruction was offered that predates any of these timeframes. The earliest known university laboratories actually began at the beginning of the seventeenth century.[4] Whether or not those laboratories could properly be called chemistry laboratories is debatable: most chemists acknowledge the beginnings of modern chemistry to have taken place at the end of the eighteenth century. Still, the notion that laboratory instruction in chemistry is an important part of advancing the discipline appears to have been very much entrenched by Liebig's time at Geissen. Perhaps the most important contribution Liebig made in this regard was solidifying this thought and establishing a widely-regarded and imitated method for doing so.[5]

The process Liebig undertook was pedagogically sound in that it led students through a well-thought out sequence of experiments. This process, which Liebig began in the 1830's, is not much unlike what happens in graduate chemistry programs today, *viz*., have novice students learn a technique (very often) from "expert" students. But one can argue that he was not likely the inventor of the process: he simply borrowed the idea from the tradesmen of the day. If a goal is to teach someone how to make horseshoes, for example, that person should know what the finished product should look like and how to manipulate all of the implements required to make the horseshoes. And it also seems logical that the novice student be given a relative simple task before being asked to do something creative, different, or out of the ordinary. Indeed, it is through apprenticeship that many tasks were taught then and continue to be taught today. It has been said that a graduate student in chemistry “is probably as close to being a traditional apprentice as anyone in modern life.”[6]

Liebig may well have had a personal interest in developing analysts as he needed capable personnel to establish the composition of many organic compounds. Indeed, it is through the work of analysts that the foundations of organic chemistry were laid. Once composition was known and empirical formulae established, patterns could be recognized, and the notion of functional groups (at that time, collections of atoms that were repeated from one compound to another) was developed. But the success of his approach was quickly recognized throughout the chemistry community and shortly thereafter other chemists of the day were employing his approach to train analysts. The idea of systematic laboratory instruction in chemistry had taken root, and his approach acted as a catalyst for changing the way chemistry was taught and understood.

Since that time, laboratory instruction in chemistry has been universally viewed as an important part of chemical research and, it follows, of the chemistry curriculum. Arguably, the discipline may not have developed as quickly as it did through the 1800s without this systematic approach which produced capable and competent chemists. By the 1860s, as a result of this work, Mendeleev worked out the first modern periodic table and Kekulé proposed a structure for benzene. Essentially the facts of chemistry were being consolidated into bigger ideas, concepts, and theories. In order to establish an overarching philosophy for the discipline, enough observations had to be collected to create the larger message. When the discipline became sufficiently mature for this to be a reality, a new venue for chemistry instruction suited to transmit the philosophy of chemical thought was to be developed: the lecture. The lecture was where the basic knowledge in chemistry could easily be transmitted, while the laboratory could train students how that knowledge was obtained. There was, and continues to be, a great deal of synergy between the lecture and laboratory components in chemistry instruction. Indeed, much as Liebig discovered, a systemic approach to instruction of chemical manipulations works well in the lecture course, and nearly all institutions of higher learning take students on a very similar path towards an enlightenment in chemistry.

Yet while lecture instruction in chemistry has become largely standardized through organizing the course by way of theoretical principles rather than descriptive chemistry[7], laboratory instruction in chemistry from institution to institution, and even between laboratory courses within an institution, has become widely divergent. This may be the result of the ever widening of understanding in chemistry, since many laboratory skills, not just elemental analyses as in Liebig's day, might be considered essential towards understanding how knowledge in chemistry is attained. Indeed, some chemists now believe that laboratory instruction in chemistry has been rendered irrelevant[8] as the tools and techniques used in modern chemistry are well beyond the grasp and interest of novice students expected to take chemistry courses. This difficulty immediately poses a question: what function should a laboratory course in chemistry serve? Is it to reinforce or illustrate concepts that appear in the lecture course? Is it to interest students in a career in chemistry or some other science? Can it enhance self-confidence in novice chemistry learners? Is it to demonstrate the scientific method? Can it still be a method to elicit change in the discipline of chemistry as in Liebig's day? Or, indeed, is it parts or all of these?

The answer to that question is partly philosophical and partly practical. Part of that philosophy involves the chemist's *belief* that chemistry begins in the laboratory. Nothing we truly understand about our discipline has been achieved without careful experimentation, except perhaps for a few theoretical constructs, which ultimately are verified by experiments later. Maybe it is because of the chemist's desire to "prove it in the lab" that all chemists naturally gravitate towards training new students in our discipline in the laboratory from the very beginning of their studies. Yet it is also clear that only a small number of these students actually go on to study our discipline in detail. For example, only about 3% of the students enrolled in Introduction to Chemical Practice, the General Chemistry laboratory course at The University of Texas at Austin, identified Chemistry as their major in Fall 1998. Furthermore, the idea of training students in the laboratory is not unique to our discipline. Rather, scientists hold a nearly universal belief that some laboratory instruction is essential to a student's education.[9]

But has this instruction been successful in achieving certain goals? And does this universal belief have any merit? Various teaching chemists have proposed certain goals for laboratory instruction in chemistry. H.I Schlesinger[10], the great experimental boron chemist, for example, *believed* that laboratory instruction had the following goals:

1. To illustrate and clarify principles discussed in the classroom, by providing actual contact with materials.
2. To give the student a feeling of the reality of science by an encounter with phenomena which otherwise might be to him no more than words.
3. To make the facts of science easy enough to learn and impressive enough to remember.
4. To give the student some insight into basic scientific laboratory methods, to let him use his hands, and to train him in their use.

While no one would doubt that these are worthy goals, several other reasonable goals were not considered by Schlesinger. One particularly notable goal was expressed by Pickering, who noted that "if lab is to illustrate something let it be the scientific method"[11]. More recently, Michael Abraham[12] undertook a study in which various goals for laboratory instruction were evaluated by chemistry faculty at 199 institutions with ACS-approved programs in chemistry. The rankings of these goals are shown in Table 1 below:

Table 1: Relative Importance of Laboratory Goals

Concepts	2.12
Laboratory Skills	2.43
Scientific Processes	2.49
Positive Attitudes	3.71
Learning Facts	4.31

(1=highest, 5=lowest)

One easily sees how the items on the Schlesinger list correspond to those on the Abraham list. Schlesinger's goal to "illustrate and clarify principles" corresponds to "Concepts" in the Abraham survey. Training students in laboratory skills ("laboratory methods") appears on both lists, as well as learning facts (giving "the student a feeling of the reality of science") and engendering positive attitudes ("easy enough to learn and impressive enough to remember"). The goal of training students in scientific processes, which Schlesinger did not include but Pickering suggested, appears as well on the laboratory survey.

Arguably, based on the observations of Schlesinger and Abraham, the goals for laboratory instruction appear to be clear and nearly universally agreed upon. In an effort to address these goals, various "styles" or "formats" of laboratory instruction have been developed. According to Domin[13], four distinct styles of chemistry laboratory instruction exist: expository (also called traditional verification laboratories), discovery (sometimes called guided or directed inquiry laboratories), inquiry (or, open inquiry laboratories), and problem-based. The various styles of laboratories, in Domin's view, are differentiated based on outcome, approach, and procedure.

Expository Laboratories

Expository laboratories are designed to confirm a concept or principle. Of all types of laboratory schemes, these are the most directed, providing virtually no opportunity for students to explore concepts on their own. A great deal of this direction is focused on developing laboratory skills either by following the teacher's instructions or by reading a laboratory manual.[14] Aside from the emphasis on developing laboratory skills, learning facts is perceived as the most important goal within this framework of laboratory instruction. Little emphasis on thinking is placed within expository laboratories.[15] The outcome of expository laboratory experiments is often known to the students even before they undertake the experiment. Thus the whole exercise becomes an effort to verify what the students already know. This format for laboratory instruction has often been criticized as being a "cookbook" for the convenience of the instructional staff, in an effort to minimize resources expended, in particular time, space, equipment, and personnel.[16] Despite the criticism of expository laboratories, the vast majority of laboratory courses in chemistry, judging from content analysis of commercially available laboratory manuals, are taught in this manner.[17]

Discovery Laboratories

Discovery laboratories are, in a sense, designed to be a bridge between expository laboratories and inquiry laboratories. This type of laboratory provides an exercise in which students follow a detailed procedure as in expository laboratories, although the result of that experiment is not known to them, as in inquiry laboratories. In this format of laboratory instruction, students study a specific phenomenon (or a series of phenomena) and then from their observations, induce the general principle(s) behind the phenomena. The chief disadvantage of discovery laboratories is that they are more time consuming than expository laboratories. But beyond the time aspect, discovery laboratories also are subject to failing because students may not actually discover what the laboratory intended for them to discover.[18] This format for laboratory instruction is designed to develop investigative strategies, data-handling and analysis, pattern recognition, and teamwork skills. The discovery laboratory format is meant to address the perceived weaknesses of the expository laboratory format by focusing more on concepts and scientific processes more than do expository laboratories. A combined discovery/ inquiry laboratory sequence was implemented by Pavelich and Abraham[19] as early as 1979; an experimental group having a laboratory course taught in this format was shown to have a gain in abstract thinking ability relative to a control group which followed a traditional verification laboratory sequence. However, the conclusion that the authors come to should be approached with some caution: the students compared in the study came from two different institutions of higher learning. In 1996, the National Research Council set new standards in science education advocating more inquiry-based laboratory instruction[20]; in response, teaching chemists have developed laboratory curricula based on the discovery approach. An example of a two-year laboratory sequence was developed by Ricci, Ditzler, Jarret, McMaster, and Herrick[21] as a part of a discovery learning-based curriculum. Discovery laboratories are more common than inquiry laboratories.

Inquiry Laboratories

Inquiry laboratories are intended to develop true research strategies and the same skills as discovery laboratories. This format is perceived as the ideal format for laboratory instruction in that it mimics the scientific process. However, inquiry as it is expressed in instructional settings and scientific research are not one and the same[22]; in inquiry laboratories, students study well-understood phenomena. This format, in which students design their own experiments *de novo*, is considered the hardest format to implement, but it may produce a better understanding of chemistry concepts than traditional laboratory experiences.[23] Examples of inquiry-based laboratory courses have been reported[24] and a combined discovery/inquiry laboratory manual based on the work of Pavelich and Abraham previously discussed is commercially available.[25] In spite of the interest in inquiry-based laboratories, only 8% of colleges and universities actually use them, according to the Abraham[12] study.

Problem-Based Laboratories

Unlike discovery and inquiry laboratories, problem-based laboratories employ a deductive approach to learning. Students must be exposed to a concept before performing an experiment in a problem-based curriculum. In this format, students are given a scenario for which they must find a resolution using the concepts to which they have been exposed.[26] This approach parallels what happens in the real world and provides for an informed and efficient resolution to the problem.[27] Many paths may be appropriate to achieving the final goal, which is the resolution of the problem. Problem-based laboratories, with their requirement of having students integrate concepts to which they have already been exposed, are more common among upper-division laboratory courses, such as Analytical Chemistry.[28]

WHAT WE KNOW ABOUT LABORATORY INSTRUCTION

Since the goals of laboratory instruction are fairly well agreed upon, one would think that teaching chemists would have been successful in meeting these goals. But the literature in the area of laboratory instruction suggests discouraging reviews regarding the effectiveness of laboratory instruction. Considering the larger goals of laboratory instruction, we should consider to what extent we know whether:

1. Laboratory courses help reinforce concepts from the lecture course;
2. Laboratory courses improve laboratory skills;
3. Laboratory courses convey scientific processes;
4. Laboratory courses promote positive attitudes towards science;
5. Students learn some facts about the nature of chemistry and chemicals as a result of laboratory instruction.

Do Laboratory Courses Help Reinforce Concepts?

According to the Abraham[12] survey, the most important goal of laboratory instruction is developing chemical concepts. Yet a review of the literature provides little evidence that laboratory instruction does, in fact, achieve this goal if we consider how the laboratory course impacts the (usually) associated lecture course. Several studies of how students perform on objective achievement tests in lecture courses have been undertaken. Cunningham[29] and Kruglak[30] in Physics; and Brown[31] and Bradley[32] all focused on whether demonstrations in the lecture setting were as effective as laboratory work towards achievement on an objective test in the lecture setting; all studies showed there was no difference between students who had performed laboratory work and students who had an equivalent demonstration experience. Kruglak[33], in a subsequent study, divided freshman physics students into three groups: one which had a conventional laboratory course, another which had the same experiments demonstrated to them, and the third which had no laboratory or demonstration experience at all. No difference was found among any of the groups on lecture examinations. Dubravcic[34] considered alternatives to laboratory instruction, films and discussion sessions, for non-science basic chemistry students. No difference in achievement on the final examination was observed between students who undertook laboratory instruction versus either students who viewed films related to lecture course content or students who attended a discussion section. It is possible that laboratory instruction does provide some insight into chemical phenomena that is neither easily nor ordinarily measured, but it also appears that laboratory instruction for the sole purpose of improving test results in the lecture course as tests are ordinarily administered is fruitless.

Do Laboratory Courses Improve Laboratory Skills?

On the surface, it seems obvious that students who receive training in manipulative tasks in the laboratory are certain to be more proficient at those tasks than students who receive no such training. Indeed, Ben-Zvi *et al.* found that high school students performing chemistry laboratory work performed better on a test of manipulative skills related to laboratory work than students who had watched films demonstrating laboratory experiments.[35] Assessing laboratory operational skills by way of a paper-and-pencil test is impossible[36] and as a consequence, Ben-Zvi *et al.* employed a checklist of manipulative skills that had been previously described.[37] So, while it seems that the obvious is true, there is still a complicating factor to this question in that there is no wide agreement on the nature of the technical skills a student should have acquired as a result of a General Chemistry laboratory experience.

Do Laboratory Courses Convey Scientific Processes?

Arguably, laboratory courses should also enhance and develop cognitive skills as well as manipulative skills. Cognitive skills such as planning an experiment and learning to draw conclusions from observations should be part of the laboratory experience. But students spend more time determining if they obtained the correct results rather than designing the experiment in the expository model[38], indicating that students would have little opportunity for higher-order cognitive thinking. Domin[17] observed in his analysis of the content of commercially available laboratory manuals that very few of them would promote cognitive growth. Hill observed that college student creativity, as measured by a general instrument to measure creative thinking, improved with involvement in chemistry laboratory activities.[39] The combined discovery/ inquiry laboratory sequence by Pavelich and Abraham[25] discussed earlier indicated that students exposed to a discovery/ inquiry format was shown to have a gain in abstract thinking ability compared to a control group which followed a traditional verification laboratory sequence; results of that study should be viewed cautiously. Both Wheatley[40] and Raghubir[41] observed the development of high-level cognitive abilities as a result of biology laboratory instruction. The enhancement of scientific thinking skills appears to be a possible outcome of laboratory instruction.[42]

Do Students Acquire Positive Attitudes towards Science as a Result of Laboratory Instruction?

Ben-Zvi discovered that laboratory work was the most effective instructional method for promoting interest and learning in high school chemistry students when compared to teacher demonstrations, group discussions, filmed demonstrations, and lectures.[43] This discovery corresponds to Pickering's observation that the value of the laboratory might be in the affective, not cognitive domain.[44] Perhaps laboratory instruction does not change students' understanding of concepts but changes the way they connect or value concepts instead.[45]

Do Students Learn Facts about the Nature of Chemistry as a Result of Laboratory Instruction?

According to the Abraham[12] survey, this particular goal of laboratory instruction is not highly valued at this time by the majority of teaching chemists. Factual information was more highly valued in the 1950s when Qualitative Analysis was more commonly a large part of the laboratory curriculum, but by the 1960s, emphasis shifted to the development of scientific processes.[46] The American Chemical Society Examinations Institute has developed several small-scale laboratory assessment activities in which students are expected to design experiments to address several very common General Chemistry laboratory questions.[47] These examinations hope to demonstrate improved problem-solving skills, but they promise to be difficult to administer and perhaps again so content-specific that no improvement in general problem-solving skills might be observed.

Summary of What We Know and its Implications

Gallagher observed that laboratory teaching had a potential for the teaching of science, even if that potential was unrealized; however, its instructional role was still uncertain.[48] Since the laboratory provides an opportunity to develop manipulative skills in students, we should carefully choose the skills we deem necessary for students to have after completing a course. As the laboratory course does not appear to help students with concepts from their associated lecture course, at least not in a way that we ordinarily measure, we are free from structuring the laboratory around the lecture course. The laboratory course does hold some promise as a means for developing scientific thinking skills in students, provided the laboratory is structured in a way to do so. The laboratory course is uniquely suited to demonstrating how the discipline advances and the source of knowledge in the discipline. Students appear to find laboratory experiences the most interesting of all of the modes of conveying the nature of chemistry to them. Capitalizing on this interest is a good way to recruit and retain students in the field. Finally, it may be a means of demonstrating the some facts about the nature of chemicals, even if that goal is not as valued as it once was.

A CONCURRENT THREAD

Even without a comprehensive review of the literature to understand the role of laboratory instruction, there are signs that a great many teaching chemists are unhappy with the approach to laboratory instruction in chemistry that is being taken in many places today. From the 1960s forward, various initiatives to improve laboratory instruction and encourage students to pursue a career in science have been undertaken. These approaches invariably involve making student work in the laboratory approximate the research process. Various reports on science education have indicated that inquiry-based laboratory experiences are valuable to students. The goal of such exercises is to mimic the research experience, in that they ask students to (1) recognize and formulate a scientific question, (2) identify an approach that should give an answer to that question, (3) and manipulate the equipment and carry out the experiment in a manner that should give an unambiguous answer to that question. Within each step of this process, some basic understanding about the discipline must be known to the student and it is unrealistic to assume that the novice student could perform each of these steps without a great deal of coaching. Indeed, the Achilles heel of most inquiry-based instruction is that it assumes that students are innately capable of solving scientific problems on their own. Although students may be capable of formulating scientific questions, their knowledge of the nature of the techniques and approaches that are capable of answering those questions is likely to be lacking. For students to learn how to approach scientific questions, they need to have a roadmap, a context in which the question is posed. And they must, as the practitioner of any trade must, envision the final product as a whole, so they can see where their work will lead, so they recognize the individual tasks that have to be performed in order to obtain the finished product. Additionally, there have been programs which are designed to encourage research at the undergraduate level. The

National Science Foundation (NSF), through various programs, supports institutions that place research-grade equipment in small colleges and universities in the hope of having lower-division undergraduate students use these instruments. The fact that the NSF has taken on this initiative suggests that it sees value in Liebig's approach, namely, having students work on modern-day chemistry problems. Arguably these students gain a marketable skill as well, but the fact that these instruments are the basis of advancing the discipline by its natural method, research, that makes the program so valuable. Additionally, the Council for Undergraduate Research (CUR) encourages faculty in a great many disciplines, not just chemistry, to provide opportunities for students to engage in research. These programs are by necessity an apprenticeship; the faculty member must work one-on-one with each student, assisting students to ply their respective trades. Although many would argue that the research environment is a powerful learning and recruiting tool, it is difficult to implement on a larger scale, such as a laboratory classroom.

But is it possible to envision structuring a laboratory classroom on a research model? And how is a research model different than any of the formats for laboratory instruction that are currently employed today? The nature of research, not just in chemistry but in any science, is inductive. The outcome of research is not predetermined or known. Research involves capitalizing on previous knowledge and skills, but unlike many of the typical formats of laboratory instruction, research is focused on a narrow problem, explored in depth, rather than being a collection of unrelated experiments. Laboratory experiences intended to mimic the research experience should not involve a series of disparate experiences but rather a sequence of experiences as part of a coherent whole.

If the goal of laboratory instruction is to mimic the research experience, a new model for laboratory instruction will have to be found. Fortunately, such a model already has been described in educational theory, and it is called Cognitive Apprenticeship Theory[2].

COGNITIVE APPRENTICESHIP THEORY

Cognitive Apprenticeship Theory resembles training in traditional crafts, but it is adapted towards developing cognitive skills. It asserts that the learning environment has an associated sociology, the consideration of which cannot be ignored in developing curricula. Collins, Brown, and Newman identified five critical elements impacting the sociology of learning: situated learning, culture of expert practice, intrinsic motivation, exploiting cooperation, and exploiting competition.

Situated Learning

A key concept within Cognitive Apprenticeship Theory is that students carry out tasks and solve problems within the environment which is natural for the knowledge that is to be attained. For chemistry, the natural environment for exploring the nature of our discipline is within the laboratory. The laboratory provides a context in which chemistry questions are posed and answered using the tools, both physical and mental, of which chemists take advantage.

Culture of Expert Practice

Another key element of the Cognitive Apprenticeship Theory is the creation of an environment in which students communicate about and participate in the skills used by expert chemists. Students are able to observe and learn from an expert; however, just observing the expert is not enough, students must learn to think as the expert does. The expert must model the skills required to perform a task and induce, in whatever ways are possible, students to do the same. Chemistry teaching laboratories provide an ideal context in which chemists, as experts, can display how they approach problems and the tools they use to solve them.

Intrinsic Motivation

Learning environments, such as laboratory courses, should promote intrinsic motivation for learning. Students are more likely to continue pursuing an activity if it provides an intrinsic reward to them. Careful selection of activities within a laboratory course may be intrinsically motivating to students if the activities are related to their experience and interest, making their learning in chemistry to seem related to other disciplines and to life in general.

Exploiting Cooperation

Chemistry laboratory courses are, by the very nature of laboratory settings, easily adapted to group work. Indeed, even if groups are not formally assigned, they may naturally spring up in laboratory courses because students are often working on the same problem and they have other students physically near them from which they can solicit advice. It is this character of the laboratory environment that can be capitalized upon to provide an additional opportunity for learning for students. Often other students may be the best source for advice to a student who is struggling with a concept, since those other students may have recently resolved that conflict for themselves; they understand it as a novice does and may be able to provide some insight in language that the struggling student will understand. The process benefits the student with the insight as well; he or she then has the opportunity to articulate and refine his or her knowledge.

Exploiting Competition

Competition can be a powerful motivator for some students. However, for other students, it may be intimidating. By establishing teams within the laboratory, any fears of competition that any individual students may have can be minimized if not quelled entirely, so that the benefits of competition may be shared by all. Additionally, the establishment of teams within the laboratory course may provide an additional source of encouragement and motivation for students that may otherwise struggle on their own; it also provides an incentive to stronger students within each team to help the less able students. Chemistry laboratory courses, which can naturally be structured in terms of projects for teams of students, are easily envisioned as being composed of teams.

Having established that Cognitive Apprenticeship Theory may provide some insight in how a laboratory course may be structured, the proof of its effectiveness remains to be demonstrated. The details of arranging such a course and comparisons to a traditionally-taught course will be described in the next chapter. The ultimate goals for teaching a course in this new manner are to introduce students to the idea of laboratory work as a vehicle for solving questions in chemistry and to the nature of chemicalresearch. This type of approach may be intrinsically more interesting and motivating to students and prompt them to continue forward in a science (perhaps chemistry) career. The research questions we should consider in deciding whether or not this new course is successful are:

1. Are students more likely to become interested in science?
2. Are students more likely to feel that they can be successful in a science career?
3. Are students more likely to pursue further research courses?
4. Are students more likely to persist as science majors?

These questions are addressed in turn over the course of the next few chapters.

Chapter 2: Experimental

Two General Chemistry laboratory courses are taught at The University of Texas at Austin. One, identified as CH 317, is intended for chemistry, biochemistry, and chemical engineering majors only. The other, which is of more importance to this study, is intended for any student for whom chemistry is a required course of study, primarily life science students, and it has been taught to roughly 700 students each long (fall or spring) semester. This course is numbered CH 204 and it is independent of the lecture course in that students register for it separately, that is, independently of the General Chemistry lecture courses CH 301 and CH 302. The course has as its only prerequisite the first half of General Chemistry lecture (CH 301); as a rule, students take it concurrently with or subsequent to the second half of General Chemistry, (CH 302). As The University has a very large number of students taking chemistry and its teaching laboratory resources are limited, the Department of Chemistry and Biochemistry decided many years ago to offer only one semester of General Chemistry laboratory instead of the more conventional two. But to assure that each student would have an equivalent laboratory experience to students at other institutions, the laboratory experience was concentrated and was allotted a larger block of time than the traditional two-semester sequence would incorporate. Each week, students in CH 204 meet for 4 hours of wet laboratory, 1 hour of computer laboratory, and 1 hour discussion/lecture, thus providing them with 6 hours of instruction, comparable to 2 semesters of 3-hour laboratory courses that they might take at comparable institutions. Each section can be composed of as many as 21 students, although with some reconfiguration of the laboratory space, that number can be increased to 24 students. Students are not obligated to take the associated laboratory course along with the lecture course. Indeed, a very common practice for students is to take CH 204 after they take the second half of General Chemistry, owing largely to the difficulty of scheduling laboratory courses since the availability of laboratory sections is so limited. As a consequence, very little carryover from the lecture content to the laboratory is expected; the laboratory is essentially a stand-alone course. This design of the General Chemistry curriculum at The University of Texas at Austin was beneficial to the purposes of this study in that a comparison between two laboratory curricula could be arranged without fear that students might be placed at a disadvantage in the General Chemistry lecture course.

STEPS TOWARDS A NEW GENERAL CHEMISTRY LABORATORY COURSE

As part of a periodic review of courses that were being taught in the Department, some consideration was given to developing another version of a General Chemistry laboratory course specifically for its largest audience, life science students. At that time a fairly conventional introductory laboratory course, numbered CH 204, had been designed, with "standard laboratory exercises" including an experiment designed to illustrate the scientific method, a one-period qualitative analysis experience, experiments on physical measurements of the density and specific heat of a solid, the vapor pressure of a salt solution, and the heat of neutralization, quantitative analyses using spectrophotometry, gravimetric analysis, acid-base titration, and redox titration, and explorations into paper chromatography, pH and buffers, and electrochemistry. The laboratory manual was created in-house and students purchased copies of it from The University's duplicating office. In all of the laboratory exercises, the course made use of a locally designed device called the ChemBox, which allowed for rapid electronic collection of different kinds of analytical data simultaneously, *e.g.*, conductivity, light absorption, and potentials. The 4-hour wet laboratory session was used for the collection of data; the 1-hour computer laboratory session was used for quizzes related to the upcoming laboratory and for electronic submission of results. Students worked individually on all aspects of instruction in the course and were evaluated from their preparation for the laboratory by writing out the procedure they would follow in their laboratory notebooks, their performance on the electronically delivered quizzes which were also electronically graded, and their experimental results, also submitted and graded electronically. Attendance at the 1-hour discussion/lecture period was voluntary, but it provided some insight on performing the upcoming experiment and the handling of data for the eventual report. It was against this structure that a new course was developed.

With the time structure imposed by the existing laboratory course, the beginnings of CH 204 AV (Alternate Version) were set in motion. In Fall 1997, Dr. Kent K. Stewart started working on some experiments and ideas for use in this new experimental course. This new course was designed around the observation that junior and senior level chemistry and biochemistry majors had little experience making quantitative measurements, and so the course was developed around the theme of quantitative measurements for life science systems. The course was also designed around the idea that students needed a practical experience; to meet this goal, modern instrumentation and the cognitive tools of the trade would be employed. Finally, the course also was intended to provide a more "enjoyable" General Chemistry laboratory experience than traditional laboratory courses; by focusing on chemistry relevant to the intended audience's field of study, students were expected to find the experience more interesting. To choose how to structure the course, consideration was then given to the identity of the chemistry techniques that are common in life science laboratories, as established from discussions with life science faculty. A summary of these preferred techniques appear in Table 2.

Table 2: Common Chemistry Techniques Used in Life Science Laboratories

pH measurements	✓
Use of UV/Vis spectroscopy to:	
Identify compounds	✓
Determine analyte concentrations	✓
Use of colorimetric reactions	
Classical reactions	✓
Enzyme-catalyzed reactions	✓
Chromatography	
Gas chromatography (GC)	
Liquid chromatography (LC)	✓
Thin layer chromatography (TLC)	
Centrifugation	
Electrophoresis	
Enzyme Linked Immunosorbent Assays (ELISA)	
Micro-titer plate assays	

(✓) indicates the techniques that were chosen for CH 204 AV

The techniques that were chosen largely followed those common to standard General Chemistry laboratory courses and those available for beginning chemistry students. Certainly, pH measurements are very common for the "standard" General Chemistry laboratory experiments, and while spectroscopy is also common for General Chemistry laboratories, it is used more commonly for quantification but not for identification of compounds owing to the fact that complete spectra must be recorded and not many General Chemistry laboratories have a spectrophotometer suitable for that purpose available. The use of colorimetric reagents is also fairly common General Chemistry laboratory experience both in quantification, as in the classic copper-ammonia system, or for qualitative analysis, as using dimethylglyoxime to establish the presence of nickel (II) ions in solution. In CH 204 AV, we also employed enzymatic reagent systems for selectivity in complex solutions, particularly useful for life-science oriented samples. Of the chromatographic techniques, gas chromatography and thin layer chromatography are commonly taught in Organic Chemistry laboratory, so only Liquid Chromatography, in the form of disposable reverse-phase columns, was chosen for CH 204 AV. The other techniques listed, centrifugation, electrophoresis, and ELISA, required substantial understanding in biochemistry and as such were not considered as the basis for viable experiences in CH 204 AV.

There was also a key element of the structure of the existing course that would eventually be modified for this new course. CH 204, like many laboratory courses, did not take advantage of the uniqueness of the laboratory environment, which encourages social interaction and all its subsequent benefits as defined by the Cognitive Apprenticeship Theory, *vide supra*. In traditional laboratory courses, a lecture model is imposed. Students work individually and focus is placed on finding the "correct" answer. Report submission is based primarily on the ease of evaluation by using data sheets. Little interaction is encouraged between students and it is often actively discouraged. This model of laboratory instruction is contrary to the way that science is actually done. Laboratory work in science naturally includes investigators working in cooperation with each other towards common goals, persons taking advantage of their unique skills and talents to address problems shared by the group, and the collegiality of a community of learners. With these observations in mind, and in the interest of recreating the research environment within the laboratory, student groups were created in CH 204 AV.

The new course then was constructed based upon the previously mentioned selection of techniques in such a way that the experiments increased in complexity and each drew from the students' previous work. The course was taught for the first time in Spring 1998 to 17 students in one section with Dr. Stewart acting as the instructor of record and Michael J. Elliott, the author of this dissertation, acting as the Teaching Assistant. The Teaching Assistant's role that semester was to make a working laboratory experience out of the experiments that Dr. Stewart planned. Students were randomly assigned to groups of 2 or 3, so that 7 groups were created, on the first day of class; these groups persisted throughout the semester. Subsequent to that semester, in Fall 1998, the course expanded to 4 sections and 75 students who eventually finished the course. Further expansion of the course ensued, and 8 sections of the course were taught in spring semesters and 7 in fall semesters. In Spring 2001, the laboratory space was reconfigured so that 24 students could enroll in each section. With this change, 8 student groups of 2 or 3, rather than 7, were created in each section. Table 3 depicts the enrollment history, based on the number of students who completed the course, of CH 204 AV from its beginning in Spring 1998 through Spring 2001.

Table 3: Enrollment History of CH 204 AV

Semester	Number of Sections	Number of Students
Spring 1998	1	17
Fall 1998	4	75
Spring 1999	8	150
Fall 1999	7	135
Spring 2000	8	155
Fall 2000	7	139
Spring 2001	8	170

From the beginnings of CH 204 AV, the course was assigned a "head teaching assistant." For semesters through Spring 2000, the head teaching assistant also taught some of the laboratory sections; the head teaching assistant also taught some of the lectures in the discussion/lecture period, although that responsibility fell primarily to the instructor of record. Beginning in Fall 2000, the head teaching assistant took on a larger administrative role and taught half of the lectures, ran the teaching assistant training sessions, and visited as many laboratory sessions as possible to assure that the laboratory was running smoothly according to the precepts of the Cognitive Apprenticeship Theory. With these additional responsibilities, the head teaching assistant was relieved of teaching individual laboratory sections. The head teaching assistant also assured that all of the required chemicals were available and the instrumentation was operational for the course. This administrative structure was somewhat different than in the traditional CH 204 course; in CH 204, the head teaching assistant was responsible for lectures in the discussion/lecture period; the instructor of record was largely invisible to students. The instructor of record managed the computer systems that delivered and evaluated the electronic quizzes and helped resolve disputes in grading.

APPLYING COGNITIVE APPRENTICESHIP THEORY TO THE NEW COURSE

The CH 204 AV course began as an idea to design a General Chemistry laboratory course that would have the "feel" of a research laboratory. Undergraduate research has been and continues to be a very successful endeavor by many measures, and our goal for this new course was to *formalize* the research experience within the context of a standard laboratory course. To achieve this goal, we needed an educational model that described the beginnings of the research process. Cognitive Apprenticeship Theory (Chapter 1) is such a model and the new course was designed with this theory as a guide. This theory resembles traditional craft-type apprenticeship but is adapted for cognitive domains. One of the important features of the theory is the interaction between student and the expert and between students. This relationship is also expressed in chemistry research environments as well; it is the basis of graduate education. Hence we believed that Cognitive Apprenticeship Theory might act as a good model for laboratory work.

Within the Cognitive Apprenticeship model, there are six stages of instruction: Modeling, Coaching, Scaffolding/Fading, Articulation, Reflection, and Exploration. The process is meant to be sequential; by the time the student reaches Exploration, the student should be ready to venture forth and complete a chemistry-related task on his/her own and be able to evaluate his/her own efforts towards that task. It seemed to us that one of the key goals of laboratory instruction is to be able to devise experiments and to analyze the results of these experiments. This goal describes the process that takes place when beginning students learn how to do research. The various activities within a suitably designed laboratory course could be fashioned into the stages of the Cognitive Apprenticeship model. Here are the stages of the theory, and how we attempted to implement them, in detail:

MODELING. In this beginning stage, the student observes the expert performing the tasks at hand. In the CH 204 AV laboratory, each teaching assistant demonstrated the day's tasks to the entire laboratory group at the beginning of the laboratory period. First, however, the teaching assistants themselves had to undergo training in how to operate all of the equipment and on what problems students typically encountered (based on our previous experience) during the coming laboratory session. The entire laboratory experience was structured so that only a small number of skills needed be presented in any one session, and the time the teaching assistants needed at the beginning of a laboratory session typically was only 10-15 minutes. On occasion, the students also received instruction during the formal 1-hour lecture associated with the course. However, since these lectures could be quite large (80-100 students), most of the "hands-on" instruction was done in each laboratory session, where the number of students was smaller (about 20), and most of the theory was developed in the formal lecture itself. By comparison, in the traditional laboratory CH 204, students also received instruction from the head teaching assistant during the discussion/lecture period and from their section's teaching assistant at the beginning of the laboratory period. The laboratory manual also included detailed procedural instructions.

COACHING. In the second stage, the expert provides feedback on student work. Once the students received their initial instruction, the teaching assistants moved around the laboratory, observing students as they started their work. Often for the first hour of a laboratory period, the students had to become oriented to the tasks they were doing, in effect figuring out what they needed to do. The teaching assistants were told that they should interact with as many student groups as they could, reminding and showing them the operation of the equipment or other tasks (some intellectual) that were important to the day's activity. One of the benefits of organizing students into groups was that the teaching assistants could interact with 7 or 8 groups, rather than 21 or 24 students, making their interaction with students more efficient. In the traditional CH 204 course, teaching assistants only assisted the students if students asked for help; less emphasis was placed on human interaction.

SCAFFOLDING/ FADING. In this stage, the expert provides support to the student for a period of time, then begins to remove those supports as the student becomes familiar with the task. Once the students knew how to operate the equipment and understood the details of the experiment they were doing that day, we advised the teaching assistants that they should observe the students and step in only when student groups appeared to be struggling. We advised the teaching assistants that they should allow time for the students to explore the task at hand and to intervene only if the students were performing a task improperly or in such a way that could be dangerous to themselves or other students. This stage requires some experience and some patience on the part of the teaching assistant acting as the expert; struggling with a problem is good for students, but too much struggle may lead to frustration. Finding the point in which it is beneficial to intervene takes some experience. In the traditional CH 204 course, little effort to interact with students was made by teaching assistants, so this process would not have taken place.

ARTICULATION. In the articulation stage, the student explains his/ her knowledge, reasoning, and problem-solving strategies. In the CH 204 AV course, we used formal laboratory reports as a means for students to articulate their knowledge. The 12 laboratory exercises were grouped into 6 reports. Student groups prepared one report for submission; they were advised that they should work out amongst themselves how best to divide the labor in preparing the report. Each student within a group received the same score for the laboratory report. Another of the benefits of having 7 or 8 groups was that it reduced the amount of grading that a teaching assistant would have to take on since there were only 7 or 8 reports to grade. The reports were detailed and required substantial documentation of student work and analysis; the smaller number of reports allowed a higher level of expectation of analysis. The reports were structured (an outline was provided) and required students to address specific issues related to the laboratory exercises. Using the outline, we could probe the students' understanding of key issues. In the traditional CH 204 course, students submitted data online for their reports; these were done individually and were evaluated by the computer. Little emphasis was placed on analysis of the data, consistent with the character of verification-style laboratories; grades were assigned based on the "correctness" of their computations.

REFLECTION. In the fifth stage, students compare their knowledge with that of the expert. Again, we used laboratory reports as the device for one of the stages of instruction. Each laboratory report was evaluated by the teaching assistants, and feedback was provided from the teaching assistant to the students. Ordinarily evaluated reported were returned to students within a week of their submission. Students could then make revisions to the laboratory reports and resubmit them for a better grade.

However, they could not receive the maximum score upon resubmission. The point of the resubmission process was to have students reevaluate their work and improve it, and many students took advantage of this opportunity. The process also paralleled the submission of papers to peer-reviewed journals. In the traditional CH 204 laboratory, none of this process was included.

EXPLORATION. The final stage of the process is exploration, in which students themselves move into problem solving modes. We included a capstone laboratory experience, one in which students had to rely on their learned skills and develop details of a procedure. We asked students to determine the concentrations of sugar and two food dyes in a carbonated grape soda. One new skill had to be presented to the students, that of separation of the materials to be analyzed, however the details of the analysis were left to the students to work out. However, students had performed similar laboratory tasks earlier in the semester, so the general plan of attack was known to them. The exploration phase parallels chemical research and as such is important to our goal of illustrating the research process. In the traditional CH 204 course, the laboratory exercises were designed as stand-alone activities and did not include a capstone experience.

STRUCTURE OF THE NEW COURSE

The CH 204 AV course maintained the weekly 4-hour laboratory session, a 1-hour formal lecture session, and a 1-hour computer laboratory format of the standard CH 204 course, for the sake of scheduling. In the first few weeks of the course, an assignment, designed to teach students some of the computer skills they needed to complete their laboratory reports, was given to students to complete during the computer laboratory session. After this first assignment was completed, the computer laboratory was used solely for the purpose of assisting students in the preparation of their laboratory reports.

The formal lecture portion of the course was used to develop the theory behind the laboratory exercises the students were performing. Since the CH 204 AV course was not designed to demonstrate concepts presented in the lecture portion of the General Chemistry course, we found it necessary to describe the details of the chemistry that was being taught in the laboratory. We also used this portion of the course to give quizzes and exams.

The laboratory portion of the course involved 12 laboratory exercises. The general theme for the laboratory exercises was the measurement of concentrations of specific substances in biological systems. Several common methods of measurements were employed. The exercises were grouped into units based on similarities of concepts. The general scheme is presented below. The first unit, comprising the first three laboratory exercises, was focused on the basics of visible spectroscopy. Within this unit, the ideas that colored compounds had unique visible spectra and that the amount of light a solution absorbed was characteristic of the concentration of that solution were developed. In the third laboratory, several unknown samples were studied: the identity of some samples was unknown, and for others, the concentration was the unknown. Students were expected to develop their own procedures based on work from the first two experiments. The limitations on the use of these concepts were also discussed.

In the second unit, we explored the nature of acid and base solutions. The first of the three laboratories in this unit addressed the concept of pH. The pH of several buffer solutions and various common household mixtures was measured using a pH meter and long–range pH papers, and students made comparisons on the precision and accuracy of the two methods. Students also shared their data so that statistical treatments could be engaged. Several dyes and pH indicators were also placed in buffer solutions of different pH, and the effect of pH on their visible spectra was also observed, with student commentary on the basis for any spectral change observed. The second and third laboratories in this unit addressed the use of titrations. For these experiments, a Mariotte flask titration system was employed. This system makes use of a Mariotte bottle, which has a narrow mouth at the top and a small outlet at the bottom. A narrow-diameter hollow glass tube, fitted with a stopper, is placed in the mouth of the bottle so that the mouth is sealed and air is only permitted in through the narrow-diameter tube. As long as the bottom of this tube is above the level of liquid in the Mariotte bottle, airflow is restricted and a constant flow of liquid can be obtained through the outlet. An illustration of the Mariotte titration system appears in Figure 1.

Figure 1: Mariotte Titration System

The second laboratory involved the titrations of many different acid solutions to observe the titration curve that resulted. These titration curves provide a qualitative insight as to the strength of the acid and the number of ionizable protons in the acid molecule. The third laboratory involved the use of titrations to determine the concentration of acid in a solution. In effect, the acid/base unit provided the same kind of information using pH as a probe as does spectroscopy, namely, qualitative and quantitative information.

The third unit, which was composed of two laboratory exercises, addressed issues associated with selecting an analytical method appropriate to the sample to be analyzed. Not all analytes (compounds of interest within a sample) are colored, and so a colorimetric agent (a compound which will produce a colored species) is employed so that visible spectroscopy can be performed on such samples. Since these agents are typically colored themselves, the techniques and logic behind the subtraction of their contribution to the total absorbance of the sample are discussed. Students are expected to be able to develop a reaction scheme, based on general instructions for the method. In the second laboratory in this unit, two methods are presented to analyze samples; both will work, but each presents a unique set of analytical considerations as each method has a concentration range in which it will work. For the first time in the laboratory sequence, students have to use their previous knowledge to select the most appropriate method.

The fourth unit was a continuation of the ideas in the third; the two laboratories here focused on difficulties associated with the use of colorimetric reagents. Sometimes samples are inherently colored, although the analyte itself is colorless. In this case, care must be taken to determine absorbance ultimately due to the analyte once the colorimetric reagent is added. Both the colorimetric agent and the sample itself are colored and hence add to the total absorbance; these must be subtracted. In the second laboratory, method validation is addressed. The great difficulty with colorimetric analyses is that the analyst is dependent upon a reaction in order to observe the analyte. Some samples may react with the colorimetric agent or otherwise hinder its effect; the wise analyst learns that he/she should confirm that this hindrance is not present. This process is described in detail, and students are again expected to create a protocol for their samples.

The fifth unit was a single laboratory exercise; it was designed to summarize the ideas and concepts in nearly all of the previous laboratory exercises. The sample to be analyzed is a carbonated grape soda which was analyzed for its dye and sugar (glucose) content. The two food dyes and the glucose in the sample were separated and analysis was made on all three. The food dyes' identities were confirmed and their concentrations determined. The glucose concentration was determined using a previously utilized method. In this exercise, students were expected to develop the bulk of their procedures which, however, were similar to those they had previously employed.

The sixth and final unit was also a single laboratory exercise. It described a different method for determining concentration, appropriate for enzyme (biological catalyst) systems and using reaction rates. Previous techniques were again employed; however, some new intellectual skills were presented.

A comparison of how the experimental course was structured relative to the existing control course follows in Table 4 on the following page.

Table 4: Comparison of the Structures of the Control and Experimental Courses

	Control	Experimental
Weekly Schedule	4 hours wet lab 1 hour computer lab 1 hour lab lecture	4 hours wet lab 1 hour computer lab 1 hour lab lecture
Nature of Wet Labs	"Standard" General Chemistry exercises, not related to each other	12 laboratory exercises in 6 units, sequentially presented
Nature of Computer Lab	Used for quizzes and electronic report submission	Used to develop necessary computer skills for report computations
Nature of Lab Lecture	Used to describe how to do the laboratory exercises and how to perform computations necessary to the report	Used to describe theory behind the laboratory exercises and some technical details and procedures
Lab Reports	Submitted electronically, grade primarily on obtaining the "correct" answer	Submitted on paper as formal reports, grade primarily on proper documentation of data and results
Quizzes	Weekly, electronically delivered and evaluated, in computer lab	Weekly, distributed on paper and hand-graded, in lab lecture
Tests	None	2 midterms, based on theory and typical computations
Final Exam	None	Based on theory and typical computations

DATA COLLECTION

In Spring 1998, the first semester in which CH 204 AV was taught, an attitudinal survey was given to students enrolled in the course. This survey, and modifications of it, was then used to evaluate student reaction to CH 204 (the standard General Chemistry laboratory, as the control) and to the experimental course, CH 204 AV. The original survey, which was developed by the Learning through Evaluation, Adaptation, and Dissemination (LEAD) Center at the University of Wisconsin Madison[49] was employed for the first two semesters and was subsequently modified. Four variants of the survey were used during the Spring 1998 to Spring 2001 time period, these are presented as Appendices A, B, C, and D. The surveys employed during each semester are outlined in Table 5.

Table 5: Survey Form Used, per Semester

Semester	Survey Form Used
Spring 1998	Appendix A
Fall 1998	Appendix A
Spring 1999	Appendix B
Fall 1999	Appendix C
Spring 2000	Appendix C
Fall 2000	Appendix C
Spring 2001	Appendix D

Although the survey was modified, largely to shorten it in an effort to encourage participation, many of the core items of the original survey were retained. The common questions are renumbered (as New #) and are presented in Appendix E. These questions are ultimately the ones that are analyzed. The original numbering on each version of the survey is also presented.

All but one of the questions that are in common across the four versions of the survey are assigned new numbers (as “New #”) for ease of comparison across semesters. The only common question excluded from this group is “Average hours each week spent on this course” because the set of possible responses changed over time. Aside from this one question, analyses are made upon this set of common questions.

The CH 204 AV course had been taught during every long (fall or spring) semesters since the Spring 1998 term. Early in the development of the CH 204 AV course, we focused on developing course content and structure; the number of sections was intentionally kept small. By Spring 1999, however, the course expanded to 8 sections and it kept this structure through Spring 2001. Little change to the structure of the course occurred over this time frame. As a consequence, merging data from one semester to the next over the Spring 1999 through Spring 2001 timeframe would not be unreasonable, if no other change was applied to the course.

Although we were able to make use of a survey that already existed, the original survey created at the University of Wisconsin-Madison does not appear to have been validated. Furthermore, as we shortened the original survey to suit our purposes, it is important to observe that this instrument, even if it had been validated, would have to be revalidated. However, even though the instrument has not been formally validated, it may be useful for understanding trends within the course. A discussion of how the survey was analyzed follows in the next chapter.

Chapter 3: Data Analysis

The first semester in which the experimental course was taught was considered to be a pilot study in which the viability of teaching this new course to beginning chemistry students was investigated. As a result, the way in which the course was evaluated was different for the first semester than it was for subsequent semesters. A discussion of the first semester follows in the next section.

SPRING 1998

In the first semester that CH 204 AV was taught, nineteen (19) academically well-prepared students were specifically chosen by the Undergraduate Advising Office of the Department of Chemistry and Biochemistry for this new experimental course. Since these students were primarily Life Sciences majors (8 Biology and 6 Biochemistry), they were expected to have a natural interest in the subject matter of the new course. Of these 19 students, 17 eventually completed the course. Given the special experimental nature of this semester and the selection process for students for the course, no comparison to the control course CH 204 would be appropriate; however, data collected during this first semester indicated that students could be successful in this course and that the course should be taught to a larger audience.

Survey Data

The survey used in Spring 1998 asked the 17 successful students in the course to rate their confidence in their ability in science areas as well as their interest in various scientific areas before and after taking the chemistry laboratory course. Items were evaluated on a 0 (low) to 5 (high) scale and average ratings with their standard deviations are presented in the two tables, Table 6 and Table 7, below. Notable is that students reported a gain with respect to each item as a result of having been enrolled in CH

204AV. In some cases, the gain was dramatic. The original numbering of items on the survey, as shown in Appendix A, is presented here.

Table 6: Student Self-Reported Confidence in Ability, Spring 1998

Items	Statement	Before	After	Change
56,57	Understand Key Concepts of Chemistry	3.438 ± 1.031	4.706 ± 0.470	1.268
58,59	Solve Chemistry Problems	3.824 ± 0.809	4.588 ± 0.618	0.765
60,61	Understand the Chemistry Underlying Lab Experiments	2.059 ± 0.827	4.676 ± 0.466	2.618
62,63	Perform Lab Experiments	2.059 ± 1.029	4.647 ± 0.493	2.588
64,65	Visualize Key Concepts of Chemistry	2.882 ± 0.857	4.529 ± 0.717	1.647
66,67	Apply your Knowledge of Chemistry to the Real World	2.176 ± 0.883	4.765 ± 0.437	2.588
68,69	Understand Other Areas of Science	3.000 ± 0.612	4.176 ± 0.636	1.176
70, 71	Succeed in Another Chemistry Course	3.235 ± 0.903	4.471 ± 0.514	1.235
72,73	Succeed in a Chemistry-Related Discipline	2.882 ± 0.993	4.706 ± 0.470	1.824

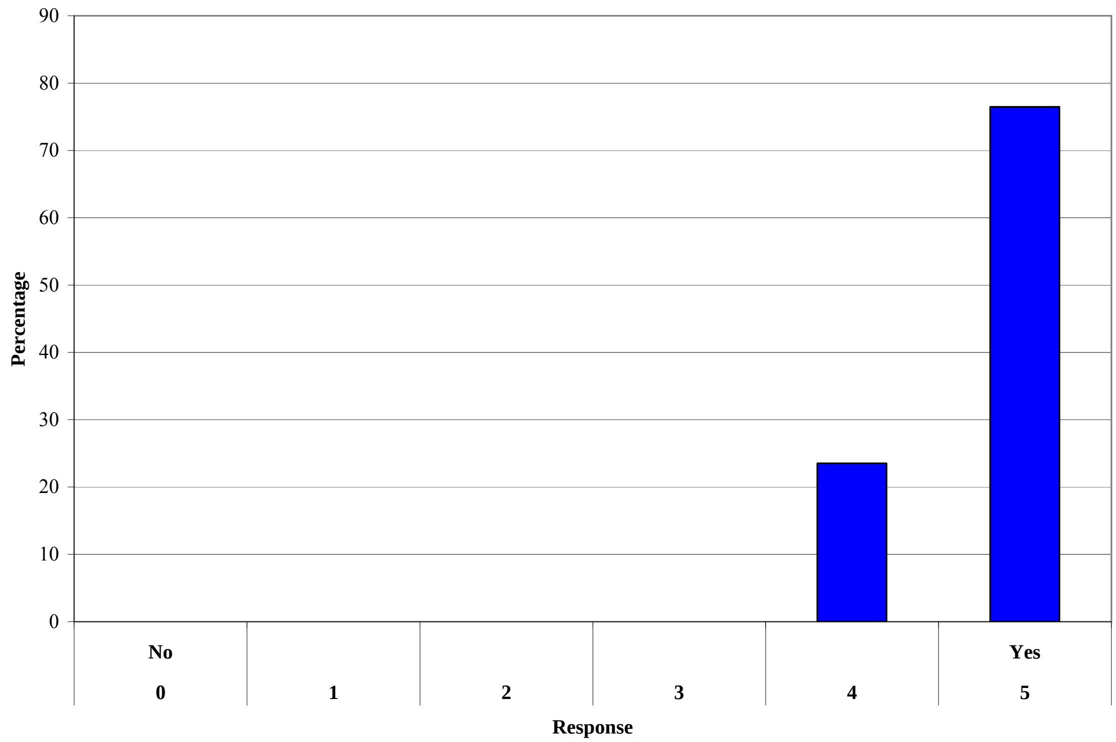
Table 7 appears on the next page.

Table 7: Student Self-Reported Interest, Spring 1998

Items	Statement	Before	After	Change
74,75	Studying Chemistry in General	2.765 ± 1.562	4.353 ± 0.702	1.588
76,77	Taking More Chemistry	2.765 ± 1.437	4.176 ± 0.951	1.412
78,79	Pursuing a Chemistry-Related Major	2.529 ± 1.875	3.353 ± 1.693	0.824
80,81	Pursuing a Science-Related Field	4.176 ± 1.380	4.529 ± 1.281	0.353
82,83	Working with Others to Learn Science	3.412 ± 1.460	4.294 ± 0.772	0.882
84,85	Chemistry in Industry	1.412 ± 1.064	2.941 ± 1.560	1.529
86,87	Chemistry in Agriculture	1.471 ± 1.586	2.529 ± 1.736	1.059
88,89	Chemistry in Medicine	3.706 ± 1.490	4.882 ± 0.332	1.176
90,91	Chemistry in Athletics	1.882 ± 1.453	2.941 ± 1.391	1.059
92,93	Chemistry in the Environment	2.529 ± 1.586	3.706 ± 1.312	1.176
94,95	Science in General	4.235 ± 0.831	4.941 ± 0.243	0.706

In addition to the positive response to the course from the Confidence and Interest questions on the survey, students also responded overwhelmingly positively toward Question 113 on the survey, namely "Would you recommend this course to a friend?" A histogram of student responses is shown in Figure 2.

Figure 2: Histogram of "Would you recommend to a friend?" in Spring 1998



The survey result reflects a very positive impression of the course on the part of the students.

Student Persistence

Although 2 of the original 19 students ultimately did not complete the course in Spring 1998, the remaining 17 did finish the course successfully which is defined as a passing grade, A, B, or C, as shown in Table 8.

Table 8: Spring 1998 Grades

	A	B	C	CR	D	F	Q	W	Students	% Success
Experimental	5	8	4	0	0	0	2	0	19	89.5%

This result suggested that beginning chemistry students would be able to understand and master the content of the new course.

Interviews

Dr. Stewart asked students for commentary on the course and also asked two Biochemistry faculty members to review the course and to speak to students privately about the course. One of the students described the course as "rewarding" while one of the faculty members remarked that he had "never seen a group of students so enthusiastic about a course in my 13 years here" at The University of Texas at Austin. The combination of survey data, student interviews, and faculty reviews of the course indicated that the course was successful by the accepted measures of success. Consequently, the Department decided to offer the course again, but with an expansion to 4 sections, in Fall 1998.

OVERVIEW OF THE ANALYSIS FROM FALL 1998 THROUGH SPRING 2001

Having taught the course for one semester, we believed that the new course was ready for comparison to the standard General Chemistry course offered by the University. For the evaluation of the laboratory courses, several factors were considered. These factors include:

1. The previously mentioned surveys, appearing as Appendices A, B, C and D, which were administered to students in both the standard laboratory courses (CH 204) which was the control and one experimental course (CH 204AV);
2. Drop and withdraw data for both laboratory courses;
3. Enrollment history in research courses subsequent to enrollment in both laboratory courses;
4. Data on retention in the sciences and Engineering for both laboratory courses.

   Each of these factors are discussed in turn.

Survey Data

The survey, as previously described, changed several times during the course of the experiment. The original survey, appearing as Appendix A, was perceived as being too long and was not readily completed by students. In addition, several items on the survey specifically asked questions about the instructional staff. These questions were removed for the next version of the survey, as well as questions that required a written response to "Other".

Version B of the survey, appearing as Appendix B, was the first that was machine-scored in an effort to reach a larger number of students. One of the consequences of machine scoring was the need to change some of scales present in the original version of the survey: the answer scale on the original survey had to be adjusted to the scale available on the mark-sense forms. Some of the questions had evaluations of "0", implying "Not Applicable", while others had "0" implying "Low". The mark sense forms in use by the Department of Chemistry and Biochemistry did not have a 0 as an option, so 0 "Not Applicable" was removed and other questions that had 0 "Low" were uniformly scaled from 1 (low) to 5 (high). Some of the original questions on Version A were scaled as high as 7, but all questions were rescaled to a maximum response value of 5, as the mark-sense forms in use did not allow a response larger than 5. Activity questions about "discussion/problem sessions" were changed to "computer lab" as the structure of both the control and experimental courses did not have a problem session but a weekly computer laboratory session instead. Version B also removed all items in reference to people (primarily, the instructional staff, but occasionally other students as well), a question about citizenship, and questions about Interest in Chemistry in Agriculture and Interest in Chemistry in Athletics. One new question was added: "The organization of the labs was important for my learning." This version of the survey was employed *only* in Spring 1999.

In an effort to further streamline the survey, Version C removed the original "Before" and "After" configuration for the Confidence in Ability and Interest items and only structured questions in the "After" Sense. Questions about "Materials" associated with the course were also removed. Four questions were added: one asking when students took the associated General Chemistry lecture course, two questions on the relationship to the lecture to the laboratory course, and one question probing student impression of the value of laboratory course. This version of the survey was in use for 3 semesters, from Fall 1999 through Fall 2000.

Version D, only in use for the last semester, rearranged the order of questions in Version C, and added four additional questions: one on student impression of taught laboratory skills and their relationship to student perceived goals and three questions about what resources were valuable towards success in the course.

In order to make comparisons between semesters, only those common questions which appeared in all versions of the survey are ultimately analyzed here, although the raw data for each of the items are presented for the reader's convenience in the Appendices.

Drop and Withdraw Data

In addition to the survey data, student add/drop data were collected for the experimental course and the control course in Summer 2005. Students may drop a course at The University of Texas at Austin without penalty until the twelfth class day. On the twelfth class day, course rosters become fixed. Students are permitted to drop courses from the thirteenth through the twentieth class day with approval from his/her dean; in this instance a "Q" (Drop) is recorded on the student's grade report. Beyond the twentieth class day until mid-semester, students may only withdraw from a class with permission of his/ her instructor, advisor, and dean. In these cases, either a "W" (Withdraw) or "WF" (Withdraw Failing) is assigned. No evaluation of "WF" was given to any student in either of the two courses at any time from Fall 1998 through Spring 2001. Data for each of the semesters under study is presented in subsequent sections of this chapter.

Longitudinal Studies

One of the chief goals of laboratory instruction is to interest students in a science career. We hypothesized that if students became interested in a science career as a result of having been in a laboratory course, they would express this interest by:

1. doing research in an undergraduate research course later in their undergraduate career.
2. remaining in a science or engineering major.

To determine if these hypotheses were true, in Summer 2005 we obtained data on students in both the experimental and control courses. Since the overwhelming majority of students who took these courses should have graduated as of this writing, an analysis of the data would be instructive.

Not all of the students who finished the two courses in finished them successfully. Consequently, longitudinal studies are performed only on students who finished course with an A, B, C, or CR (Credit). Summaries of each of the semesters are presented in the relevant sections.

Enrollment in Research Courses

The University of Texas at Austin offers research courses in many areas within the College of Natural Sciences. Given that the majority of students taking General Chemistry laboratories are Biology majors, it is reasonable to assume that these students might pursue research in Biology or perhaps Chemistry. The numbers of students who enrolled in upper-division research courses in Biology and Chemistry are compiled and presented in the tables for each semester.

Retention in Science and Engineering Majors

A reasonable question is if the successful students from the two courses remain in a science or engineering major. The College of Natural Sciences at The University of Texas at Austin offers Bachelor's degree programs in Chemistry and Biochemistry, Astronomy, Biology (including Botany, Zoology, Ecology, Microbiology, Nutrition, and Evolution), Computer Sciences, Geological Sciences, Mathematics, and Physics. Some students are also in the College of Natural Sciences and had not yet chosen a major at the time of their enrollment in General Chemistry laboratory. For purposes of this study, all of these majors are consolidated into "Science" majors. The College of Engineering offers concentrations in Aerospace, Architectural, Chemical, Civil, Electrical, Geosystems, Mechanical, and Petroleum Engineering. As in the case of the Natural Sciences, there are also students in the College of Engineering who had not yet chosen a major at the time of their enrollment in General Chemistry laboratory. All students within the College of Engineering are consolidated into "Engineering" majors. The enrollments on the twelfth class day, by college, of the students who successfully completed either the experimental or control course are outlined for each semester, in turn.

In addition, although the course was taught for six semesters beyond the time that the pilot study was performed, changes to the structure of the course took place over that time. Some of these changes were instituted by us, and some were imposed by a division of the University. The decision to offer the experimental course came so late in Fall 1998 that students were not advised of the change until classes started. As a consequence, a reasonably random student distribution occurred between the control and experimental courses for that semester. Beyond that time, within the University's listing of course offerings, a statement that "Intended for Life Science majors" appeared with the experimental sections. In Fall 2000, in an effort to better understand how the instructor impacted the course, the head teaching assistant for the course acted as the course's instructor. In Spring 2000, one of the teaching assistants assigned to the experimental course also had an assignment in the control course. This fortuitous circumstance allows us to assess what impact the teaching assistant has, if any, on student impression of the laboratory course. Further, an at-risk student group was placed in the experimental course in Fall 2000 and Spring 2001. This group, as part of a project developed by the College of Natural Sciences called PENS (Partnership for Excellence in the Natural Sciences), was composed of primarily first-generation college students coming from high schools which were typically underrepresented at The University of Texas at Austin. These students took the same courses other Natural Sciences students took but in sections, intentionally kept small, unique to them. Additionally, these students received additional support from the College of Natural Sciences in the form of a tutor assigned to each class that was part of the program. The PENS group provides us an opportunity to evaluate the effectiveness of the experimental course on an at-risk student population. The changes in the course over time are summarized in Table 9, below.

Table 9: Variations of the Experimental Course from Fall 1998 to Spring 2001

Term	Random Student Enrollment	Instructor	Teaching Assistant	PENS
Fall 1998	Yes	Original	Unique to each course	No
Spring 1999	No	Original	Unique to each course	No
Fall 1999	No	Original	Unique to each course	No
Spring 2000	No	Original	One TA assigned to both courses, otherwise unique to each course	No
Fall 2000	No	Head TA	Unique to each course	Yes
Spring 2001	No	Original	Unique to each course	Yes

In order to better understand the impact of each of these variations on the laboratory courses, five analyses are performed.

1. A simple control versus experimental comparison for Fall 1998, which was the semester in which the student distribution is as random as it likely can be.

2. Control versus experimental comparison for Spring 1999, Fall 1999, Spring 2000, and Spring 2001, semesters in which the original instructor taught the experimental course. Students who are in special circumstances (the common teaching assistant or part of PENS) are excluded from this analysis.
3. Control versus experimental for students in the two sections in Spring 2000 which were taught by the common teaching assistant.
4. Control versus experimental for Fall 2000, the semester in which a different instructor taught the experimental course.
5. Experimental versus PENS in Fall 2000 and Spring 2001.

The analyses follow, in turn, over the course of the next several sections.

FALL 1998

The second semester that CH 204 AV was taught included an expansion of the number of sections that were offered. As part of this expansion, two teaching assistants handled the duties of instruction in the laboratory sections, and the instructor remained in charge of the associated laboratory lecture. As the Department's decision to allow the course to be taught came within a few days of the beginning of classes, 4 sections of the existing CH 204 laboratory were selected to be taught as CH 204AV. This fortunate circumstance assured a reasonably random distribution of students to be placed in the experimental and control courses, as students would not have been aware of the identity of the laboratory identity at the time of their registration. Survey data was collected from the 4 CH 204AV (experimental) sections and 4 sections of CH 204 (control) taught by experienced teaching assistants in the same time slots as the CH 204AV sections. Additionally, drop and withdraw, persistence in Science and Engineering majors, and future enrollment in research course data were collected in Summer 2005 on all sections of the courses to assess immediate and longitudinal effects of the two courses on student enrollment patterns. These data are presented in the following sections.

Survey Data

The survey used in Fall 1998, Version A, was the same used in Spring 1998. Forms were hand-marked by students and were later coded by the author of this dissertation. 48 surveys were obtained from the control group and 65 surveys were obtained from the experimental group. Different scales were used for different groups of questions; therefore, comparisons in the absolute scores between items may be misleading, but comparison of responses from the two student groups on the same survey item may be illustrative of a difference in student opinion. Presented here are the survey responses for the common questions, as defined in Appendix E. The complete set of survey responses, along with the original numbering, is presented in Appendix F. For items 10 through 24, a rating of "0" implies "Not Applicable" and as such, was not included in the average rating. These questions were scaled from 1 (negative) to 7 (positive). For the remaining questions, "0" implies "Strongly Disagree" and was included in the average rating. These were scaled from 0 (Strongly Disagree) to 5 (Strongly Agree). Average ratings are presented in Table 10 below.

Table 10: Common Questions from Survey for Control versus Experimental, Fall 1998

New #	Statement	Control	Experimental
	IMPACT ON LEARNING		
10	Activities: Lab Lecture	4.435 ± 1.734	4.177 ± 1.553
11	Activities: Wet Lab	4.729 ± 1.783	5.766 ± 0.938
12	Activities: Exams	4.061 ± 1.870	5.391 ± 1.280
13	Activities: Quizzes	3.955 ± 1.904	5.203 ± 1.250

Table 10 continues on the next page

Table 10, continued

New #	Statement	Control	Experimental
14	Activities: Homework/Exercises	4.182 ± 1.920	5.500 ± 1.168
	IMPACT ON CONFIDENCE		
15	Activities: Lab Lecture	4.213 ± 1.641	4.476 ± 1.490
16	Activities: Wet Lab	4.458 ± 1.901	5.387 ± 1.486
17	Activities: Exams	3.485 ± 2.017	4.938 ± 1.661
18	Activities: Quizzes	3.795 ± 1.837	4.723 ± 1.709
19	Activities: Homework/Exercises	3.816 ± 1.887	5.000 ± 1.560
	IMPACT ON ENTHUSIASM		
20	Activities: Lab Lecture	3.652 ± 1.741	4.254 ± 1.685
21	Activities: Wet Lab	4.234 ± 2.013	5.302 ± 1.613
22	Activities: Exams	3.250 ± 1.867	4.554 ± 1.687
23	Activities: Quizzes	3.143 ± 1.855	4.462 ± 1.687
24	Activities: Homework/Exercises	3.277 ± 1.850	4.594 ± 1.571
	CONFIDENCE IN YOUR ABILITY TO…		
25	Understand Key Concepts of Chemistry	3.478 ± 1.027	3.754 ± 1.031
26	Solve Chemistry Problems	3.422 ± 1.158	3.708 ± 1.011
27	Understand the Chemistry Underlying Lab Experiments	3.478 ± 1.260	4.016 ± 0.852
28	Perform Lab Experiments	3.889 ± 1.112	3.954 ± 1.082
29	Visualize Key Concepts of Chemistry	3.489 ± 1.058	3.631 ± 0.961
30	Apply your Knowledge of Chemistry to the Real World	3.239 ± 1.303	3.446 ± 1.186
31	Understand Other Areas of Science	3.043 ± 1.228	3.692 ± 0.951
32	Succeed in Another Chemistry Course	3.304 ± 1.245	3.492 ± 1.239

Table 10 continues on the next page

Table 10, continued

New #	Statement	Control	Experimental
33	Succeed in a Chemistry-Related Discipline	3.178 ± 1.173	3.400 ± 1.321
	INTEREST IN..		
34	Studying Chemistry in General	3.106 ± 1.220	3.077 ± 1.315
35	Taking More Chemistry	2.915 ± 1.231	2.815 ± 1.467
36	Pursuing a Chemistry-Related Major	2.277 ± 1.741	2.092 ± 1.627
37	Pursuing a Science-Related Field	3.681 ± 1.321	4.000 ± 1.118
38	Working with Others to Learn Science	3.809 ± 1.209	3.662 ± 1.253
39	Chemistry in Industry	2.085 ± 1.282	2.400 ± 1.589
40	Chemistry in Medicine	3.511 ± 1.586	3.938 ± 1.180
41	Chemistry in the Environment	2.617 ± 1.497	3.000 ± 1.521
42	Science in General	3.638 ± 1.293	4.123 ± 0.910
	IMPRESSIONS OF LECTURE		
43	I enjoyed the formal laboratory (1 hour) lectures.	2.000 ± 1.549	2.308 ± 1.560
44	The organization of the lectures was important for my learning.	2.739 ± 1.769	2.708 ± 1.476
45	The applications of chemistry discussed in this course made certain concepts easier to understand.	2.644 ± 1.612	3.323 ± 1.324
46	The applications of chemistry discussed in this course made learning chemistry interesting.	2.591 ± 1.661	3.246 ± 1.287
	IMPRESSIONS OF LABS		
47	I enjoyed the labs.	2.681 ± 1.617	3.246 ± 1.347
48	I understood the chemistry behind the labs before I did them.	2.652 ± 1.433	2.446 ± 1.212

Table 10 continues on the next page

Table 10, continued

New #	Statement	Control	Experimental
49	Eventually I understood the chemistry behind the labs.	3.370 ± 1.323	3.875 ± 0.968
50	The labs helped me understand important concepts in this course.	3.043 ± 1.429	3.723 ± 1.023
51	Enough time was allowed for labs.	3.196 ± 1.721	4.338 ± 0.889
	GENERAL QUESTION		
52	Would you recommend this course to a friend?	1.522 ± 1.683	3.477 ± 1.501

A Multiple Analysis of Variance (MANOVA) is utilized, using the single independent variable "q1" (which is course identity) and each of the 43 questions “q10” through “q52” (following the common numbering scheme) as dependent variables. A MANOVA is chosen rather than running individual ANOVA (Analysis of Variance) tests for each dependent variable as one could reasonably assume that the dependent variables may be correlated to each other. Standard assumptions for MANOVA were considered, the ones of primary interest being: (1) the dependent variables should be quantitative, (2) data are drawn from a population which has normally distributed dependent variables, (3) in the population, the variance-covariance matrices for all cells are the same. In order to control the Type I error rate (finding significance through statistical tests when significance, in fact, does not exist), a Bonferroni correction was applied, so that the desired α level of 0.05 was adjusted to 0.05/43 = 0.00116. Failure to meet the assumption of homogeneity of covariances is not necessarily fatal to MANOVA, assuming that the samples were of similar size. Of the 113 surveys that were submitted, only 15 students in the control course and 52 in the experimental course completed all items within the survey. Uncompleted surveys were not analyzed.

With the described caveats, the overall MANOVA is shown in Table 11.

Table 11: Overall MANOVA on Survey Data, Fall 1998

Multivariate Tests(b)

Effect		Value	F	Hypothesis df	Error df	Sig.
Intercept	Pillai's Trace	.990	52.223(a)	43.000	23.000	.000
	Wilks' Lambda	.010	52.223(a)	43.000	23.000	.000
	Hotelling's Trace	97.635	52.223(a)	43.000	23.000	.000
	Roy's Largest Root	97.635	52.223(a)	43.000	23.000	.000
Q1	Pillai's Trace	.786	1.961(a)	43.000	23.000	.043
	Wilks' Lambda	.214	1.961(a)	43.000	23.000	.043
	Hotelling's Trace	3.667	1.961(a)	43.000	23.000	.043
	Roy's Largest Root	3.667	1.961(a)	43.000	23.000	.043

a Exact statistic
b Design: Intercept+Q1

The null hypothesis is that there is no difference in how the two groups respond to the survey. An α level is 0.05 is chosen, and since the observed significance, 0.00, is less than this value, the null hypothesis is rejected and we can conclude that the two groups responded differently to the survey. With an overall effect having been verified, the individual dependent variables can be checked, as shown in Table 12 beginning on the following page.

Table 12: MANOVA Survey Results, Fall 1998

Tests of Between-Subjects Effects

Source	Dependent Variable	Type III Sum of Squares	df	Mean Square	F	Sig.
Corrected Model	Q10	11.792(a)	1	11.792	5.861	.01828
	Q11	1.003(b)	1	1.003	1.001	.32084
	Q12	9.619(c)	1	9.619	4.717	.03353
	Q13	4.227(d)	1	4.227	2.057	.15629
	Q14	.442(e)	1	.442	.252	.61709
	Q15	3.996(f)	1	3.996	1.999	.16212
	Q16	4.520(g)	1	4.520	1.824	.18156
	Q17	12.524(h)	1	12.524	3.985	.05009
	Q18	2.822(i)	1	2.822	.884	.35060
	Q19	2.955(j)	1	2.955	1.143	.28905
	Q20	.926(k)	1	.926	.355	.55344
	Q21	3.738(l)	1	3.738	1.643	.20453
	Q22	10.907(m)	1	10.907	4.236	.04360
	Q23	5.559(d)	1	5.559	2.047	.15734
	Q24	3.154(n)	1	3.154	1.239	.26981
	Q25	.011(o)	1	.011	.011	.91582
	Q26	.158(p)	1	.158	.140	.70934
	Q27	.271(q)	1	.271	.362	.54973
	Q28	.086(r)	1	.086	.080	.77839
	Q29	.042(s)	1	.042	.051	.82285
	Q30	.289(t)	1	.289	.213	.64612
	Q31	.370(u)	1	.370	.411	.52349
	Q32	1.416(b)	1	1.416	.987	.32418
	Q33	.294(t)	1	.294	.186	.66768
	Q34	1.075(v)	1	1.075	.684	.41120
	Q35	5.518(w)	1	5.518	2.982	.08894
	Q36	10.994(m)	1	10.994	4.232	.04368
	Q37	1.084(x)	1	1.084	.893	.34805
	Q38	1.711(y)	1	1.711	1.332	.25269
	Q39	1.395(z)	1	1.395	.575	.45113
	Q40	2.634(aa)	1	2.634	1.607	.20950
	Q41	9.947(bb)	1	9.947	4.078	.04758
	Q42	1.875(cc)	1	1.875	1.716	.19476
	Q43	2.691(y)	1	2.691	1.335	.25208
	Q44	1.084(dd)	1	1.084	.547	.46231
	Q45	.031(o)	1	.031	.017	.89692

Table 12 continues on the next page

Table 12, continued

Source	Dependent Variable	Type III Sum of Squares	df	Mean Square	F	Sig.
	Q46	.641(u)	1	.641	.402	.52837
	Q47	.868(dd)	1	.868	.517	.47449
	Q48	8.667(a)	1	8.667	5.902	.01790
	Q49	.176(ee)	1	.176	.173	.67845
	Q50	.122(ff)	1	.122	.101	.75127
	Q51	5.831(gg)	1	5.831	4.943	.02969
	Q52	10.253(hh)	1	10.253	4.369	.04050
Intercept	Q10	1086.418	1	1086.418	539.987	.000
	Q11	1502.436	1	1502.436	1498.387	.000
	Q12	1158.514	1	1158.514	568.069	.000
	Q13	1149.302	1	1149.302	559.316	.000
	Q14	1339.905	1	1339.905	764.944	.000
	Q15	1061.190	1	1061.190	530.946	.000
	Q16	1216.699	1	1216.699	490.932	.000
	Q17	895.509	1	895.509	284.981	.000
	Q18	920.553	1	920.553	288.398	.000
	Q19	1007.732	1	1007.732	389.620	.000
	Q20	953.762	1	953.762	365.445	.000
	Q21	1267.261	1	1267.261	556.818	.000
	Q22	802.251	1	802.251	311.524	.000
	Q23	826.216	1	826.216	304.168	.000
	Q24	898.915	1	898.915	353.043	.000
	Q25	666.996	1	666.996	681.349	.000
	Q26	675.382	1	675.382	597.412	.000
	Q27	723.972	1	723.972	966.008	.000
	Q28	736.265	1	736.265	684.515	.000
	Q29	638.609	1	638.609	763.386	.000
	Q30	577.364	1	577.364	424.403	.000
	Q31	611.056	1	611.056	680.039	.000
	Q32	589.834	1	589.834	411.184	.000
	Q33	534.264	1	534.264	337.779	.000
	Q34	491.284	1	491.284	312.707	.000
	Q35	434.831	1	434.831	234.999	.000
	Q36	278.935	1	278.935	107.374	.000
	Q37	703.173	1	703.173	579.614	.000
	Q38	723.502	1	723.502	563.317	.000
	Q39	219.902	1	219.902	90.599	.000
	Q40	639.052	1	639.052	389.811	.000
	Q41	313.708	1	313.708	128.601	.000
	Q42	720.681	1	720.681	659.861	.000

Table 12 continues on the next page

Table 12, continued

Source	Dependent Variable	Type III Sum of Squares	df	Mean Square	F	Sig.
	Q43	354.631	1	354.631	175.988	.000
	Q44	451.591	1	451.591	227.800	.000
	Q45	525.404	1	525.404	290.300	.000
	Q46	564.820	1	564.820	354.178	.000
	Q47	558.599	1	558.599	332.981	.000
	Q48	374.338	1	374.338	254.912	.000
	Q49	694.385	1	694.385	682.909	.000
	Q50	643.705	1	643.705	532.569	.000
	Q51	727.980	1	727.980	617.118	.000
	Q52	438.671	1	438.671	186.946	.000
Q1	Q10	11.792	1	11.792	5.861	.018
	Q11	1.003	1	1.003	1.001	.321
	Q12	9.619	1	9.619	4.717	.034
	Q13	4.227	1	4.227	2.057	.156
	Q14	.442	1	.442	.252	.617
	Q15	3.996	1	3.996	1.999	.162
	Q16	4.520	1	4.520	1.824	.182
	Q17	12.524	1	12.524	3.985	.050
	Q18	2.822	1	2.822	.884	.351
	Q19	2.955	1	2.955	1.143	.289
	Q20	.926	1	.926	.355	.553
	Q21	3.738	1	3.738	1.643	.205
	Q22	10.907	1	10.907	4.236	.044
	Q23	5.559	1	5.559	2.047	.157
	Q24	3.154	1	3.154	1.239	.270
	Q25	.011	1	.011	.011	.916
	Q26	.158	1	.158	.140	.709
	Q27	.271	1	.271	.362	.550
	Q28	.086	1	.086	.080	.778
	Q29	.042	1	.042	.051	.823
	Q30	.289	1	.289	.213	.646
	Q31	.370	1	.370	.411	.523
	Q32	1.416	1	1.416	.987	.324
	Q33	.294	1	.294	.186	.668
	Q34	1.075	1	1.075	.684	.411
	Q35	5.518	1	5.518	2.982	.089
	Q36	10.994	1	10.994	4.232	.044
	Q37	1.084	1	1.084	.893	.348
	Q38	1.711	1	1.711	1.332	.253
	Q39	1.395	1	1.395	.575	.451

Table 12 continues on the next page

Table 12, continued

Source	Dependent Variable	Type III Sum of Squares	df	Mean Square	F	Sig.
	Q40	2.634	1	2.634	1.607	.209
	Q41	9.947	1	9.947	4.078	.048
	Q42	1.875	1	1.875	1.716	.195
	Q43	2.691	1	2.691	1.335	.252
	Q44	1.084	1	1.084	.547	.462
	Q45	.031	1	.031	.017	.897
	Q46	.641	1	.641	.402	.528
	Q47	.868	1	.868	.517	.474
	Q48	8.667	1	8.667	5.902	.018
	Q49	.176	1	.176	.173	.678
	Q50	.122	1	.122	.101	.751
	Q51	5.831	1	5.831	4.943	.030
	Q52	10.253	1	10.253	4.369	.041
Error	Q10	130.776	65	2.012		
	Q11	65.176	65	1.003		
	Q12	132.560	65	2.039		
	Q13	133.564	65	2.055		
	Q14	113.856	65	1.752		
	Q15	129.914	65	1.999		
	Q16	161.092	65	2.478		
	Q17	204.253	65	3.142		
	Q18	207.477	65	3.192		
	Q19	168.119	65	2.586		
	Q20	169.641	65	2.610		
	Q21	147.933	65	2.276		
	Q22	167.391	65	2.575		
	Q23	176.560	65	2.716		
	Q24	165.503	65	2.546		
	Q25	63.631	65	.979		
	Q26	73.483	65	1.131		
	Q27	48.714	65	.749		
	Q28	69.914	65	1.076		
	Q29	54.376	65	.837		
	Q30	88.427	65	1.360		
	Q31	58.406	65	.899		
	Q32	93.241	65	1.434		
	Q33	102.810	65	1.582		
	Q34	102.119	65	1.571		
	Q35	120.273	65	1.850		
	Q36	168.856	65	2.598		

Table 12 continues on the next page

Table 12, continued

Source	Dependent Variable	Type III Sum of Squares	df	Mean Square	F	Sig.
	Q37	78.856	65	1.213		
	Q38	83.483	65	1.284		
	Q39	157.769	65	2.427		
	Q40	106.560	65	1.639		
	Q41	158.560	65	2.439		
	Q42	70.991	65	1.092		
	Q43	130.981	65	2.015		
	Q44	128.856	65	1.982		
	Q45	117.641	65	1.810		
	Q46	103.658	65	1.595		
	Q47	109.042	65	1.678		
	Q48	95.453	65	1.469		
	Q49	66.092	65	1.017		
	Q50	78.564	65	1.209		
	Q51	76.677	65	1.180		
	Q52	152.523	65	2.347		
Total	Q10	1531.000	67			
	Q11	2290.000	67			
	Q12	1981.000	67			
	Q13	1904.000	67			
	Q14	2081.000	67			
	Q15	1559.000	67			
	Q16	2036.000	67			
	Q17	1679.000	67			
	Q18	1617.000	67			
	Q19	1709.000	67			
	Q20	1496.000	67			
	Q21	2086.000	67			
	Q22	1486.000	67			
	Q23	1481.000	67			
	Q24	1548.000	67			
	Q25	1019.000	67			
	Q26	1029.000	67			
	Q27	1113.000	67			
	Q28	1142.000	67			
	Q29	965.000	67			
	Q30	899.000	67			
	Q31	962.000	67			
	Q32	898.000	67			
	Q33	852.000	67			

Table 12 continues on the next page

Table 12, continued

Source	Dependent Variable	Type III Sum of Squares	df	Mean Square	F	Sig.
	Q34	774.000	67			
	Q35	676.000	67			
	Q36	498.000	67			
	Q37	1136.000	67			
	Q38	1071.000	67			
	Q39	504.000	67			
	Q40	1095.000	67			
	Q41	713.000	67			
	Q42	1169.000	67			
	Q43	596.000	67			
	Q44	745.000	67			
	Q45	880.000	67			
	Q46	887.000	67			
	Q47	879.000	67			
	Q48	556.000	67			
	Q49	1083.000	67			
	Q50	1019.000	67			
	Q51	1236.000	67			
	Q52	905.000	67			
Corrected Total	Q10	142.567	66			
	Q11	66.179	66			
	Q12	142.179	66			
	Q13	137.791	66			
	Q14	114.299	66			
	Q15	133.910	66			
	Q16	165.612	66			
	Q17	216.776	66			
	Q18	210.299	66			
	Q19	171.075	66			
	Q20	170.567	66			
	Q21	151.672	66			
	Q22	178.299	66			
	Q23	182.119	66			
	Q24	168.657	66			
	Q25	63.642	66			
	Q26	73.642	66			
	Q27	48.985	66			
	Q28	70.000	66			
	Q29	54.418	66			
	Q30	88.716	66			

Table 12 continues on the next page

Table 12, continued

Source	Dependent Variable	Type III Sum of Squares	df	Mean Square	F	Sig.
	Q31	58.776	66			
	Q32	94.657	66			
	Q33	103.104	66			
	Q34	103.194	66			
	Q35	125.791	66			
	Q36	179.851	66			
	Q37	79.940	66			
	Q38	85.194	66			
	Q39	159.164	66			
	Q40	109.194	66			
	Q41	168.507	66			
	Q42	72.866	66			
	Q43	133.672	66			
	Q44	129.940	66			
	Q45	117.672	66			
	Q46	104.299	66			
	Q47	109.910	66			
	Q48	104.119	66			
	Q49	66.269	66			
	Q50	78.687	66			
	Q51	82.507	66			
	Q52	162.776	66			

a R Squared = .083 (Adjusted R Squared = .069)
b R Squared = .015 (Adjusted R Squared = .000)
c R Squared = .068 (Adjusted R Squared = .053)
d R Squared = .031 (Adjusted R Squared = .016)
e R Squared = .004 (Adjusted R Squared = -.011)
f R Squared = .030 (Adjusted R Squared = .015)
g R Squared = .027 (Adjusted R Squared = .012)
h R Squared = .058 (Adjusted R Squared = .043)
i R Squared = .013 (Adjusted R Squared = -.002)
j R Squared = .017 (Adjusted R Squared = .002)
k R Squared = .005 (Adjusted R Squared = -.010)
l R Squared = .025 (Adjusted R Squared = .010)
m R Squared = .061 (Adjusted R Squared = .047)
n R Squared = .019 (Adjusted R Squared = .004)
o R Squared = .000 (Adjusted R Squared = -.015)
p R Squared = .002 (Adjusted R Squared = -.013)
q R Squared = .006 (Adjusted R Squared = -.010)
r R Squared = .001 (Adjusted R Squared = -.014)
s R Squared = .001 (Adjusted R Squared = -.015)
t R Squared = .003 (Adjusted R Squared = -.012)
u R Squared = .006 (Adjusted R Squared = -.009)
v R Squared = .010 (Adjusted R Squared = -.005)

Table 12 continues on the next page

Table 12, continued

w R Squared = .044 (Adjusted R Squared = .029)
x R Squared = .014 (Adjusted R Squared = -.002)
y R Squared = .020 (Adjusted R Squared = .005)
z R Squared = .009 (Adjusted R Squared = -.006)
aa R Squared = .024 (Adjusted R Squared = .009)
bb R Squared = .059 (Adjusted R Squared = .045)
cc R Squared = .026 (Adjusted R Squared = .011)
dd R Squared = .008 (Adjusted R Squared = -.007)
ee R Squared = .003 (Adjusted R Squared = -.013)
ff R Squared = .002 (Adjusted R Squared = -.014)
gg R Squared = .071 (Adjusted R Squared = .056)
hh R Squared = .063 (Adjusted R Squared = .049)

The null hypothesis, in the case of each of the individual variables, is that there is no difference between the experimental and control groups. In no item on the survey is a significant difference found. There appears to be no difference between the two groups in terms of any of the variables we considered.

Drop and Withdraw Data

In Summer 2005, final course grade information for the control and experimental courses was obtained from the registrar of The University of Texas at Austin. Of particular interest was the number of students that either dropped (with a grade of Q) or withdrew (with a grade of W) from the control and experimental courses under study. This information is summarized in Table 13.

Table 13: Drops and Withdraws, Fall 1998

	Q	**W**	**Total Dropped**	**Students**	**% Dropped**
Control	26	8	34	314	10.8%
Experimental	1	2	3	78	3.9%

The number of students who dropped the course either with a "Q" or "W" were combined and compared to the number of students officially registered in the course on the twelfth class day. (Table 13) The percentage of students that dropped the control course is larger than for the experimental course in Fall 1998. To judge whether or not these observed differences are statistically significant, a χ^2 test is performed. Statistical significance is found at an α level of 0.05. The null hypothesis is that there is no difference in the drop rates between the two courses; if a difference is found, it must be due to the alternative hypothesis, that the identity of the course does impact the drop rate. Using SPSS, we are able to determine the statistical significance of our drop results.

For Fall 1998, as shown in Table 14, a total of 392 students were enrolled in the experimental and control courses at the twelfth class day.

Table 14: Drop-Withdraw Cases, Fall 1998

Case Processing Summary

	Cases					
	Valid		Missing		Total	
	N	Percent	N	Percent	N	Percent
Course * Total	392	100.0%	0	.0%	392	100.0%

Of these 392 students, 78 were enrolled in the experimental course and 314 were enrolled in the control course, as shown in Table 15.

Table 15: Drop – Withdraw Count, Fall 1998

Course * Total Crosstabulation

Count

		Total		
		Finished Course	Dropped or Withdrawn	Total
Course	Control	280	34	314
	Experimental	75	3	78
Total		355	37	392

A χ^2 analysis is then performed to determine statistical significance. An α level of 0.05 is selected. The null hypothesis is that there is no difference in the drop and withdraw rate of the students in the experimental course as compared to that of students in the control course. If the observed significance is less than 0.05, the null hypothesis is rejected in favor of the alternative hypothesis, which is that the drop and withdraw rates between the two courses are different. The χ^2 analysis is shown in Table 16.

Table 16: χ^2 analysis on Drop – Withdraw Data, Fall 1998

Chi-Square Tests

	Value	df	Asymp. Sig. (2-sided)	Exact Sig. (2-sided)	Exact Sig. (1-sided)
Pearson Chi-Square	3.563[b]	1	.059		
Continuity Correction[a]	2.793	1	.095		
Likelihood Ratio	4.282	1	.039		
Fisher's Exact Test				.081	.039
Linear-by-Linear Association	3.554	1	.059		
N of Valid Cases	392				

a. Computed only for a 2x2 table

b. 0 cells (.0%) have expected count less than 5. The minimum expected count is 7.
36.

According to the analysis, we fail to reject the null hypothesis as the observed significance (0.059 for the Pearson Chi-Square) exceeds the desired α level of 0.05. Thus, students in Fall 1998 are not more likely to drop or withdraw from the control course than the experimental course.

Longitudinal Studies

Longitudinal studies are best performed on students who completed the control and experimental courses successfully. Defining success as a final course grade of A, B, C, or CR, as described earlier, 265 of 314 students in the control group and 65 of 78 students in the experimental group were successful in Fall 1998. A breakdown of the grade distribution in Fall 1998 appears in Table 17.

Table 17: Final Course Grades, Fall 1998

	A	B	C	CR	D	F	Q	W	Students	% Success
Control	107	117	40	1	8	7	26	8	314	84.4%
Experimental	16	34	15	0	6	4	1	2	78	83.3%

It is on the group of successful students that the desired longitudinal studies are performed.

Enrollment in Research Courses

Compiling information obtained from the registrar at The University of Texas at Austin, Table 18 shows the number of successful students who took research courses in Chemistry or Biology after having been enrolled in either the experimental or control course in Fall 1998.

Table 18: Biology and Chemistry Research Enrollment, Fall 1998

	Took Biology or Chemistry Research	Did Not Take Biology or Chemistry Research	Successful Students	% Taking Research
Control	36	229	265	13.6%
Experimental	5	60	65	7.7%
Total	41	289	330	12.4%

A χ^2 analysis is then performed to determine if students from one of the two laboratory courses is more likely to enroll in Biology or Chemistry research courses. An α level of 0.05 is selected. The null hypothesis is that there is no difference in the number of students who subsequently enroll in Biology or Chemistry research courses in the experimental course as compared to students in the control course. If the observed significance is less than 0.05, the null hypothesis is rejected in favor of the alternative hypothesis, which is that students in one course enroll more frequently in subsequent Biology or Chemistry research courses than students in the other course. A summary of the enrollment information is found in Table 19.

Table 19: Biology and Chemistry Research Course Enrollment, Fall 1998

Course * ChemBio Crosstabulation

Count

		ChemBio		
		Did Not Take Chem or Bio Upper Div Research	Took Chem or Bio Upper Div Research	Total
Course	Control	229	36	265
	Experimental	60	5	65
Total		289	41	330

To determine statistical significance, a χ^2 analysis is performed and shown in Table 20.

Table 20: χ^2 analysis on Biology and Chemistry Research Course Enrollment, Fall 1998

Chi-Square Tests

	Value	df	Asymp. Sig. (2-sided)	Exact Sig. (2-sided)	Exact Sig. (1-sided)
Pearson Chi-Square	1.666[b]	1	.197		
Continuity Correction[a]	1.168	1	.280		
Likelihood Ratio	1.840	1	.175		
Fisher's Exact Test				.293	.138
Linear-by-Linear Association	1.661	1	.198		
N of Valid Cases	330				

a. Computed only for a 2x2 table

b. 0 cells (.0%) have expected count less than 5. The minimum expected count is 8. 08.

Based on the observed significance, we fail to reject the null hypothesis and conclude that students in the two courses are equally likely to enroll in Biology or Chemistry research courses subsequent to their having successfully completed their General Chemistry laboratory.

Broadening the research course selection to any upper division research course within the realm of the College of Natural Sciences, Table 21 focuses on Fall 1998.

Table 21: Natural Sciences Research Enrollment, Fall 1998

	Took Upper Division Research	**Did Not Take Upper Division Research**	**Successful Students**	**% Taking Research**
Control	41	224	265	15.5%
Experimental	8	57	65	12.3%
Total	49	281	330	14.8%

A χ^2 analysis is then performed to determine if one group of students is more likely to participate in an upper division Natural Sciences research course. An α level of 0.05 is selected. The null hypothesis is that there is no difference in the number of students who subsequently enroll in upper division Natural Sciences research courses in the experimental course as compared to students in the control course. If the observed significance is less than 0.05, the null hypothesis is rejected in favor of the alternative hypothesis, which is that students in one course enroll more frequently in subsequent upper division Natural Sciences research courses than students in the other course. A summary of the enrollment information is found in Table 22.

Table 22: Upper Division Natural Sciences Research Course Enrollment, Fall 1998

Course * AllUpperDiv Crosstabulation

Count

		AllUpperDiv		
		Did Not Take an Upper Div Research Course	Took an Upper Div Research Course	Total
Course	Control	224	41	265
	Experimental	57	8	65
Total		281	49	330

The χ^2 analysis is shown in Table 23.

Table 23: χ^2 analysis on Upper Division Natural Sciences Research Course Enrollment, Fall 1998

Chi-Square Tests

	Value	df	Asymp. Sig. (2-sided)	Exact Sig. (2-sided)	Exact Sig. (1-sided)
Pearson Chi-Square	.413[b]	1	.520		
Continuity Correction[a]	.201	1	.654		
Likelihood Ratio	.430	1	.512		
Fisher's Exact Test				.697	.336
Linear-by-Linear Association	.412	1	.521		
N of Valid Cases	330				

a. Computed only for a 2x2 table

b. 0 cells (.0%) have expected count less than 5. The minimum expected count is 9.65.

As in the case of considering only Biology and Chemistry research, we fail to reject the null hypothesis as the observed significance of 0.520 for the Pearson Chi-Square exceeds the desired α level of 0.05. We conclude that students in the two courses are equally likely to enroll in upper division Natural Sciences research courses subsequent to their having successfully completed their General Chemistry laboratory.

Retention in Science and Engineering Majors

A reasonable question is if the 330 successful students in Fall 1998 remain in a science or engineering major. Defining science and engineering majors as before, the enrollment on the twelfth class day, by college, of the students who successfully completed either the experimental or control course in Fall 1998 is outlined in Table 24.

Table 24: Enrollment by College, Fall 1998

	Control	**Experimental**	**Total**
Architecture	1	0	1
Business	5	1	6
Communication	2	1	3
Education	7	1	8
Engineering	31	9	40
Fine Arts	3	2	5
Liberal Arts	40	2	42
Natural Sciences	176	49	225
Nursing	0	0	0
Pharmacy	0	0	0
Social Work	0	0	0
Total	265	65	330

As Table 24 shows, in Fall 1998, 225 (68.2%) of the 330 successful students in the experimental and control courses were in the College of Natural Sciences at the beginning of their laboratory experience. An additional 40 (12.1%) were in the College of Engineering. In sum, 265 (80.3%) of the students in the two courses were represented by these two colleges. It is this combination of students that are of special interest for this study. Most of these students remained as Science or Engineering majors, although some eventually became Pharmacy majors. Since Pharmacy is related to both Biology and Chemistry, and since students cannot enter The University as first-year Pharmacy majors but rather transfer into the school after having taken two years of pre-professional coursework, these students are also considered as having been retained, but as Pharmacy majors. Table 25 shows the number of students who began as Natural Science majors and who were retained as Natural Science, Engineering, or Pharmacy majors in Fall 1998 for both the experimental and control courses.

Table 25: Natural Sciences Retention, Fall 1998

	At start of Laboratory	**Ending Science**	**Ending Eng.**	**Ending Pharm.**	**Total Retained**	**% Retained**
Control	176	129	3	6	138	78.4%
Experimental	49	31	2	2	35	71.4%

Likewise, Table 26 shows retention data for Engineering majors in Fall 1998.

Table 26: Engineering Retention, Fall 1998

	At start of Laboratory	**Ending Science**	**Ending Eng.**	**Ending Pharm.**	**Total Retained**	**% Retained**
Control	31	7	22	0	29	93.5%
Experimental	9	2	7	0	9	100%

In sum, 79.6% of successful students are retained as Science and Engineering majors, as shown in Table 27.

Table 27: Total Natural Sciences and Engineering Retention, Fall 1998

	At start of Laboratory	**Ending Science**	**Ending Eng.**	**Ending Pharm.**	**Total Retained**	**% Retained**
Control	207	136	25	6	167	80.7%
Experimental	58	33	9	2	44	75.9%
Total	265	169	34	8	211	79.6%

A χ^2 analysis is then performed to determine if students in one group are more likely to be retained as Science or Engineering majors. An α level of 0.05 is selected. The null hypothesis is that there is no difference in the retention rate as Science, Engineering, and Pharmacy majors for students in the experimental course as compared to the retention rate of the students in the control course. If the observed significance is less than 0.05, the null hypothesis is rejected in favor of the alternative hypothesis, which is that there is a difference in the retention rates between the students in the two courses. A summary of the retention data is found in Table 28.

Table 28: Summary of Retention Data, Fall 1998

Course * Retention Crosstabulation

Count

		Retention		
		Not Retained	Retained	Total
Course	Control	40	167	207
	Experimental	14	44	58
Total		54	211	265

The χ^2 analysis on the retention data is shown in Table 29.

Table 29: χ^2 analysis on Retention Data, Fall 1998

Chi-Square Tests

	Value	df	Asymp. Sig. (2-sided)	Exact Sig. (2-sided)	Exact Sig. (1-sided)
Pearson Chi-Square	.647[b]	1	.421		
Continuity Correction[a]	.384	1	.535		
Likelihood Ratio	.628	1	.428		
Fisher's Exact Test				.461	.264
Linear-by-Linear Association	.645	1	.422		
N of Valid Cases	265				

a. Computed only for a 2x2 table

b. 0 cells (.0%) have expected count less than 5. The minimum expected count is 11.82.

Based on the observed significance of 0.421 for the Pearson Chi-Square, we fail to reject the null hypothesis and conclude that students in the two courses are equally likely to be retained as Natural Sciences, Engineering, or Pharmacy majors.

CONTROL VERSUS EXPERIMENTAL FOR SPRING 1999, FALL 1999, SPRING 2000, AND SPRING 2001

In these semesters in which the experimental course CH 204 AV was offered, students could elect to take this course by either observing that the catalog description of the course included the line "Intended for Life Science majors" and was listed as being taught by Dr. Stewart, the original instructor of the course. As a consequence, the students in the experimental group may be somewhat self-selected. For all of the Spring semesters within this grouping, 8 sections were taught; this arrangement necessitated the use of several teaching assistants. In Spring 1999 and Spring 2000, the head teaching assistant taught individual laboratory sections as one of the 4 assigned teaching assistants. The arrangement in Fall 1999 was similar, but only 7 sections of the experimental course were offered. In Spring 2001, the head teaching assistant's duties were modified away from teaching individual laboratory sections and towards a more administrative role of teaching some of the lecture sections and supervising other teaching assistants. The same data collected for Fall 1998 was also collected for the laboratory courses taught during this time period.

Survey Data

Survey data collected over the four semesters under study are compiled and organized in Table 30. These data reflect the merger of all data using the common numbering scheme. Surveys from students in special circumstances (specifically, those in the two sections with the common TA in Spring 2000 and PENS students in Spring 2001) are excluded from this analysis. Data for individual semesters can be found in Appendices G (Spring 1999), H (Fall 1999), I (Spring 2000) and K (Spring 2001).

Table 30: Merger of Survey Responses for Control versus Experimental

New #	Statement	Control	Experimental
	IMPACT ON LEARNING		
10	Activities: Lab Lecture	3.202 ± 1.139	3.184 ± 1.089
11	Activities: Wet Lab	3.295 ± 1.151	4.146 ± 0.906
12	Activities: Exams	2.631 ± 0.984	3.677 ± 0.985
13	Activities: Quizzes	2.758 ± 1.117	3.383 ± 1.105
14	Activities: Homework/Exercises	2.624 ± 1.243	3.386 ± 1.090
	IMPACT ON CONFIDENCE		
15	Activities: Lab Lecture	3.253 ± 1.141	3.147 ± 1.063
16	Activities: Wet Lab	3.162 ± 1.131	3.895 ± 1.032

Table 30 continues on the next page

Table 30, continued

New #	Statement	Control	Experimental
17	Activities: Exams	2.744 ± 1.004	3.726 ± 0.977
18	Activities: Quizzes	2.840 ± 1.145	3.266 ± 1.084
19	Activities: Homework/Exercises	2.588 ± 1.220	3.411 ± 0.950
	IMPACT ON ENTHUSIASM		
20	Activities: Lab Lecture	2.382 ± 1.139	2.564 ± 1.206
21	Activities: Wet Lab	2.676 ± 1.310	3.574 ± 1.180
22	Activities: Exams	2.148 ± 1.001	2.951 ± 1.123
23	Activities: Quizzes	2.134 ± 1.022	2.645 ± 1.107
24	Activities: Homework/Exercises	1.935 ± 1.061	2.799 ± 0.990
	CONFIDENCE IN YOUR ABILITY TO…		
25	Understand Key Concepts of Chemistry	3.596 ± 0.958	3.867 ± 0.799
26	Solve Chemistry Problems	3.462 ± 0.942	3.837 ± 0.818
27	Understand the Chemistry Underlying Lab Experiments	3.270 ± 1.019	3.681 ± 0.921
28	Perform Lab Experiments	3.651 ± 0.966	3.969 ± 0.880
29	Visualize Key Concepts of Chemistry	3.421 ± 0.920	3.707 ± 0.856
30	Apply your Knowledge of Chemistry to the Real World	3.169 ± 1.010	3.519 ± 0.942
31	Understand Other Areas of Science	3.795 ± 0.926	3.926 ± 0.807
32	Succeed in Another Chemistry Course	3.551 ± 1.000	3.841 ± 0.868
33	Succeed in a Chemistry-Related Discipline	3.332 ± 1.042	3.615 ± 0.925
	INTEREST IN..		
34	Studying Chemistry in General	2.875 ± 1.180	3.161 ± 1.141
35	Taking More Chemistry	2.758 ± 1.282	3.027 ± 1.242

Table 30 continues on the next page

Table 30, continued

New #	Statement	Control	Experimental
36	Pursuing a Chemistry-Related Major	2.490 ± 1.327	2.629 ± 1.384
37	Pursuing a Science-Related Field	4.132 ± 1.039	4.300 ± 0.920
38	Working with Others to Learn Science	3.710 ± 1.120	3.870 ± 1.066
39	Chemistry in Industry	2.622 ± 1.180	2.641 ± 1.196
40	Chemistry in Medicine	3.703 ± 1.243	3.946 ± 1.127
41	Chemistry in the Environment	2.925 ± 1.185	3.114 ± 1.158
42	Science in General	3.974 ± 1.035	4.184 ± 0.950
	IMPRESSIONS OF LECTURE		
43	I enjoyed the formal laboratory (1 hour) lectures.	2.427 ± 1.112	2.528 ± 1.213
44	The organization of the lectures was important for my learning.	2.982 ± 1.244	3.122 ± 1.159
45	The applications of chemistry discussed in this course made certain concepts easier to understand.	2.867 ± 1.162	3.542 ± 1.015
46	The applications of chemistry discussed in this course made learning chemistry interesting.	2.616 ± 1.180	3.420 ± 1.046
	IMPRESSIONS OF LABS		
47	I enjoyed the labs.	2.567 ± 1.258	3.580 ± 1.112
48	I understood the chemistry behind the labs before I did them.	2.565 ± 1.125	3.041 ± 1.051
49	Eventually I understood the chemistry behind the labs.	3.236 ± 1.114	4.048 ± 0.887
50	The labs helped me understand important concepts in this course.	2.906 ± 1.146	3.947 ± 0.920
51	Enough time was allowed for labs.	3.475 ± 1.255	4.336 ± 0.933
	GENERAL QUESTION		
52	Would you recommend this course to a friend?	1.890 ± 1.104	3.847 ± 1.227

As in Fall 1998, a Multiple Analysis of Variance (MANOVA) is utilized, using the single independent variable "q1" (which is course identity) and each of the 43 questions "q10" through "q52" (following the common numbering scheme) as dependent variables. Standard assumptions for MANOVA were considered, the ones of primary interest being: (1) the dependent variables should be quantitative, (2) data are drawn from a population which has normally distributed dependent variables, (3) in the population, the variance-covariance matrices for all cells are the same. In order to control the Type I error (finding significance through statistical tests when significance, in fact, does not exist) rate, a Bonferroni correction was applied, so that the desired α level of 0.05 was adjusted to 0.05/43 = 0.00116.

For the survey data, the homogeneity of covariance assumption was checked with Box's M Test (Table 31). One of the important assumptions of MANOVA is that the covariance matrices across groups are equal. The null hypothesis is that there is no difference in the observed covariance matrices. An α level of 0.05 is chosen. Should the observed significance be less than 0.05, the null hypothesis must be rejected in favor of the alternative hypothesis, which is that the covariance matrices between the two groups are different.

Table 31: Box's Test on Survey Data, Control versus Experimental

Box's Test of Equality of Covariance Matrices[a]

Box's M	1653.488
F	1.663
df1	946
df2	2341664
Sig.	.000

Tests the null hypothesis that the observed covariance matrices of the dependent variables are equal across groups.

a. Design: Intercept+q1

As the observed significance is less than 0.05 (Table 31), the null hypothesis in this case is rejected and it is appropriate to conclude that the observed covariance matrices among groups are different. An inspection of Levene's Test in Table 32 sheds insight on the source of the difficulty.

Table 32: Levene's Test of Equality of Error Variances, Control versus Experimental

	F	df1	df2	Sig.
q10	3.194	1	915	.074
q11	40.354	1	915	.000
q12	.118	1	915	.731
q13	.459	1	915	.498
q14	29.443	1	915	.000
q15	5.874	1	915	.016
q16	9.655	1	915	.002
q17	.038	1	915	.845
q18	2.355	1	915	.125
q19	48.036	1	915	.000
q20	.615	1	915	.433
q21	16.058	1	915	.000
q22	1.132	1	915	.288
q23	.518	1	915	.472
q24	14.661	1	915	.000
q25	38.530	1	915	.000
q26	22.726	1	915	.000
q27	3.196	1	915	.074
q28	18.261	1	915	.000
q29	5.272	1	915	.022
q30	.554	1	915	.457
q31	14.040	1	915	.000
q32	17.468	1	915	.000
q33	7.243	1	915	.007
q34	.455	1	915	.500
q35	2.768	1	915	.097
q36	2.023	1	915	.155
q37	3.123	1	915	.078
q38	1.730	1	915	.189
q39	.448	1	915	.503
q40	11.763	1	915	.001
q41	.043	1	915	.837
q42	.112	1	915	.738

Table 32 continues on the next page

Table 32, continued

	F	df1	df2	Sig.
q43	6.637	1	915	.010
q44	1.639	1	915	.201
q45	5.540	1	915	.019
q46	10.397	1	915	.001
q47	19.071	1	915	.000
q48	18.301	1	915	.000
q49	45.686	1	915	.000
q50	26.324	1	915	.000
q51	64.565	1	915	.000
q52	.192	1	915	.662

Tests the null hypothesis that the error variance of the dependent variable is equal across groups.
a Design: Intercept+q1

Levene's Test is used to assess the assumption that the error variance of the dependent variable is equal across groups. The null hypothesis is that there is no difference in the error variances. If an α level of 0.05 is chosen, in several cases, the null hypothesis should be rejected in favor of the alternative hypothesis, which is that the error variances are indeed different. In the case of these variables, the responses of the students are very skewed.

The failure of these two tests indicates that any conclusion should be approached with some caution. The observed significance of 0.000 in Box's M Test implies strong significance, which could cause a great deal of concern. Failure to meet the assumption of homogeneity of covariances is not necessarily fatal to MANOVA, assuming that the samples were of similar size. Of the 1087 surveys that were submitted over the course of these four semesters, 503 students in the control course and 414 in the experimental course completed all items within the survey. Uncompleted surveys were not analyzed.

With the described caveats, the overall MANOVA is shown in Table 33. Significance, as measured as an α level less than 0.05, suggests that the students in the two groups respond differently to the survey.

Table 33: Overall MANOVA on Survey Data for Control versus Experimental

Multivariate Tests[b]

Effect		Value	F	Hypothesis df	Error df	Sig.
Intercept	Pillai's Trace	.980	982.757[a]	43.000	873.000	.000
	Wilks' Lambda	.020	982.757[a]	43.000	873.000	.000
	Hotelling's Trace	48.406	982.757[a]	43.000	873.000	.000
	Roy's Largest Root	48.406	982.757[a]	43.000	873.000	.000
q1	Pillai's Trace	.528	22.753[a]	43.000	873.000	.000
	Wilks' Lambda	.472	22.753[a]	43.000	873.000	.000
	Hotelling's Trace	1.121	22.753[a]	43.000	873.000	.000
	Roy's Largest Root	1.121	22.753[a]	43.000	873.000	.000

a. Exact statistic

b. Design: Intercept+q1

The observed significance is indeed less than 0.05, implying that there are survey items on which students in the two groups responded differently. A question by question analysis follows. Using the Bonferroni correction, as previously described, implies that a calculated significance of less than 0.00116 represents a difference between the two student groups.

Table 34: MANOVA Survey Results, Control versus Experimental

Tests of Between-Subjects Effects

Source	Dependent Variable	Type III Sum of Squares	df	Mean Square	F	Sig.
Corrected Model	q10	.034(a)	1	.034	.027	.87006
	q11	153.867(b)	1	153.867	139.061	**.00000**
	q12	245.085(c)	1	245.085	253.425	**.00000**
	q13	96.208(d)	1	96.208	76.548	**.00000**
	q14	129.196(e)	1	129.196	92.130	**.00000**
	q15	2.107(f)	1	2.107	1.720	.19006
	q16	112.508(g)	1	112.508	95.126	**.00000**
	q17	222.404(h)	1	222.404	224.548	**.00000**
	q18	43.983(i)	1	43.983	34.806	**.00000**
	q19	146.947(j)	1	146.947	119.226	**.00000**
	q20	8.226(k)	1	8.226	6.012	.01439
	q21	171.425(l)	1	171.425	109.620	**.00000**
	q22	153.511(m)	1	153.511	137.488	**.00000**
	q23	62.745(n)	1	62.745	55.329	**.00000**
	q24	175.876(o)	1	175.876	164.545	**.00000**
	q25	20.185(p)	1	20.185	25.582	**.00000**
	q26	35.171(q)	1	35.171	43.847	**.00000**
	q27	36.667(r)	1	36.667	38.845	**.00000**
	q28	21.501(p)	1	21.501	25.096	**.00000**
	q29	22.021(s)	1	22.021	28.163	**.00000**
	q30	32.550(t)	1	32.550	34.353	**.00000**
	q31	5.731(u)	1	5.731	7.347	.00684
	q32	18.563(v)	1	18.563	21.239	**.00000**
	q33	18.253(w)	1	18.253	18.611	**.00002**
	q34	15.246(x)	1	15.246	11.381	**.00077**
	q35	13.080(y)	1	13.080	8.229	.00422
	q36	3.509(f)	1	3.509	1.950	.16293
	q37	9.473(z)	1	9.473	9.663	.00194
	q38	5.708(aa)	1	5.708	4.809	.02856
	q39	.930(bb)	1	.930	.684	.40845
	q40	18.167(cc)	1	18.167	12.699	**.00038**
	q41	13.227(dd)	1	13.227	9.817	.00178
	q42	10.217(dd)	1	10.217	10.145	.00150
	q43	1.727(bb)	1	1.727	1.294	.25560
	q44	3.526(ee)	1	3.526	2.415	.12055
	q45	95.687(ff)	1	95.687	78.430	**.00000**
	q46	135.105(gg)	1	135.105	107.512	**.00000**

Table 34 continues on the next page

Table 34, continued

Source	Dependent Variable	Type III Sum of Squares	df	Mean Square	F	Sig.
	q47	204.666(hh)	1	204.666	143.137	**.00000**
	q48	45.673(ii)	1	45.673	38.619	**.00000**
	q49	154.221(jj)	1	154.221	148.837	**.00000**
	q50	230.376(kk)	1	230.376	210.964	**.00000**
	q51	181.894(ll)	1	181.894	141.410	**.00000**
	q52	846.432(mm)	1	846.432	620.366	**.00000**
Intercept	q10	9157.277	1	9157.277	7285.695	.000
	q11	12595.271	1	12595.271	11383.280	.000
	q12	9011.222	1	9011.222	9317.899	.000
	q13	8511.266	1	8511.266	6772.023	.000
	q14	8226.243	1	8226.243	5866.168	.000
	q15	9303.612	1	9303.612	7591.572	.000
	q16	11503.770	1	11503.770	9726.524	.000
	q17	9561.047	1	9561.047	9653.217	.000
	q18	8533.231	1	8533.231	6752.657	.000
	q19	8287.357	1	8287.357	6724.017	.000
	q20	5563.768	1	5563.768	4066.362	.000
	q21	9013.929	1	9013.929	5764.078	.000
	q22	5907.823	1	5907.823	5291.157	.000
	q23	5154.436	1	5154.436	4545.194	.000
	q24	5129.787	1	5129.787	4799.279	.000
	q25	12541.013	1	12541.013	15894.622	.000
	q26	11996.759	1	11996.759	14956.278	.000
	q27	10895.542	1	10895.542	11542.813	.000
	q28	13185.292	1	13185.292	15389.320	.000
	q29	11507.543	1	11507.543	14717.365	.000
	q30	10087.503	1	10087.503	10646.003	.000
	q31	13400.348	1	13400.348	17178.939	.000
	q32	12419.523	1	12419.523	14209.718	.000
	q33	10948.678	1	10948.678	11163.643	.000
	q34	8285.762	1	8285.762	6185.417	.000
	q35	7635.763	1	7635.763	4804.016	.000
	q36	5857.128	1	5857.128	3254.501	.000
	q37	16095.885	1	16095.885	16418.749	.000
	q38	12999.981	1	12999.981	10952.871	.000
	q39	6190.321	1	6190.321	4554.123	.000
	q40	13154.316	1	13154.316	9194.609	.000
	q41	8215.364	1	8215.364	6097.768	.000
	q42	15048.935	1	15048.935	14943.045	.000
	q43	5600.165	1	5600.165	4196.312	.000

Table 34 continues on the next page

Table 34, continued

Source	Dependent Variable	Type III Sum of Squares	df	Mean Square	F	Sig.
	q44	8430.077	1	8430.077	5773.674	.000
	q45	9355.504	1	9355.504	7668.180	.000
	q46	8338.464	1	8338.464	6635.433	.000
	q47	8689.765	1	8689.765	6077.372	.000
	q48	7145.748	1	7145.748	6042.057	.000
	q49	12026.722	1	12026.722	11606.873	.000
	q50	10724.269	1	10724.269	9820.640	.000
	q51	13835.713	1	13835.713	10756.265	.000
	q52	7585.486	1	7585.486	5559.542	.000
q1	q10	.034	1	.034	.027	.870
	q11	153.867	1	153.867	139.061	.000
	q12	245.085	1	245.085	253.425	.000
	q13	96.208	1	96.208	76.548	.000
	q14	129.196	1	129.196	92.130	.000
	q15	2.107	1	2.107	1.720	.190
	q16	112.508	1	112.508	95.126	.000
	q17	222.404	1	222.404	224.548	.000
	q18	43.983	1	43.983	34.806	.000
	q19	146.947	1	146.947	119.226	.000
	q20	8.226	1	8.226	6.012	.014
	q21	171.425	1	171.425	109.620	.000
	q22	153.511	1	153.511	137.488	.000
	q23	62.745	1	62.745	55.329	.000
	q24	175.876	1	175.876	164.545	.000
	q25	20.185	1	20.185	25.582	.000
	q26	35.171	1	35.171	43.847	.000
	q27	36.667	1	36.667	38.845	.000
	q28	21.501	1	21.501	25.096	.000
	q29	22.021	1	22.021	28.163	.000
	q30	32.550	1	32.550	34.353	.000
	q31	5.731	1	5.731	7.347	.007
	q32	18.563	1	18.563	21.239	.000
	q33	18.253	1	18.253	18.611	.000
	q34	15.246	1	15.246	11.381	.001
	q35	13.080	1	13.080	8.229	.004
	q36	3.509	1	3.509	1.950	.163
	q37	9.473	1	9.473	9.663	.002
	q38	5.708	1	5.708	4.809	.029
	q39	.930	1	.930	.684	.408
	q40	18.167	1	18.167	12.699	.000

Table 34 continues on the next page

Table 34, continued

Source	Dependent Variable	Type III Sum of Squares	df	Mean Square	F	Sig.
	q41	13.227	1	13.227	9.817	.002
	q42	10.217	1	10.217	10.145	.001
	q43	1.727	1	1.727	1.294	.256
	q44	3.526	1	3.526	2.415	.121
	q45	95.687	1	95.687	78.430	.000
	q46	135.105	1	135.105	107.512	.000
	q47	204.666	1	204.666	143.137	.000
	q48	45.673	1	45.673	38.619	.000
	q49	154.221	1	154.221	148.837	.000
	q50	230.376	1	230.376	210.964	.000
	q51	181.894	1	181.894	141.410	.000
	q52	846.432	1	846.432	620.366	.000
Error	q10	1150.049	915	1.257		
	q11	1012.421	915	1.106		
	q12	884.885	915	.967		
	q13	1149.997	915	1.257		
	q14	1283.123	915	1.402		
	q15	1121.349	915	1.226		
	q16	1082.190	915	1.183		
	q17	906.263	915	.990		
	q18	1156.272	915	1.264		
	q19	1127.738	915	1.233		
	q20	1251.942	915	1.368		
	q21	1430.887	915	1.564		
	q22	1021.640	915	1.117		
	q23	1037.647	915	1.134		
	q24	978.013	915	1.069		
	q25	721.944	915	.789		
	q26	733.942	915	.802		
	q27	863.691	915	.944		
	q28	783.956	915	.857		
	q29	715.441	915	.782		
	q30	866.998	915	.948		
	q31	713.741	915	.780		
	q32	799.725	915	.874		
	q33	897.381	915	.981		
	q34	1225.701	915	1.340		
	q35	1454.350	915	1.589		
	q36	1646.726	915	1.800		
	q37	897.007	915	.980		

Table 34 continues on the next page

Table 34, continued

Source	Dependent Variable	Type III Sum of Squares	df	Mean Square	F	Sig.
	q38	1086.015	915	1.187		
	q39	1243.740	915	1.359		
	q40	1309.050	915	1.431		
	q41	1232.756	915	1.347		
	q42	921.484	915	1.007		
	q43	1221.108	915	1.335		
	q44	1335.981	915	1.460		
	q45	1116.339	915	1.220		
	q46	1149.841	915	1.257		
	q47	1308.318	915	1.430		
	q48	1082.141	915	1.183		
	q49	948.098	915	1.036		
	q50	999.192	915	1.092		
	q51	1176.959	915	1.286		
	q52	1248.434	915	1.364		
Total	q10	10391.000	917			
	q11	13610.000	917			
	q12	9938.000	917			
	q13	9662.000	917			
	q14	9516.000	917			
	q15	10543.000	917			
	q16	12586.000	917			
	q17	10497.000	917			
	q18	9695.000	917			
	q19	9426.000	917			
	q20	6835.000	917			
	q21	10460.000	917			
	q22	6954.000	917			
	q23	6193.000	917			
	q24	6148.000	917			
	q25	13304.000	917			
	q26	12753.000	917			
	q27	11776.000	917			
	q28	14012.000	917			
	q29	12256.000	917			
	q30	10971.000	917			
	q31	14193.000	917			
	q32	13262.000	917			
	q33	11881.000	917			
	q34	9536.000	917			

Table 34 continues on the next page

Table 34, continued

Source	Dependent Variable	Type III Sum of Squares	df	Mean Square	F	Sig.
	q35	9114.000	917			
	q36	7535.000	917			
	q37	17079.000	917			
	q38	14162.000	917			
	q39	7479.000	917			
	q40	14511.000	917			
	q41	9475.000	917			
	q42	16047.000	917			
	q43	6857.000	917			
	q44	9816.000	917			
	q45	10472.000	917			
	q46	9496.000	917			
	q47	10026.000	917			
	q48	8230.000	917			
	q49	12978.000	917			
	q50	11750.000	917			
	q51	15017.000	917			
	q52	9264.000	917			
Corrected Total	q10	1150.083	916			
	q11	1166.288	916			
	q12	1129.969	916			
	q13	1246.205	916			
	q14	1412.318	916			
	q15	1123.457	916			
	q16	1194.698	916			
	q17	1128.667	916			
	q18	1200.255	916			
	q19	1274.685	916			
	q20	1260.168	916			
	q21	1602.312	916			
	q22	1175.152	916			
	q23	1100.393	916			
	q24	1153.889	916			
	q25	742.129	916			
	q26	769.112	916			
	q27	900.358	916			
	q28	805.457	916			
	q29	737.461	916			
	q30	899.549	916			
	q31	719.472	916			

Table 34 continues on the next page

Table 34, continued

Source	Dependent Variable	Type III Sum of Squares	df	Mean Square	F	Sig.
	q32	818.288	916			
	q33	915.634	916			
	q34	1240.947	916			
	q35	1467.431	916			
	q36	1650.236	916			
	q37	906.480	916			
	q38	1091.723	916			
	q39	1244.670	916			
	q40	1327.217	916			
	q41	1245.983	916			
	q42	931.701	916			
	q43	1222.835	916			
	q44	1339.507	916			
	q45	1212.026	916			
	q46	1284.947	916			
	q47	1512.984	916			
	q48	1127.815	916			
	q49	1102.318	916			
	q50	1229.568	916			
	q51	1358.853	916			
	q52	2094.866	916			

a R Squared = .000 (Adjusted R Squared = -.001)
b R Squared = .132 (Adjusted R Squared = .131)
c R Squared = .217 (Adjusted R Squared = .216)
d R Squared = .077 (Adjusted R Squared = .076)
e R Squared = .091 (Adjusted R Squared = .090)
f R Squared = .002 (Adjusted R Squared = .001)
g R Squared = .094 (Adjusted R Squared = .093)
h R Squared = .197 (Adjusted R Squared = .196)
i R Squared = .037 (Adjusted R Squared = .036)
j R Squared = .115 (Adjusted R Squared = .114)
k R Squared = .007 (Adjusted R Squared = .005)
l R Squared = .107 (Adjusted R Squared = .106)
m R Squared = .131 (Adjusted R Squared = .130)
n R Squared = .057 (Adjusted R Squared = .056)
o R Squared = .152 (Adjusted R Squared = .151)
p R Squared = .027 (Adjusted R Squared = .026)
q R Squared = .046 (Adjusted R Squared = .045)
r R Squared = .041 (Adjusted R Squared = .040)
s R Squared = .030 (Adjusted R Squared = .029)
t R Squared = .036 (Adjusted R Squared = .035)
u R Squared = .008 (Adjusted R Squared = .007)
v R Squared = .023 (Adjusted R Squared = .022)
w R Squared = .020 (Adjusted R Squared = .019)

Table 34 continues on the next page

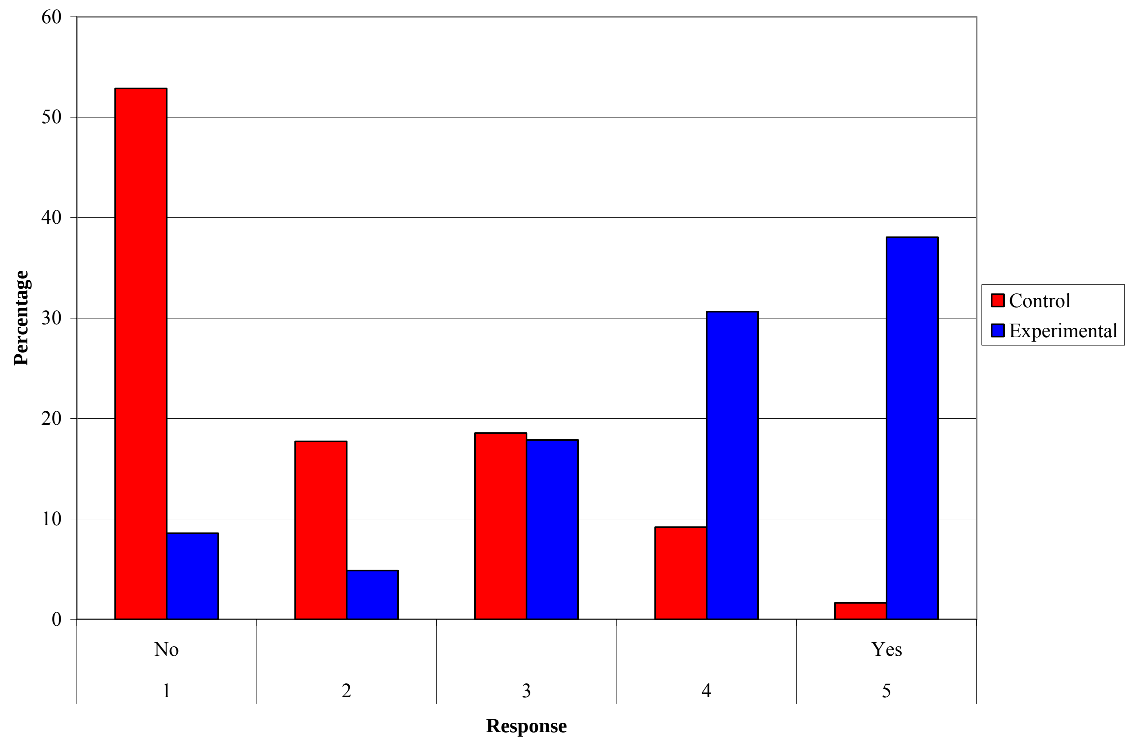
Table 34, continued

x R Squared = .012 (Adjusted R Squared = .011)
y R Squared = .009 (Adjusted R Squared = .008)
z R Squared = .010 (Adjusted R Squared = .009)
aa R Squared = .005 (Adjusted R Squared = .004)
bb R Squared = .001 (Adjusted R Squared = .000)
cc R Squared = .014 (Adjusted R Squared = .013)
dd R Squared = .011 (Adjusted R Squared = .010)
ee R Squared = .003 (Adjusted R Squared = .002)
ff R Squared = .079 (Adjusted R Squared = .078)
gg R Squared = .105 (Adjusted R Squared = .104)
hh R Squared = .135 (Adjusted R Squared = .134)
ii R Squared = .040 (Adjusted R Squared = .039)
jj R Squared = .140 (Adjusted R Squared = .139)
kk R Squared = .187 (Adjusted R Squared = .186)
ll R Squared = .134 (Adjusted R Squared = .133)
mm R Squared = .404 (Adjusted R Squared = .403)

The survey demonstrates differences on most questions except q10, q15, q20, q31, q35, q36, q37, q38, q39, q41, q42, q43, and q44. Notably, q10, q15, and q20 address the impact of learning, impact on confidence, and impact on enthusiasm (respectively) of the lecture component of the laboratory course. Two other questions in this group, q43 and q44, also addressed the laboratory lecture as well. Of the remaining questions in which no difference was found between the two groups, all but one (q31) address student interest with respect to some aspect of science. Indeed, of the nine "interest" questions, only in 2 is a significant difference found: studying chemistry in general (q34) and chemistry in medicine (q40). Within the group of confidence questions, in all but one (q31, understand areas of science) a significant difference is found.

Although many of the survey items display a difference in opinion between the two student groups, a particularly dramatic result occurs with q52, "Would you recommend this course to a friend?" Figure 3 on the next page demonstrates student response to this question.

Figure 3: Histogram of “Would you recommend this course to a friend?”, Control versus Experimental



Drop and Withdraw Data

As is the case for Fall 1998, final course grade information for the control and experimental courses was obtained from the registrar of The University of Texas at Austin for all of the semesters under study. Of particular interest was the number of students that either dropped (with a grade of Q) or withdrew (with a grade of W) from the two courses under study. For Spring 1999, this information is summarized in Table 35.

Table 35: Drops and Withdraws, Spring 1999

	Q	W	Total Dropped	Students	% Dropped
Control	34	7	41	427	9.6%
Experimental	4	4	8	157	5.1%

In Fall 1999, a smaller number of sections of both the control and experimental courses were offered. This reduction is reflected in the number of students who dropped and withdrew from the two courses, as described by Table 36.

Table 36: Drops and Withdraws, Fall 1999

	Q	W	Total Dropped	Students	% Dropped
Control	21	7	28	261	10.7%
Experimental	9	1	10	144	6.9%

The student groups in Spring 2000 were further subdivided in that one section of the control course and one section of the experimental course were taught by the same teaching assistant (TA). Hence, the tally of students who either dropped or withdrew from the two courses is kept separate for those two sections from the other sections in which the courses were taught. For those students in the sections were not taught by the common TA, the number of students who either dropped or withdrew from the control and experimental courses is shown in Table 37.

Table 37: Drops and Withdraws, Spring 2000

		Q	W	Total Dropped	Students	% Dropped
Without Common TA	**Control**	36	6	42	454	9.3%
	Experimental	1	2	3	138	2.2%
With Common TA	**Control**	0	0	0	20	0%
	Experimental	0	0	0	20	0%

Notably, and following the pattern observed in previous semesters, the number of students who dropped the course with either a "Q" or "W" is higher in the control group than it is in the experimental group. No student in either of the sections taught by the common TA dropped or withdrew from either of the two courses.

Finally, in Spring 2001, two sections of the PENS group joined traditional control and experimental groups. The PENS students are analyzed later, but their drop and withdraw data are shown in Table 38, along with the drop and withdraw data for the control and experimental groups.

Table 38: Drops and Withdraws, Spring 2001

	Q	W	Total Dropped	Students	% Dropped
Control	26	5	31	479	6.5%
Experimental	5	2	7	135	5.2%
PENS	0	1	1	41	2.4%

Combining the numbers for these four semesters, we find, in Table 39, the total number of drops and withdraws for the control and experimental groups.

Table 39: Total Drops and Withdraws for Control versus Experimental Comparison

	Q	W	Total Dropped	Students	% Dropped
Control	117	25	142	1621	8.7%
Experimental	19	9	28	574	4.9%

The number of students who dropped the course either with a "Q" or "W" were combined and compared to the number of students officially registered in the course on the twelfth class day. (Table 39) As in Fall 1998, the percentage of students that dropped the control course is larger than for the experimental course during this time period. To judge whether or not these observed differences are statistically significant, a χ^2 test is performed. Statistical significance is found at an α level of 0.05. The null hypothesis is that there is no difference in the drop rates between the two courses; if a difference is found, it must be due to the alternative hypothesis, that the identity of the course does impact the drop rate. Using SPSS, we are able to determine the statistical significance of our drop results.

Saving the analysis of the PENS students for later, for the control versus experimental comparison, as shown in Table 40, a total of 2195 students were enrolled in the experimental and control courses at the twelfth class day over the four semesters under study.

Table 40: Drop-Withdraw Cases, Control versus Experimental

Case Processing Summary

	Cases					
	Valid		Missing		Total	
	N	Percent	N	Percent	N	Percent
Course * Total	2195	100.0%	0	.0%	2195	100.0%

Of these 2195 students, 574 were enrolled in the experimental course and 1621 were enrolled in the control course, as shown in Table 41.

Table 41: Drop – Withdraw Count, Control versus Experimental

Course * Total Crosstabulation

Count

		Total		
		Finished Course	Dropped or Withdrawn	Total
Course	Control	1479	142	1621
	Experimental	546	28	574
Total		2025	170	2195

A χ^2 analysis is then performed to determine statistical significance. An α level of 0.05 is selected. The null hypothesis is that there is no difference in the drop and withdraw rate of the students in the experimental course as compared to that of students in the control course. If the observed significance is less than 0.05, the null hypothesis is rejected in favor of the alternative hypothesis, which is that the drop and withdraw rates between the two courses are different. The χ^2 analysis is shown in Table 42.

Table 42: χ^2 analysis on Drop – Withdraw Data, Control versus Experimental

Chi-Square Tests

	Value	df	Asymp. Sig. (2-sided)	Exact Sig. (2-sided)	Exact Sig. (1-sided)
Pearson Chi-Square	8.940[b]	1	.003		
Continuity Correction[a]	8.405	1	.004		
Likelihood Ratio	9.779	1	.002		
Fisher's Exact Test				.003	.001
Linear-by-Linear Association	8.936	1	.003		
N of Valid Cases	2195				

a. Computed only for a 2x2 table

b. 0 cells (.0%) have expected count less than 5. The minimum expected count is 44.46.

According to the analysis, we must reject the null hypothesis as the observed significance (0.003 for the Pearson Chi-Square) is less than the desired α level of 0.05. Instead, the alternative hypothesis must be true, that students in the control course are more likely to drop or withdraw than students in the experimental course.

Longitudinal Studies

Longitudinal studies are best performed on students who completed the control and experimental courses successfully. Defining success as a final course grade of A, B, C, or CR, as described earlier, 352 of 427 students in the control group and 144 of 157 students in the experimental group were successful in Spring 1999. A breakdown of the grade distribution in Spring 1999 appears in Table 43.

Table 43: Final Course Grades, Spring 1999

	A	**B**	**C**	**CR**	**D**	**F**	**Q**	**W**	**Students**	**% Success**
Control	173	109	68	2	21	13	34	7	427	82.4%
Experimental	56	70	18	0	2	3	4	4	157	91.7%

The pattern of a larger number of students in the experimental group being successful is repeated in Fall 1999, as depicted in Table 44.

Table 44: Final Course Grades, Fall 1999

	A	**B**	**C**	**CR**	**D**	**F**	**Q**	**W**	**Students**	**% Success**
Control	88	50	65	2	11	17	21	7	261	78.5%
Experimental	46	63	21	0	2	2	9	1	144	90.3%

In Spring 2000, four student groups exist, two each of control and experimental. Only those sections without the common teaching assistant are analyzed for now. The final grade information is shown in Table 45.

Table 45: Final Course Grades for Sections without the Common TA, Spring 2000

	A	B	C	CR	D	F	Q	W	Students	% Success
Control	126	194	66	1	14	11	36	6	454	85.2%
Experimental	81	47	5	0	1	1	1	2	138	96.4%

The last semester in which a comparison between control and experimental groups is done is Spring 2001. In this semester, the PENS group is also present. The analysis of the PENS group is performed later in this dissertation. The relevant grade information is presented in Table 46.

Table 46: Final Course Grades, Spring 2001

	A	B	C	CR	D	F	Q	W	Students	% Success
Control	142	165	97	1	29	14	26	5	479	84.6%
Experimental	56	50	16	0	4	2	5	2	135	90.4%

Summing the four semesters under study, and focusing strictly on the control and experimental groups, we find that 1349 (83.2%) of the 1621 control students received an A, B, C, or CR (Credit) in their laboratory course and are deemed successful. By contrast, 529 (92.2%) of the students in the experimental course are ultimately successful in their laboratory course. It is on the group of 1878 successful students that the desired longitudinal studies are performed. The summed data appear in Table 47.

Table 47: Final Course Grades, Control versus Experimental

	A	B	C	CR	D	F	Q	W	Students	% Success
Control	529	518	296	6	75	55	117	25	1621	83.2%
Experimental	239	230	60	0	9	8	19	9	574	92.2%

Enrollment in Research Courses

Compiling information obtained from the registrar at The University of Texas at Austin, Table 48 shows the number of successful students who took research courses in Chemistry or Biology after having been enrolled in either the experimental or control course in Spring 1999.

Table 48: Biology and Chemistry Research Enrollment, Spring 1999

	Took Biology or Chemistry Research	Did Not Take Biology or Chemistry Research	Successful Students	% Taking Research
Control	49	303	352	13.9%
Experimental	29	115	144	20.1%
Total	78	418	496	15.7%

For Fall 1999, as in Spring 1999, a larger proportion of the experimental students pursued upper division research courses in Biology and Chemistry. Data are tabulated in Table 49.

Table 49: Biology and Chemistry Research Enrollment, Fall 1999

	Took Biology or Chemistry Research	Did Not Take Biology or Chemistry Research	Successful Students	% Taking Research
Control	28	177	387	13.7%
Experimental	22	108	133	16.9%
Total	50	285	335	14.9%

In Spring 2000, the previous pattern is reversed. Considering only the students in sections without the common TA, a larger percentage of students in the control group took research courses in Biology or Chemistry. The data are presented in Table 50.

Table 50: Biology and Chemistry Research Enrollment for Sections without the Common TA, Spring 2000

	Took Biology or Chemistry Research	Did Not Take Biology or Chemistry Research	Successful Students	% Taking Research
Control	52	335	387	13.4%
Experimental	14	119	133	10.5%
Total	66	454	520	12.7%

Finally, in Spring 2001, the percentages of students pursing upper division research in Chemistry and Biology are roughly the same between the control and experimental groups. These data are shown in Table 51.

Table 51: Biology and Chemistry Research Enrollment, Spring 2001

	Took Biology or Chemistry Research	**Did Not Take Biology or Chemistry Research**	**Successful Students**	**% Taking Research**
Control	52	353	405	12.8%
Experimental	16	106	122	13.1%
Total	68	459	527	12.9%

A consolidation of these results is displayed in Table 52.

Table 52: Biology and Chemistry Research Enrollment for Control versus Experimental

	Took Biology or Chemistry Research	**Did Not Take Biology or Chemistry Research**	**Successful Students**	**% Taking Research**
Control	181	1168	1349	13.4%
Experimental	81	448	529	15.3%
Total	262	1616	1878	14.0%

A χ^2 analysis is then performed to determine if students from one of the two laboratory courses is more likely to enroll in Biology or Chemistry research courses. An α level of 0.05 is selected. The null hypothesis is that there is no difference in the number of students who subsequently enroll in Biology or Chemistry research courses in the experimental course as compared to students in the control course. If the observed significance is less than 0.05, the null hypothesis is rejected in favor of the alternative hypothesis, which is that students in one course enroll more frequently in subsequent

Biology or Chemistry research courses than students in the other course. A summary of the enrollment information is found in Table 53.

Table 53: Biology and Chemistry Research Course Enrollment, Control versus Experimental

Course * ChemBio Crosstabulation

Count

		ChemBio		
		Did Not Take Chem or Bio Upper Div Research	Took Chem or Bio Upper Div Research	Total
Course	Control	1168	181	1349
	Experimental	448	81	529
Total		1616	262	1878

To determine statistical significance, a χ^2 analysis is performed and shown in Table 54.

Table 54: χ^2 analysis on Biology and Chemistry Research Course Enrollment, Control versus Experimental

Chi-Square Tests

	Value	df	Asymp. Sig. (2-sided)	Exact Sig. (2-sided)	Exact Sig. (1-sided)
Pearson Chi-Square	1.136[b]	1	.286		
Continuity Correction[a]	.984	1	.321		
Likelihood Ratio	1.118	1	.290		
Fisher's Exact Test				.300	.161
Linear-by-Linear Association	1.136	1	.287		
N of Valid Cases	1878				

a. Computed only for a 2x2 table

b. 0 cells (.0%) have expected count less than 5. The minimum expected count is 73. 80.

Based on the observed significance, we fail to reject the null hypothesis and conclude that students in the two courses are equally likely to enroll in Biology or

Chemistry research courses subsequent to their having successfully completed their General Chemistry laboratory.

Broadening the research course selection to any upper division research course within the realm of the College of Natural Sciences, Table 55 focuses on Spring 1999.

Table 55: Upper Division Research Enrollment for Control versus Experimental, Spring 1999

	Took Upper Division Research	**Did Not Take Upper Division Research**	**Successful Students**	**% Taking Research**
Control	59	293	352	16.8%
Experimental	31	113	144	21.5%
Total	90	406	496	18.2%

Fall 1999 displays the same pattern in that a larger percentage of students in the experimental group took an upper division research course within the College of Natural Sciences. The data are presented in Table 56.

Table 56: Upper Division Research Enrollment for Control versus Experimental, Fall 1999

	Took Upper Division Research	**Did Not Take Upper Division Research**	**Successful Students**	**% Taking Research**
Control	32	173	205	15.6%
Experimental	22	108	130	16.9%
Total	54	281	335	16.1%

The Natural Sciences upper division research result parallels that of only chemistry and biochemistry in Spring 2000 in that a larger number of students in the control group took a subsequent research course. Only data corresponding to students who did not have the common TA are shown in Table 57.

Table 57: Upper Division Research Enrollment for Control versus Experimental, Spring 2000

	Took Upper Division Research	**Did Not Take Upper Division Research**	**Successful Students**	**% Taking Research**
Control	64	323	387	16.5%
Experimental	15	118	133	11.3%
Total	79	441	520	15.2%

Similar percentages of students took upper division research courses in Spring 2001, as shown in Table 58. Only students in the control and experimental groups are displayed here.

Table 58: Upper Division Research Enrollment for Control versus Experimental, Spring 2001

	Took Upper Division Research	**Did Not Take Upper Division Research**	**Successful Students**	**% Taking Research**
Control	66	339	405	16.3%
Experimental	19	103	122	15.6%
Total	85	442	527	16.1%

The combination of all of the semesters under study is shown in Table 59.

Table 59: Natural Sciences Research Enrollment for Control versus Experimental

	Took Upper Division Research	Did Not Take Upper Division Research	Successful Students	% Taking Research
Control	221	1128	1349	16.4%
Experimental	87	442	529	16.4%
Total	308	1570	1878	16.4%

The summation provides the astonishing result that 16.4% of students in both groups took an upper division research course subsequent to their introductory chemistry laboratory experience. Still, in the interest of establishing the relationship, a χ^2 analysis is performed to determine if one group of students is more likely to participate in an upper division Natural Sciences research course. An α level of 0.05 is selected. The null hypothesis is that there is no difference in the number of students who subsequently enroll in upper division Natural Sciences research courses in the experimental course as compared to students in the control course. If the observed significance is less than 0.05, the null hypothesis is rejected in favor of the alternative hypothesis, which is that students in one course enroll more frequently in subsequent upper division Natural Sciences research courses than students in the other course. A summary of the enrollment information is found in Table 60.

Table 60: Upper Division Natural Sciences Research Course Enrollment for Control versus Experimental

Course * AllUpperDiv Crosstabulation

Count

		AllUpperDiv		
		Did Not Take an Upper Div Research Course	Took an Upper Div Research Course	Total
Course	Control	1128	221	1349
	Experimental	442	87	529
Total		1570	308	1878

The χ^2 analysis is shown in Table 61.

Table 61: χ^2 analysis on Upper Division Natural Sciences Research Course Enrollment for Control versus Experimental

Chi-Square Tests

	Value	df	Asymp. Sig. (2-sided)	Exact Sig. (2-sided)	Exact Sig. (1-sided)
Pearson Chi-Square	.001[b]	1	.973		
Continuity Correction[a]	.000	1	1.000		
Likelihood Ratio	.001	1	.973		
Fisher's Exact Test				1.000	.512
Linear-by-Linear Association	.001	1	.973		
N of Valid Cases	1878				

a. Computed only for a 2x2 table

b. 0 cells (.0%) have expected count less than 5. The minimum expected count is 86.76.

As in the case of considering only Biology and Chemistry research, we fail to reject the null hypothesis as the observed significance of 0.973 for the Pearson Chi-

Square exceeds the desired α level of 0.05. We conclude that students in the two courses are equally likely to enroll in upper division Natural Sciences research courses subsequent to their having successfully completed their General Chemistry laboratory.

Retention in Science and Engineering Majors

A reasonable question is if the 1878 successful students over the study period remain in a science or engineering major. Defining science and engineering majors as before, the enrollment on the twelfth class day, by college, of the students who successfully completed either the experimental or control course in Spring 1999 is outlined in Table 62.

Table 62: Enrollment by College, Spring 1999

	Control	**Experimental**	**Total**
Architecture	0	0	0
Business	8	2	10
Communication	3	0	3
Education	5	2	7
Engineering	60	15	75
Fine Arts	2	0	2
Liberal Arts	50	22	72
Natural Sciences	220	103	323
Nursing	4	0	4
Pharmacy	0	0	0
Social Work	0	0	0
Total	352	144	496

Similarly, for Fall 1999, Table 63 outlines the enrollment by school for the control and experimental courses.

Table 63: Enrollment by College, Fall 1999

	Control	Experimental	Total
Architecture	0	0	0
Business	5	2	7
Communication	2	0	2
Education	3	2	5
Engineering	17	12	29
Fine Arts	1	1	2
Liberal Arts	27	22	49
Natural Sciences	149	89	238
Nursing	1	2	3
Pharmacy	0	0	0
Social Work	0	0	0
Total	205	130	335

The data for Spring 2000 also includes that of the groups with the common TA, although these data are analyzed later. Table 64 reveals the enrollment data for Spring 2000.

Table 64: Enrollment by College, Spring 2000

	Control		Experimental		Total
	Without Common TA	With Common TA	Without Common TA	With Common TA	
Architecture	0	0	0	0	0
Business	9	0	3	1	13
Communication	1	0	1	0	2
Education	3	0	1	1	5
Engineering	50	1	14	3	68
Fine Arts	1	0	2	0	3
Liberal Arts	30	2	13	3	48
Natural Sciences	287	16	99	12	414
Nursing	6	0	0	0	6
Pharmacy	0	0	0	0	0
Social Work	0	1	0	0	1
Total	387	20	133	20	560

Spring 2001 has three student groups, only two of which are of interest for the study at hand. These data are presented in Table 65.

Table 65: Spring 2001 Enrollment by College

	Control	Experimental	PENS	Total
Architecture	1	0	0	1
Business	13	2	0	15
Communication	2	2	0	4
Education	10	0	0	10
Engineering	57	5	0	62
Fine Arts	3	1	1	5
Liberal Arts	37	9	0	46
Natural Sciences	280	102	37	419
Nursing	2	0	0	2
Pharmacy	0	1	0	1
Social Work	0	0	0	0
Total	405	122	38	565

The data for the four semesters under study are summed and presented in Table 66.

Table 66: Enrollment by College for Control versus Experimental

	Control	Experimental	Total
Architecture	1	0	1
Business	35	9	44
Communication	8	3	11
Education	21	5	26
Engineering	184	46	230
Fine Arts	7	4	11
Liberal Arts	144	66	210
Natural Sciences	936	393	1329
Nursing	13	2	15
Pharmacy	0	1	1
Social Work	0	0	0
Total	1349	529	1878

As Table 66 shows, 1329 (70.8%) of the 1878 successful students in the experimental and control courses were in the College of Natural Sciences at the beginning of their laboratory experience. An additional 230 (12.2%) were in the College of Engineering. As in the analysis of Fall 1998, students are perceived as having been retained if they remain in degree programs in Natural Sciences, Engineering, or Pharmacy. Table 67 shows the number of students in the control group who began as Natural Science majors and who were retained as Natural Science, Engineering, or Pharmacy majors.

Table 67: Natural Sciences Retention in the Control Group

	At start of Laboratory	Ending Science	Ending Eng.	Ending Pharm.	Total Retained	% Retained
Spring 1999	220	149	8	16	173	78.6%
Fall 1999	149	118	1	4	123	82.6%
Spring 2000	287	221	5	10	236	82.2%
Spring 2001	280	218	4	15	237	84.6%
Sum	936	706	18	45	769	82.2%

Likewise, Table 68 shows retention data for Engineering majors in the control group.

Table 68: Engineering Retention in the Control Group

	At start of Laboratory	Ending Science	Ending Eng.	Ending Pharm.	Total Retained	% Retained
Spring 1999	60	10	39	1	50	83.3%
Fall 1999	17	5	10	0	15	88.2%
Spring 2000	50	10	31	0	41	82.0%
Spring 2001	57	4	49	0	53	93.0%
Sum	184	29	129	1	159	86.4%

In sum, 82.9% of successful students are retained as Science and Engineering majors within the control group, as shown in Table 69.

Table 69: Total Natural Sciences and Engineering Retention for the Control Group

	At start of Laboratory	Ending Science	Ending Eng.	Ending Pharm.	Total Retained	% Retained
Science	936	706	18	45	769	82.2%
Engineering	184	29	129	1	159	86.4%
Total	1120	735	147	46	928	82.9%

Turning our attention to the experimental group, Table 70 shows the number of students who began as Natural Science majors and who were retained as Natural Science, Engineering, or Pharmacy majors.

Table 70: Natural Sciences Retention in the Experimental Group

	At start of Laboratory	Ending Science	Ending Eng.	Ending Pharm.	Total Retained	% Retained
Spring 1999	103	74	3	3	80	77.7%
Fall 1999	89	57	0	5	62	69.7%
Spring 2000	99	65	0	11	76	76.8%
Spring 2001	102	80	1	6	87	85.3%
Sum	393	276	4	25	305	77.6%

Retention data for Engineering majors in the experimental group is presented in Table 71.

Table 71: Engineering Retention in the Experimental Group

	At start of Laboratory	Ending Science	Ending Eng.	Ending Pharm.	Total Retained	% Retained
Spring 1999	15	1	11	1	13	86.7%
Fall 1999	12	2	10	0	12	100%
Spring 2000	14	2	9	0	11	78.6%
Spring 2001	5	1	4	0	5	100%
Sum	46	6	34	1	41	89.1%

In sum, 78.8% of successful students are retained as Science and Engineering majors within the experimental group, as shown in Table 72.

Table 72: Total Natural Sciences and Engineering Retention for the Experimental Group

	At start of Laboratory	Ending Science	Ending Eng.	Ending Pharm.	Total Retained	% Retained
Science	393	276	4	25	305	77.6%
Engineering	46	6	34	1	41	89.1%
Total	439	282	38	26	346	78.8%

A χ^2 analysis is then performed to determine if students in one group are more likely to be retained as Science or Engineering majors. An α level of 0.05 is selected. The null hypothesis is that there is no difference in the retention rate as Science, Engineering, and Pharmacy majors for students in the experimental course as compared to the retention rate of the students in the control course. If the observed significance is less than 0.05, the null hypothesis is rejected in favor of the alternative hypothesis, which is that there is a difference in the retention rates between the students in the two courses. A summary of the retention data is found in Table 73.

Table 73: Summary of Retention Data for Control versus Experimental

Course * Retention Crosstabulation

Count

		Retention		
		Not Retained	Retained	Total
Course	Control	192	928	1120
	Experimental	93	346	439
Total		285	1274	1559

The χ^2 analysis on the retention data is shown in Table 74.

Table 74: χ^2 analysis on Retention Data for Control versus Experimental

Chi-Square Tests

	Value	df	Asymp. Sig. (2-sided)	Exact Sig. (2-sided)	Exact Sig. (1-sided)
Pearson Chi-Square	3.449[b]	1	.063		
Continuity Correction[a]	3.183	1	.074		
Likelihood Ratio	3.371	1	.066		
Fisher's Exact Test				.069	.038
Linear-by-Linear Association	3.446	1	.063		
N of Valid Cases	1559				

a. Computed only for a 2x2 table

b. 0 cells (.0%) have expected count less than 5. The minimum expected count is 80. 25.

Based on the observed significance of 0.063 for the Pearson Chi-Square, we fail to reject the null hypothesis and conclude that students in the control and experimental groups are equally likely to be retained as Natural Sciences, Engineering, or Pharmacy majors.

EVALUATION OF THE EFFECT OF THE TEACHING ASSISTANT

In Spring 2000, by chance, one section of the control laboratory course and one section of the experimental laboratory course had the same teaching assistant in charge of the laboratory. Although the numbers of students in each section was small (20 in each case), the circumstance provides us with an opportunity to evaluate what impact the teaching assistant had on the control and experimental courses.

Survey Data

The same survey as was given all of the other students in the experimental course was given to the students in these two sections. 30 surveys were returned in total, 18 from the control group and 12 from the experimental group. Although the number of surveys returned is not large, a summary of the responses from the experimental and control groups for the common questions is presented in Table 75. The full set of survey responses appears in Appendix H.

Table 75: Survey Data for Control versus Experimental

New #	Statement	Control	Experimental
	IMPACT ON LEARNING		
10	Activities: Lab Lecture	3.111 ± 1.278	2.917 ± 1.165
11	Activities: Wet Lab	2.778 ± 1.215	4.333 ± 0.492
12	Activities: Exams	2.500 ± 1.366	3.333 ± 0.492
13	Activities: Quizzes	2.667 ± 1.237	3.083 ± 0.900
14	Activities: Homework/Exercises	2.222 ± 1.114	2.500 ± 0.905

Table 75 continues on the next page

Table 75, continued

New #	Statement	Control	Experimental
	IMPACT ON CONFIDENCE		
15	Activities: Lab Lecture	3.000 ± 1.085	2.583 ± 1.165
16	Activities: Wet Lab	2.706 ± 1.160	4.167 ± 0.718
17	Activities: Exams	2.533 ± 1.060	3.667 ± 0.888
18	Activities: Quizzes	2.706 ± 1.213	3.333 ± 0.651
19	Activities: Homework/Exercises	2.176 ± 1.185	2.833 ± 0.937
	IMPACT ON ENTHUSIASM		
20	Activities: Lab Lecture	2.882 ± 1.054	2.250 ± 1.055
21	Activities: Wet Lab	2.529 ± 1.419	4.083 ± 0.669
22	Activities: Exams	2.313 ± 1.250	2.750 ± 0.622
23	Activities: Quizzes	2.471 ± 1.231	2.583 ± 0.793
24	Activities: Homework/Exercises	2.118 ± 1.111	2.167 ± 0.835
	CONFIDENCE IN YOUR ABILITY TO…		
25	Understand Key Concepts of Chemistry	3.722 ± 1.074	4.000 ± 0.853
26	Solve Chemistry Problems	3.556 ± 1.042	3.917 ± 0.900
27	Understand the Chemistry Underlying Lab Experiments	3.333 ± 1.029	4.000 ± 0.853
28	Perform Lab Experiments	3.889 ± 0.832	4.167 ± 0.718
29	Visualize Key Concepts of Chemistry	3.667 ± 1.029	3.750 ± 0.866
30	Apply your Knowledge of Chemistry to the Real World	3.556 ± 0.922	3.750 ± 0.965
31	Understand Other Areas of Science	4.056 ± 0.873	4.167 ± 0.718
32	Succeed in Another Chemistry Course	3.889 ± 1.023	3.917 ± 0.793
33	Succeed in a Chemistry-Related Discipline	3.444 ± 1.149	3.667 ± 0.651

Table 75 continues on the next page

Table 75, continued

New #	Statement	Control	Experimental
	INTEREST IN..		
34	Studying Chemistry in General	3.000 ± 1.283	3.167 ± 1.030
35	Taking More Chemistry	2.667 ± 1.188	3.083 ± 1.165
36	Pursuing a Chemistry-Related Major	2.278 ± 0.826	2.833 ± 1.267
37	Pursuing a Science-Related Field	3.944 ± 1.305	4.500 ± 0.522
38	Working with Others to Learn Science	3.833 ± 1.200	4.250 ± 0.754
39	Chemistry in Industry	2.444 ± 1.097	1.917 ± 0.900
40	Chemistry in Medicine	3.611 ± 1.290	4.250 ± 0.754
41	Chemistry in the Environment	2.833 ± 1.043	2.500 ± 1.000
42	Science in General	3.778 ± 1.166	4.167 ± 0.937
	IMPRESSIONS OF LECTURE		
43	I enjoyed the formal laboratory (1 hour) lectures.	2.706 ± 0.985	2.500 ± 1.087
44	The organization of the lectures was important for my learning.	3.294 ± 1.312	3.417 ± 0.996
45	The applications of chemistry discussed in this course made certain concepts easier to understand.	2.706 ± 1.359	3.833 ± 0.937
46	The applications of chemistry discussed in this course made learning chemistry interesting.	2.529 ± 1.419	3.750 ± 0.754
	IMPRESSIONS OF LABS		
47	I enjoyed the labs.	2.118 ± 1.219	4.000 ± 0.632
48	I understood the chemistry behind the labs before I did them.	2.235 ± 1.091	2.909 ± 1.044
49	Eventually I understood the chemistry behind the labs.	2.882 ± 1.409	4.273 ± 0.647

Table 75 continues on the next page

Table 75, continued

New #	Statement	Control	Experimental
50	The labs helped me understand important concepts in this course.	2.353 ± 1.320	4.182 ± 0.603
51	Enough time was allowed for labs.	3.235 ± 1.348	4.091 ± 1.044
	GENERAL QUESTION		
52	Would you recommend this course to a friend?	1.667 ± 1.291	3.900 ± 0.876

As was the case with the larger group of students, a MANOVA (Multiple Analysis of Variance) is utilized to analyze the survey results. Applying the Bonferroni correction, the desired α level of 0.05 is adjusted to 0.05/43 = 0.00116. First, however, an overall MANOVA is performed to determine if students in the two groups responded differently to the survey, as shown in Table 76.

Table 76: Overall MANOVA for Sections with the Common TA, Spring 2000

Multivariate Tests[b]

Effect		Value	F	Hypothesis df	Error df	Sig.
Intercept	Pillai's Trace	1.000	3071.027[a]	25.000	1.000	.014
	Wilks' Lambda	.000	3071.027[a]	25.000	1.000	.014
	Hotelling's Trace	76775.679	3071.027[a]	25.000	1.000	.014
	Roy's Largest Root	76775.679	3071.027[a]	25.000	1.000	.014
Q1	Pillai's Trace	1.000	1213.621[a]	25.000	1.000	.023
	Wilks' Lambda	.000	1213.621[a]	25.000	1.000	.023
	Hotelling's Trace	30340.521	1213.621[a]	25.000	1.000	.023
	Roy's Largest Root	30340.521	1213.621[a]	25.000	1.000	.023

a. Exact statistic

b. Design: Intercept+Q1

As the observed significance of 0.023 is less than our desired α level of 0.05, the null hypothesis that there is no difference between the student groups is rejected in favor of the alternative hypothesis, which is that the students in the two laboratory groups responded differently to the survey. With this result in hand, analysis of individual items on the survey is appropriate. Of the 30 surveys that were received, only 15 in the control group and 12 in the experimental group had all items marked. Uncompleted surveys were not considered in the analysis. An item-by-item analysis follows in Table 77.

Table 77: MANOVA Survey Results for Sections with the Common TA, Spring 2000

Tests of Between-Subjects Effects

Source	Dependent Variable	Type III Sum of Squares	df	Mean Square	F	Sig.
Corrected Model	Q10	1.067(a)	1	1.067	1.042	.31721
	Q11	.980(b)	1	.980	.919	.34692
	Q12	2.963(c)	1	2.963	2.924	.09966
	Q13	.363(d)	1	.363	.547	.46658
	Q14	.046(e)	1	.046	.045	.83329
	Q15	.150(f)	1	.150	.157	.69508
	Q16	.007(g)	1	.007	.011	.91866
	Q17	.091(h)	1	.091	.097	.75769
	Q18	.267(i)	1	.267	.253	.61970
	Q19	.896(j)	1	.896	.658	.42501
	Q20	2.535(k)	1	2.535	1.941	.17581
	Q21	3.267(l)	1	3.267	2.981	.09661
	Q22	2.141(m)	1	2.141	1.788	.19322
	Q23	.980(n)	1	.980	.875	.35847
	Q24	.817(o)	1	.817	.790	.38263
	Q25	.363(p)	1	.363	.325	.57380
	Q26	3.424(q)	1	3.424	3.059	.09256
	Q27	.896(r)	1	.896	.699	.41111
	Q28	.224(s)	1	.224	1.455	.23901
	Q29	1.252(t)	1	1.252	.922	.34607
	Q30	12.757(u)	1	12.757	10.184	.00380
	Q31	11.557(v)	1	11.557	12.832	.00144
	Q32	.150(h)	1	.150	.099	.75555
	Q33	21.600(w)	1	21.600	26.471	**.00003**
	Q34	.417(x)	1	.417	.344	.56259
	Q35	5.807(y)	1	5.807	5.136	.03234
	Q36	1.557(z)	1	1.557	1.365	.25363
	Q37	.363(p)	1	.363	.325	.57380
	Q38	1.157(n)	1	1.157	.879	.35743

Table 77 continues on the next page

Table 77, continued

Source	Dependent Variable	Type III Sum of Squares	df	Mean Square	F	Sig.
	Q39	16.363(aa)	1	16.363	16.190	**.00047**
	Q40	.896(o)	1	.896	.798	.38010
	Q41	8.563(bb)	1	8.563	8.774	.00661
	Q42	2.963(cc)	1	2.963	2.849	.10387
	Q43	2.674(dd)	1	2.674	2.223	.14844
	Q44	1.557(ee)	1	1.557	1.546	.22525
	Q45	17.424(ff)	1	17.424	15.204	**.00064**
	Q46	.474(gg)	1	.474	.367	.54994
	Q47	2.535(hh)	1	2.535	3.172	.08708
	Q48	.669(r)	1	.669	.701	.41046
	Q49	.007(g)	1	.007	.007	.93350
	Q50	.067(ii)	1	.067	.063	.80439
	Q51	.535(jj)	1	.535	.386	.53996
	Q52	11.267(kk)	1	11.267	8.433	.00760
Intercept	Q10	385.067	1	385.067	376.042	.000
	Q11	370.017	1	370.017	347.108	.000
	Q12	358.519	1	358.519	353.801	.000
	Q13	437.400	1	437.400	658.735	.000
	Q14	366.713	1	366.713	358.351	.000
	Q15	360.150	1	360.150	377.516	.000
	Q16	459.267	1	459.267	659.866	.000
	Q17	396.980	1	396.980	425.639	.000
	Q18	339.230	1	339.230	321.240	.000
	Q19	237.341	1	237.341	174.174	.000
	Q20	205.350	1	205.350	157.236	.000
	Q21	164.452	1	164.452	150.047	.000
	Q22	474.141	1	474.141	395.997	.000
	Q23	439.202	1	439.202	392.378	.000
	Q24	116.669	1	116.669	112.832	.000
	Q25	182.585	1	182.585	163.412	.000
	Q26	403.869	1	403.869	360.812	.000
	Q27	423.119	1	423.119	329.874	.000
	Q28	36.817	1	36.817	239.069	.000
	Q29	287.474	1	287.474	211.793	.000
	Q30	118.535	1	118.535	94.626	.000
	Q31	283.113	1	283.113	314.337	.000
	Q32	238.669	1	238.669	157.641	.000
	Q33	314.341	1	314.341	385.221	.000
	Q34	161.157	1	161.157	133.188	.000
	Q35	219.141	1	219.141	193.816	.000

Table 77 continues on the next page

Table 77, continued

Source	Dependent Variable	Type III Sum of Squares	df	Mean Square	F	Sig.
	Q36	215.335	1	215.335	188.780	.000
	Q37	151.474	1	151.474	135.567	.000
	Q38	207.824	1	207.824	157.841	.000
	Q39	305.252	1	305.252	302.030	.000
	Q40	237.341	1	237.341	211.408	.000
	Q41	256.267	1	256.267	262.568	.000
	Q42	240.000	1	240.000	230.769	.000
	Q43	168.896	1	168.896	140.435	.000
	Q44	165.557	1	165.557	164.352	.000
	Q45	286.017	1	286.017	249.578	.000
	Q46	171.141	1	171.141	132.599	.000
	Q47	158.980	1	158.980	198.890	.000
	Q48	156.817	1	156.817	164.378	.000
	Q49	127.119	1	127.119	121.917	.000
	Q50	173.400	1	173.400	162.970	.000
	Q51	286.017	1	286.017	206.361	.000
	Q52	270.230	1	270.230	202.268	.000
Q1	Q10	1.067	1	1.067	1.042	.317
	Q11	.980	1	.980	.919	.347
	Q12	2.963	1	2.963	2.924	.100
	Q13	.363	1	.363	.547	.467
	Q14	.046	1	.046	.045	.833
	Q15	.150	1	.150	.157	.695
	Q16	.007	1	.007	.011	.919
	Q17	.091	1	.091	.097	.758
	Q18	.267	1	.267	.253	.620
	Q19	.896	1	.896	.658	.425
	Q20	2.535	1	2.535	1.941	.176
	Q21	3.267	1	3.267	2.981	.097
	Q22	2.141	1	2.141	1.788	.193
	Q23	.980	1	.980	.875	.358
	Q24	.817	1	.817	.790	.383
	Q25	.363	1	.363	.325	.574
	Q26	3.424	1	3.424	3.059	.093
	Q27	.896	1	.896	.699	.411
	Q28	.224	1	.224	1.455	.239
	Q29	1.252	1	1.252	.922	.346
	Q30	12.757	1	12.757	10.184	.004
	Q31	11.557	1	11.557	12.832	.001
	Q32	.150	1	.150	.099	.756

Table 77 continues on the next page

Table 77, continued

Source	Dependent Variable	Type III Sum of Squares	df	Mean Square	F	Sig.
	Q33	21.600	1	21.600	26.471	.000
	Q34	.417	1	.417	.344	.563
	Q35	5.807	1	5.807	5.136	.032
	Q36	1.557	1	1.557	1.365	.254
	Q37	.363	1	.363	.325	.574
	Q38	1.157	1	1.157	.879	.357
	Q39	16.363	1	16.363	16.190	.000
	Q40	.896	1	.896	.798	.380
	Q41	8.563	1	8.563	8.774	.007
	Q42	2.963	1	2.963	2.849	.104
	Q43	2.674	1	2.674	2.223	.148
	Q44	1.557	1	1.557	1.546	.225
	Q45	17.424	1	17.424	15.204	.001
	Q46	.474	1	.474	.367	.550
	Q47	2.535	1	2.535	3.172	.087
	Q48	.669	1	.669	.701	.410
	Q49	.007	1	.007	.007	.933
	Q50	.067	1	.067	.063	.804
	Q51	.535	1	.535	.386	.540
	Q52	11.267	1	11.267	8.433	.008
Error	Q10	25.600	25	1.024		
	Q11	26.650	25	1.066		
	Q12	25.333	25	1.013		
	Q13	16.600	25	.664		
	Q14	25.583	25	1.023		
	Q15	23.850	25	.954		
	Q16	17.400	25	.696		
	Q17	23.317	25	.933		
	Q18	26.400	25	1.056		
	Q19	34.067	25	1.363		
	Q20	32.650	25	1.306		
	Q21	27.400	25	1.096		
	Q22	29.933	25	1.197		
	Q23	27.983	25	1.119		
	Q24	25.850	25	1.034		
	Q25	27.933	25	1.117		
	Q26	27.983	25	1.119		
	Q27	32.067	25	1.283		
	Q28	3.850	25	.154		
	Q29	33.933	25	1.357		

Table 77 continues on the next page

Table 77, continued

Source	Dependent Variable	Type III Sum of Squares	df	Mean Square	F	Sig.
	Q30	31.317	25	1.253		
	Q31	22.517	25	.901		
	Q32	37.850	25	1.514		
	Q33	20.400	25	.816		
	Q34	30.250	25	1.210		
	Q35	28.267	25	1.131		
	Q36	28.517	25	1.141		
	Q37	27.933	25	1.117		
	Q38	32.917	25	1.317		
	Q39	25.267	25	1.011		
	Q40	28.067	25	1.123		
	Q41	24.400	25	.976		
	Q42	26.000	25	1.040		
	Q43	30.067	25	1.203		
	Q44	25.183	25	1.007		
	Q45	28.650	25	1.146		
	Q46	32.267	25	1.291		
	Q47	19.983	25	.799		
	Q48	23.850	25	.954		
	Q49	26.067	25	1.043		
	Q50	26.600	25	1.064		
	Q51	34.650	25	1.386		
	Q52	33.400	25	1.336		
Total	Q10	412.000	27			
	Q11	398.000	27			
	Q12	384.000	27			
	Q13	457.000	27			
	Q14	396.000	27			
	Q15	387.000	27			
	Q16	482.000	27			
	Q17	424.000	27			
	Q18	368.000	27			
	Q19	272.000	27			
	Q20	238.000	27			
	Q21	192.000	27			
	Q22	505.000	27			
	Q23	469.000	27			
	Q24	147.000	27			
	Q25	215.000	27			
	Q26	432.000	27			

Table 77 continues on the next page

Table 77, continued

Source	Dependent Variable	Type III Sum of Squares	df	Mean Square	F	Sig.
	Q27	457.000	27			
	Q28	42.000	27			
	Q29	322.000	27			
	Q30	173.000	27			
	Q31	308.000	27			
	Q32	281.000	27			
	Q33	342.000	27			
	Q34	192.000	27			
	Q35	248.000	27			
	Q36	244.000	27			
	Q37	180.000	27			
	Q38	248.000	27			
	Q39	335.000	27			
	Q40	266.000	27			
	Q41	282.000	27			
	Q42	266.000	27			
	Q43	199.000	27			
	Q44	198.000	27			
	Q45	320.000	27			
	Q46	204.000	27			
	Q47	179.000	27			
	Q48	181.000	27			
	Q49	155.000	27			
	Q50	203.000	27			
	Q51	322.000	27			
	Q52	306.000	27			
Corrected Total	Q10	26.667	26			
	Q11	27.630	26			
	Q12	28.296	26			
	Q13	16.963	26			
	Q14	25.630	26			
	Q15	24.000	26			
	Q16	17.407	26			
	Q17	23.407	26			
	Q18	26.667	26			
	Q19	34.963	26			
	Q20	35.185	26			
	Q21	30.667	26			
	Q22	32.074	26			

Table 77 continues on the next page

Table 77, continued

Source	Dependent Variable	Type III Sum of Squares	df	Mean Square	F	Sig.
	Q23	28.963	26			
	Q24	26.667	26			
	Q25	28.296	26			
	Q26	31.407	26			
	Q27	32.963	26			
	Q28	4.074	26			
	Q29	35.185	26			
	Q30	44.074	26			
	Q31	34.074	26			
	Q32	38.000	26			
	Q33	42.000	26			
	Q34	30.667	26			
	Q35	34.074	26			
	Q36	30.074	26			
	Q37	28.296	26			
	Q38	34.074	26			
	Q39	41.630	26			
	Q40	28.963	26			
	Q41	32.963	26			
	Q42	28.963	26			
	Q43	32.741	26			
	Q44	26.741	26			
	Q45	46.074	26			
	Q46	32.741	26			
	Q47	22.519	26			
	Q48	24.519	26			
	Q49	26.074	26			
	Q50	26.667	26			
	Q51	35.185	26			
	Q52	44.667	26			

a R Squared = .040 (Adjusted R Squared = .002)
b R Squared = .035 (Adjusted R Squared = -.003)
c R Squared = .105 (Adjusted R Squared = .069)
d R Squared = .021 (Adjusted R Squared = -.018)
e R Squared = .002 (Adjusted R Squared = -.038)
f R Squared = .006 (Adjusted R Squared = -.034)
g R Squared = .000 (Adjusted R Squared = -.040)
h R Squared = .004 (Adjusted R Squared = -.036)
i R Squared = .010 (Adjusted R Squared = -.030)
j R Squared = .026 (Adjusted R Squared = -.013)
k R Squared = .072 (Adjusted R Squared = .035)
l R Squared = .107 (Adjusted R Squared = .071)

Table 77 continues on the next page

Table 77, continued

m R Squared = .067 (Adjusted R Squared = .029)
n R Squared = .034 (Adjusted R Squared = -.005)
o R Squared = .031 (Adjusted R Squared = -.008)
p R Squared = .013 (Adjusted R Squared = -.027)
q R Squared = .109 (Adjusted R Squared = .073)
r R Squared = .027 (Adjusted R Squared = -.012)
s R Squared = .055 (Adjusted R Squared = .017)
t R Squared = .036 (Adjusted R Squared = -.003)
u R Squared = .289 (Adjusted R Squared = .261)
v R Squared = .339 (Adjusted R Squared = .313)
w R Squared = .514 (Adjusted R Squared = .495)
x R Squared = .014 (Adjusted R Squared = -.026)
y R Squared = .170 (Adjusted R Squared = .137)
z R Squared = .052 (Adjusted R Squared = .014)
aa R Squared = .393 (Adjusted R Squared = .369)
bb R Squared = .260 (Adjusted R Squared = .230)
cc R Squared = .102 (Adjusted R Squared = .066)
dd R Squared = .082 (Adjusted R Squared = .045)
ee R Squared = .058 (Adjusted R Squared = .021)
ff R Squared = .378 (Adjusted R Squared = .353)
gg R Squared = .014 (Adjusted R Squared = -.025)
hh R Squared = .113 (Adjusted R Squared = .077)
ii R Squared = .003 (Adjusted R Squared = -.037)
jj R Squared = .015 (Adjusted R Squared = -.024)
kk R Squared = .252 (Adjusted R Squared = .222)

In only 3 of the questions is a difference between the control and experimental group found. The control group responded more positively to q39, “Interest in Chemistry in Industry”, and the experimental group responded more positively to q33, “Confidence in Ability to Succeed in a Chemistry-Related Discipline” and q45, “the Applications of chemistry discussed in this course made certain concepts easier to understand”.

Drop and Withdraw Data

No student in the control or experimental course dropped or withdrew from their laboratory course. As a result, no evaluation of the impact of the teaching assistant on the drop and withdraw rate can be determined.

Longitudinal Studies

Focusing solely on students who were in sections with the common TA, all 40 students were successful in Spring 2000, as shown in Table 78.

Table 78: Final Course Grades for Sections with the Common TA, Spring 2000

	A	B	C	CR	D	F	Q	W	Students	% Success
Control	5	10	5	0	0	0	0	0	20	100%
Experimental	9	7	4	0	0	0	0	0	20	100%

As a result, we are able to perform the same analyses as was done for the standard control versus experimental groups.

Enrollment in Research Courses

A small number of students from these sections went on to take upper division research courses in Biology or Chemistry as well as other areas within the College of Natural Sciences. As was done for all other control and experimental groups, data were obtained from the registrar and are analyzed here. Focusing first only on Biology and Chemistry, a summary of the enrollment data is presented in Table 79.

Table 79: Biology and Chemistry Research Enrollment in Sections with the Common TA

	Took Biology or Chemistry Research	Did Not Take Biology or Chemistry Research	Successful Students	% Taking Research
Control	2	18	20	10.0%
Experimental	4	16	20	20.0%
Total	6	34	40	15.0%

A χ^2 analysis is then performed to determine if one group of students is more likely to participate in an upper division Natural Sciences research course. An α level of

0.05 is selected. The null hypothesis is that there is no difference in the number of students who subsequently enroll in upper division Natural Sciences research courses in the experimental course as compared to students in the control course. If the observed significance is less than 0.05, the null hypothesis is rejected in favor of the alternative hypothesis, which is that students in one course enroll more frequently in subsequent upper division Natural Sciences research courses than students in the other course. A summary of the enrollment information is found in Table 80.

Table 80: Biology and Chemistry Research Course Enrollment in Sections with the Common TA

Course * ChemBio Crosstabulation

Count

		ChemBio		
		Did Not Take Chem or Bio Upper Div Research	Took Chem or Bio Upper Div Research	Total
Course	Control	18	2	20
	Experimental	16	4	20
Total		34	6	40

To determine statistical significance, a χ^2 analysis is performed and shown in Table 81.

Table 81: χ^2 analysis on Biology and Chemistry Research Course Enrollment in Sections with the Common TA, Spring 2000

Chi-Square Tests

	Value	df	Asymp. Sig. (2-sided)	Exact Sig. (2-sided)	Exact Sig. (1-sided)
Pearson Chi-Square	.784[b]	1	.376		
Continuity Correction[a]	.196	1	.658		
Likelihood Ratio	.797	1	.372		
Fisher's Exact Test				.661	.331
Linear-by-Linear Association	.765	1	.382		
N of Valid Cases	40				

a. Computed only for a 2x2 table

b. 2 cells (50.0%) have expected count less than 5. The minimum expected count is 3.00.

Based on the observed significance, we fail to reject the null hypothesis and conclude that students in the two courses are equally likely to enroll in Biology or Chemistry research courses subsequent to their having successfully completed their General Chemistry laboratory.

Broadening the research course selection to any upper division research course within the realm of the College of Natural Sciences, Table 82 focuses on those students in sections with the common TA in Spring 2000.

Table 82: Natural Sciences Research Enrollment in Sections without the Common TA, Spring 2000

	Took Upper Division Research	Did Not Take Upper Division Research	Successful Students	% Taking Research
Control	2	18	20	10.0%
Experimental	5	15	20	25.0%
Total	7	33	40	17.5%

A χ^2 analysis is then performed to determine if one group of students is more likely to participate in an upper division Natural Sciences research course. The same α level and null hypothesis apply here as in the case of only Biology and Chemistry research courses. A summary of the enrollment information is found in Table 83.

Table 83: Upper Division Natural Sciences Research Course Enrollment in Sections with the Common TA

Course * AllUpperDiv Crosstabulation

Count

		AllUpperDiv		
		Did Not Take an Upper Div Research Course	Took an Upper Div Research Course	Total
Course	Control	18	2	20
	Experimental	15	5	20
Total		33	7	40

The χ^2 analysis is shown in Table 84.

Table 84: χ^2 analysis on Upper Division Natural Sciences Research Course Enrollment in Sections with the Common TA, Spring 2000

Chi-Square Tests

	Value	df	Asymp. Sig. (2-sided)	Exact Sig. (2-sided)	Exact Sig. (1-sided)
Pearson Chi-Square	1.558[b]	1	.212		
Continuity Correction[a]	.693	1	.405		
Likelihood Ratio	1.601	1	.206		
Fisher's Exact Test				.407	.204
Linear-by-Linear Association	1.519	1	.218		
N of Valid Cases	40				

a. Computed only for a 2x2 table

b. 2 cells (50.0%) have expected count less than 5. The minimum expected count is 3.50.

As in the case of considering only Biology and Chemistry research, we fail to reject the null hypothesis as the observed significance of 0.212 for the Pearson Chi-Square exceeds the desired α level of 0.05. We conclude that students in the control and experimental groups are equally likely to enroll in upper division Natural Sciences research courses subsequent to their having successfully completed their General Chemistry laboratory.

Retention in Science and Engineering Majors

Defining science and engineering majors as before, the enrollment on the twelfth class day, by college, of the students who successfully completed either the experimental or control course in Spring 2000 is outlined in Table 85.

Table 85: Enrollment by College, Spring 2000

	Control		Experimental		Total
	Without Common TA	With Common TA	Without Common TA	With Common TA	
Architecture	0	0	0	0	0
Business	9	0	3	1	13
Communication	1	0	1	0	2
Education	3	0	1	1	5
Engineering	50	1	14	3	68
Fine Arts	1	0	2	0	3
Liberal Arts	30	2	13	3	48
Natural Sciences	287	16	99	12	414
Nursing	6	0	0	0	6
Pharmacy	0	0	0	0	0
Social Work	0	1	0	0	1
Total	387	20	133	20	560

Comparing only those sections which had the common TA, Table 86 shows the number of students who began as Natural Science majors and who were retained as Natural Science, Engineering, or Pharmacy majors in Spring 2000 for both the experimental and control courses.

Table 86: Natural Sciences Retention in Sections with the Common TA

	At start of Laboratory	Ending Science	Ending Eng.	Ending Pharm.	Total Retained	% Retained
Control	16	13	0	1	14	87.5%
Experimental	12	10	0	1	11	91.7%

Likewise, Table 87 shows retention data for Engineering majors in those sections.

Table 87: Engineering Retention in Sections with the Common TA

	At start of Laboratory	Ending Science	Ending Eng.	Ending Pharm.	Total Retained	% Retained
Control	1	0	0	1	1	100.0
Experimental	3	1	2	0	3	100.0

In sum, 90.6% of successful students are retained as Science and Engineering majors between the two sections, as shown in Table 88.

Table 88: Total Natural Sciences and Engineering Retention in Sections with the Common TA, Spring 2000

	At start of Laboratory	Ending Science	Ending Eng.	Ending Pharm.	Total Retained	% Retained
Control	17	13	0	2	15	88.2
Experimental	15	11	2	1	14	93.3
Total	32	24	2	3	29	90.6%

A χ^2 analysis is then performed to determine if students in one group are more likely to be retained as Science or Engineering majors. An α level of 0.05 is selected. The null hypothesis is that there is no difference in the retention rate as Science, Engineering, and Pharmacy majors for students in the experimental course as compared to the retention rate of the students in the control course. If the observed significance is less than 0.05, the null hypothesis is rejected in favor of the alternative hypothesis, which is that there is a difference in the retention rates between the students in the two courses. A summary of the retention data is found in Table 89.

Table 89: Summary of Retention Data in Sections with the Common TA, Spring 2000

Course * Retention Crosstabulation

Count

		Retention		
		Not Retained	Retained	Total
Course	Control	2	15	17
	Experimental	1	14	15
Total		3	29	32

The χ^2 analysis on the retention data is shown in Table 39.

Table 90: χ^2 analysis on Retention Data in Sections with the Common TA

Chi-Square Tests

	Value	df	Asymp. Sig. (2-sided)	Exact Sig. (2-sided)	Exact Sig. (1-sided)
Pearson Chi-Square	.244[b]	1	.621		
Continuity Correction[a]	.000	1	1.000		
Likelihood Ratio	.249	1	.618		
Fisher's Exact Test				1.000	.548
Linear-by-Linear Association	.236	1	.627		
N of Valid Cases	32				

a. Computed only for a 2x2 table

b. 2 cells (50.0%) have expected count less than 5. The minimum expected count is 1.41.

Based on the observed significance of 0.621 for the Pearson Chi-Square, we fail to reject the null hypothesis and conclude that students in the control and experimental groups are equally likely to be retained as Natural Sciences, Engineering, or Pharmacy majors.

EFFECT OF A DIFFERENT INSTRUCTOR ON THE EXPERIMENTAL COURSE

In Fall 2000, the head teaching assistant assumed the role of the instructor for the experimental course. One section of the experimental course was also chosen by the College of Natural Sciences to service the PENS (Partnership for Excellence in the Natural Sciences) students. The analysis of the impact of the experimental course on these students follows this section.

Survey Data

The same survey that was used in Spring 2000 was employed again for students in the experimental, control, and PENS groups. A total of 100 surveys were returned: 39 from the control group, 46 from the experimental group, and 15 from the PENS group. The surveys from the PENS group are excluded from this analysis. As before, only the common survey responses are included in Table 91, but the full set of survey responses appears for the control and experimental groups in Appendix I.

Table 91: Survey Data for Control versus Experimental

New #	Statement	Control	Experimental
	IMPACT ON LEARNING		
10	Activities: Lab Lecture	3.436 ± 1.142	3.152 ± 1.074
11	Activities: Wet Lab	3.410 ± 1.141	3.717 ± 0.958
12	Activities: Exams	2.811 ± 1.126	3.174 ± 0.902
13	Activities: Quizzes	3.000 ± 1.162	3.000 ± 0.816

Table 91 continues on the next page

Table 91, continued

New #	Statement	Control	Experimental
14	Activities: Homework/Exercises	3.077 ± 1.285	3.047 ± 1.090
	IMPACT ON CONFIDENCE		
15	Activities: Lab Lecture	3.436 ± 1.142	3.326 ± 0.967
16	Activities: Wet Lab	3.385 ± 1.091	3.587 ± 0.884
17	Activities: Exams	2.865 ± 1.110	3.022 ± 1.043
18	Activities: Quizzes	2.974 ± 1.219	3.043 ± 0.815
19	Activities: Homework/Exercises	2.923 ± 1.306	2.952 ± 1.035
	IMPACT ON ENTHUSIASM		
20	Activities: Lab Lecture	2.921 ± 1.148	2.500 ± 1.027
21	Activities: Wet Lab	3.053 ± 1.413	3.196 ± 1.185
22	Activities: Exams	2.500 ± 1.254	2.400 ± 1.009
23	Activities: Quizzes	2.459 ± 1.238	2.239 ± 0.899
24	Activities: Homework/Exercises	2.474 ± 1.289	2.349 ± 1.066
	CONFIDENCE IN YOUR ABILITY TO…		
25	Understand Key Concepts of Chemistry	3.526 ± 1.033	3.682 ± 0.829
26	Solve Chemistry Problems	3.282 ± 1.075	3.422 ± 0.917
27	Understand the Chemistry Underlying Lab Experiments	3.205 ± 1.080	3.489 ± 0.920
28	Perform Lab Experiments	3.667 ± 0.982	3.867 ± 0.786
29	Visualize Key Concepts of Chemistry	3.462 ± 1.097	3.267 ± 1.009
30	Apply your Knowledge of Chemistry to the Real World	3.103 ± 1.188	3.111 ± 0.982
31	Understand Other Areas of Science	3.718 ± 1.050	3.867 ± 0.726
32	Succeed in Another Chemistry Course	3.487 ± 1.097	3.533 ± 0.919

Table 91 continues on the next page

Table 91, continued

New #	Statement	Control	Experimental
33	Succeed in a Chemistry-Related Discipline	3.436 ± 1.165	3.222 ± 0.997
	INTEREST IN..		
34	Studying Chemistry in General	3.128 ± 1.281	2.689 ± 1.125
35	Taking More Chemistry	2.897 ± 1.410	2.511 ± 1.199
36	Pursuing a Chemistry-Related Major	2.487 ± 1.393	2.178 ± 1.284
37	Pursuing a Science-Related Field	3.872 ± 1.174	4.200 ± 0.968
38	Working with Others to Learn Science	3.641 ± 1.158	3.705 ± 1.112
39	Chemistry in Industry	2.436 ± 1.273	2.311 ± 1.145
40	Chemistry in Medicine	3.744 ± 1.163	3.978 ± 1.055
41	Chemistry in the Environment	2.872 ± 1.361	2.756 ± 1.190
42	Science in General	4.103 ± 1.046	4.089 ± 0.925
	IMPRESSIONS OF LECTURE		
43	I enjoyed the formal laboratory (1 hour) lectures.	2.895 ± 1.034	2.717 ± 1.167
44	The organization of the lectures was important for my learning.	3.421 ± 1.130	3.022 ± 1.125
45	The applications of chemistry discussed in this course made certain concepts easier to understand.	3.395 ± 1.220	3.304 ± 1.030
46	The applications of chemistry discussed in this course made learning chemistry interesting.	3.184 ± 1.111	3.043 ± 1.032
	IMPRESSIONS OF LABS		
47	I enjoyed the labs.	2.973 ± 1.142	3.152 ± 1.229
48	I understood the chemistry behind the labs before I did them.	2.703 ± 1.077	2.891 ± 0.994

Table 91 continues on the next page

Table 91, continued

New #	Statement	Control	Experimental
49	Eventually I understood the chemistry behind the labs.	3.378 ± 1.089	3.674 ± 1.012
50	The labs helped me understand important concepts in this course.	3.135 ± 1.110	3.500 ± 0.863
51	Enough time was allowed for labs.	3.351 ± 1.184	3.935 ± 1.181
	GENERAL QUESTION		
52	Would you recommend this course to a friend?	2.216 ± 1.134	4.087 ± 1.092

As with the other survey data, a MANOVA (Multiple Analysis of Variance) is utilized to assess differences in student reaction to the two courses. An overall MANOVA is performed first in order to determine if students in the two groups respond differently to the survey. As has been the case in the analysis of previous surveys, the null hypothesis is that there is no difference in how students in the two groups respond to the survey. An α level of 0.05 is selected, and should the observed significance be less than this value, the null hypothesis is rejected in favor of the alternative hypothesis, that there is a difference in how students in the two groups respond to the survey. The analysis is shown in Table 92.

Table 92: Overall MANOVA on Survey Data for Sections with the Different Instructor

Multivariate Tests[b]

Effect		Value	F	Hypothesis df	Error df	Sig.
Intercept	Pillai's Trace	.991	79.210[a]	43.000	30.000	.000
	Wilks' Lambda	.009	79.210[a]	43.000	30.000	.000
	Hotelling's Trace	113.535	79.210[a]	43.000	30.000	.000
	Roy's Largest Root	113.535	79.210[a]	43.000	30.000	.000
Q1	Pillai's Trace	.784	2.532[a]	43.000	30.000	.005
	Wilks' Lambda	.216	2.532[a]	43.000	30.000	.005
	Hotelling's Trace	3.630	2.532[a]	43.000	30.000	.005
	Roy's Largest Root	3.630	2.532[a]	43.000	30.000	.005

a. Exact statistic

b. Design: Intercept+Q1

The observed significance is indeed less than 0.05, implying that there are survey items on which students in the two groups responded differently. A question by question analysis follows. Using the Bonferroni correction, as previously described, implies that a calculated significance of less than 0.00116 represents a difference between the two student groups. Of the 85 surveys submitted by the control and experimental groups, only 34 from the control group and 40 from the experimental group were fully completed. Uncompleted surveys were not analyzed. The item-by-item analysis follows in Table 93.

Table 93: MANOVA Survey Results, Different Instructor

Tests of Between-Subjects Effects

Source	Dependent Variable	Type III Sum of Squares	df	Mean Square	F	Sig.
Corrected Model	Q10	1.069(a)	1	1.069	.887	.34947
	Q11	2.158(b)	1	2.158	2.044	.15713
	Q12	.943(c)	1	.943	.958	.33096
	Q13	.046(d)	1	.046	.046	.83076
	Q14	.746(e)	1	.746	.549	.46132
	Q15	.301(f)	1	.301	.275	.60155
	Q16	1.450(g)	1	1.450	1.433	.23514
	Q17	.315(f)	1	.315	.282	.59692
	Q18	.001(h)	1	.001	.001	.96946
	Q19	.041(i)	1	.041	.030	.86311
	Q20	2.687(j)	1	2.687	2.210	.14147
	Q21	.508(f)	1	.508	.279	.59882
	Q22	.287(k)	1	.287	.211	.64718
	Q23	1.108(c)	1	1.108	.913	.34260
	Q24	.248(l)	1	.248	.180	.67254
	Q25	.563(m)	1	.563	.640	.42618
	Q26	.472(n)	1	.472	.470	.49535
	Q27	1.375(o)	1	1.375	1.359	.24753
	Q28	1.176(p)	1	1.176	1.426	.23632
	Q29	.582(q)	1	.582	.527	.47033
	Q30	.092(d)	1	.092	.078	.78088
	Q31	.882(r)	1	.882	1.099	.29809
	Q32	.016(h)	1	.016	.015	.90168
	Q33	.859(s)	1	.859	.692	.40822
	Q34	3.138(t)	1	3.138	1.991	.16258
	Q35	3.116(u)	1	3.116	1.858	.17707
	Q36	3.138(v)	1	3.138	1.686	.19825
	Q37	1.043(a)	1	1.043	.875	.35271
	Q38	.010(h)	1	.010	.007	.93197
	Q39	1.190(w)	1	1.190	.790	.37713
	Q40	.746(m)	1	.746	.625	.43173
	Q41	1.837(x)	1	1.837	1.128	.29172
	Q42	.095(d)	1	.095	.094	.75995
	Q43	.077(d)	1	.077	.067	.79629
	Q44	3.366(y)	1	3.366	2.619	.10999
	Q45	.301(k)	1	.301	.229	.63399
	Q46	.943(a)	1	.943	.840	.36259

Table 93 continues on the next page

Table 93, continued

Source	Dependent Variable	Type III Sum of Squares	df	Mean Square	F	Sig.
	Q47	.138(z)	1	.138	.099	.75381
	Q48	1.176(aa)	1	1.176	1.041	.31112
	Q49	1.405(bb)	1	1.405	1.248	.26764
	Q50	1.736(cc)	1	1.736	1.753	.18968
	Q51	3.601(dd)	1	3.601	2.450	.12187
	Q52	59.157(ee)	1	59.157	46.520	**.00000**
Intercept	Q10	810.583	1	810.583	672.509	.000
	Q11	928.374	1	928.374	879.461	.000
	Q12	634.024	1	634.024	644.395	.000
	Q13	650.641	1	650.641	651.545	.000
	Q14	695.449	1	695.449	511.379	.000
	Q15	795.220	1	795.220	727.153	.000
	Q16	867.180	1	867.180	857.252	.000
	Q17	601.126	1	601.126	538.765	.000
	Q18	637.839	1	637.839	658.109	.000
	Q19	608.257	1	608.257	447.500	.000
	Q20	532.417	1	532.417	437.956	.000
	Q21	725.697	1	725.697	399.291	.000
	Q22	436.774	1	436.774	321.305	.000
	Q23	405.217	1	405.217	333.643	.000
	Q24	417.491	1	417.491	303.148	.000
	Q25	946.130	1	946.130	1076.592	.000
	Q26	822.472	1	822.472	818.011	.000
	Q27	806.997	1	806.997	797.677	.000
	Q28	1046.797	1	1046.797	1269.600	.000
	Q29	783.177	1	783.177	708.938	.000
	Q30	690.470	1	690.470	587.838	.000
	Q31	1070.180	1	1070.180	1332.316	.000
	Q32	892.989	1	892.989	863.364	.000
	Q33	816.697	1	816.697	658.056	.000
	Q34	610.436	1	610.436	387.202	.000
	Q35	538.251	1	538.251	320.984	.000
	Q36	416.976	1	416.976	224.030	.000
	Q37	1194.448	1	1194.448	1001.922	.000
	Q38	1000.010	1	1000.010	721.153	.000
	Q39	424.217	1	424.217	281.649	.000
	Q40	1132.097	1	1132.097	948.727	.000
	Q41	569.405	1	569.405	349.634	.000
	Q42	1242.420	1	1242.420	1224.734	.000
	Q43	548.834	1	548.834	478.880	.000

Table 93 continues on the next page

Table 93, continued

Source	Dependent Variable	Type III Sum of Squares	df	Mean Square	F	Sig.
	Q44	724.339	1	724.339	563.568	.000
	Q45	795.220	1	795.220	604.349	.000
	Q46	689.807	1	689.807	614.367	.000
	Q47	720.949	1	720.949	516.448	.000
	Q48	565.500	1	565.500	500.414	.000
	Q49	880.972	1	880.972	782.689	.000
	Q50	786.709	1	786.709	794.384	.000
	Q51	954.682	1	954.682	649.662	.000
	Q52	707.806	1	707.806	556.604	.000
Q1	Q10	1.069	1	1.069	.887	.349
	Q11	2.158	1	2.158	2.044	.157
	Q12	.943	1	.943	.958	.331
	Q13	.046	1	.046	.046	.831
	Q14	.746	1	.746	.549	.461
	Q15	.301	1	.301	.275	.602
	Q16	1.450	1	1.450	1.433	.235
	Q17	.315	1	.315	.282	.597
	Q18	.001	1	.001	.001	.969
	Q19	.041	1	.041	.030	.863
	Q20	2.687	1	2.687	2.210	.141
	Q21	.508	1	.508	.279	.599
	Q22	.287	1	.287	.211	.647
	Q23	1.108	1	1.108	.913	.343
	Q24	.248	1	.248	.180	.673
	Q25	.563	1	.563	.640	.426
	Q26	.472	1	.472	.470	.495
	Q27	1.375	1	1.375	1.359	.248
	Q28	1.176	1	1.176	1.426	.236
	Q29	.582	1	.582	.527	.470
	Q30	.092	1	.092	.078	.781
	Q31	.882	1	.882	1.099	.298
	Q32	.016	1	.016	.015	.902
	Q33	.859	1	.859	.692	.408
	Q34	3.138	1	3.138	1.991	.163
	Q35	3.116	1	3.116	1.858	.177
	Q36	3.138	1	3.138	1.686	.198
	Q37	1.043	1	1.043	.875	.353
	Q38	.010	1	.010	.007	.932
	Q39	1.190	1	1.190	.790	.377
	Q40	.746	1	.746	.625	.432

Table 93 continues on the next page

Table 93, continued

Source	Dependent Variable	Type III Sum of Squares	df	Mean Square	F	Sig.
	Q41	1.837	1	1.837	1.128	.292
	Q42	.095	1	.095	.094	.760
	Q43	.077	1	.077	.067	.796
	Q44	3.366	1	3.366	2.619	.110
	Q45	.301	1	.301	.229	.634
	Q46	.943	1	.943	.840	.363
	Q47	.138	1	.138	.099	.754
	Q48	1.176	1	1.176	1.041	.311
	Q49	1.405	1	1.405	1.248	.268
	Q50	1.736	1	1.736	1.753	.190
	Q51	3.601	1	3.601	2.450	.122
	Q52	59.157	1	59.157	46.520	.000
Error	Q10	86.782	72	1.205		
	Q11	76.004	72	1.056		
	Q12	70.841	72	.984		
	Q13	71.900	72	.999		
	Q14	97.916	72	1.360		
	Q15	78.740	72	1.094		
	Q16	72.834	72	1.012		
	Q17	80.334	72	1.116		
	Q18	69.782	72	.969		
	Q19	97.865	72	1.359		
	Q20	87.529	72	1.216		
	Q21	130.857	72	1.817		
	Q22	97.875	72	1.359		
	Q23	87.446	72	1.215		
	Q24	99.157	72	1.377		
	Q25	63.275	72	.879		
	Q26	72.393	72	1.005		
	Q27	72.841	72	1.012		
	Q28	59.365	72	.825		
	Q29	79.540	72	1.105		
	Q30	84.571	72	1.175		
	Q31	57.834	72	.803		
	Q32	74.471	72	1.034		
	Q33	89.357	72	1.241		
	Q34	113.510	72	1.577		
	Q35	120.735	72	1.677		
	Q36	134.010	72	1.861		
	Q37	85.835	72	1.192		

Table 93 continues on the next page

Table 93, continued

Source	Dependent Variable	Type III Sum of Squares	df	Mean Square	F	Sig.
	Q38	99.841	72	1.387		
	Q39	108.446	72	1.506		
	Q40	85.916	72	1.193		
	Q41	117.257	72	1.629		
	Q42	73.040	72	1.014		
	Q43	82.518	72	1.146		
	Q44	92.540	72	1.285		
	Q45	94.740	72	1.316		
	Q46	80.841	72	1.123		
	Q47	100.510	72	1.396		
	Q48	81.365	72	1.130		
	Q49	81.041	72	1.126		
	Q50	71.304	72	.990		
	Q51	105.804	72	1.470		
	Q52	91.559	72	1.272		
Total	Q10	899.000	74			
	Q11	1020.000	74			
	Q12	714.000	74			
	Q13	726.000	74			
	Q14	795.000	74			
	Q15	877.000	74			
	Q16	953.000	74			
	Q17	688.000	74			
	Q18	712.000	74			
	Q19	711.000	74			
	Q20	620.000	74			
	Q21	865.000	74			
	Q22	536.000	74			
	Q23	493.000	74			
	Q24	518.000	74			
	Q25	1020.000	74			
	Q26	904.000	74			
	Q27	892.000	74			
	Q28	1120.000	74			
	Q29	865.000	74			
	Q30	781.000	74			
	Q31	1141.000	74			
	Q32	974.000	74			
	Q33	908.000	74			
	Q34	724.000	74			

Table 93 continues on the next page

Table 93, continued

Source	Dependent Variable	Type III Sum of Squares	df	Mean Square	F	Sig.
	Q35	659.000	74			
	Q36	551.000	74			
	Q37	1295.000	74			
	Q38	1107.000	74			
	Q39	533.000	74			
	Q40	1231.000	74			
	Q41	687.000	74			
	Q42	1322.000	74			
	Q43	634.000	74			
	Q44	817.000	74			
	Q45	893.000	74			
	Q46	772.000	74			
	Q47	828.000	74			
	Q48	656.000	74			
	Q49	975.000	74			
	Q50	871.000	74			
	Q51	1080.000	74			
	Q52	897.000	74			
Corrected Total	Q10	87.851	73			
	Q11	78.162	73			
	Q12	71.784	73			
	Q13	71.946	73			
	Q14	98.662	73			
	Q15	79.041	73			
	Q16	74.284	73			
	Q17	80.649	73			
	Q18	69.784	73			
	Q19	97.905	73			
	Q20	90.216	73			
	Q21	131.365	73			
	Q22	98.162	73			
	Q23	88.554	73			
	Q24	99.405	73			
	Q25	63.838	73			
	Q26	72.865	73			
	Q27	74.216	73			
	Q28	60.541	73			
	Q29	80.122	73			
	Q30	84.662	73			
	Q31	58.716	73			

Table 93 continues on the next page

Table 93, continued

Source	Dependent Variable	Type III Sum of Squares	df	Mean Square	F	Sig.
	Q32	74.486	73			
	Q33	90.216	73			
	Q34	116.649	73			
	Q35	123.851	73			
	Q36	137.149	73			
	Q37	86.878	73			
	Q38	99.851	73			
	Q39	109.635	73			
	Q40	86.662	73			
	Q41	119.095	73			
	Q42	73.135	73			
	Q43	82.595	73			
	Q44	95.905	73			
	Q45	95.041	73			
	Q46	81.784	73			
	Q47	100.649	73			
	Q48	82.541	73			
	Q49	82.446	73			
	Q50	73.041	73			
	Q51	109.405	73			
	Q52	150.716	73			

a R Squared = .012 (Adjusted R Squared = -.002)
b R Squared = .028 (Adjusted R Squared = .014)
c R Squared = .013 (Adjusted R Squared = -.001)
d R Squared = .001 (Adjusted R Squared = -.013)
e R Squared = .008 (Adjusted R Squared = -.006)
f R Squared = .004 (Adjusted R Squared = -.010)
g R Squared = .020 (Adjusted R Squared = .006)
h R Squared = .000 (Adjusted R Squared = -.014)
i R Squared = .000 (Adjusted R Squared = -.013)
j R Squared = .030 (Adjusted R Squared = .016)
k R Squared = .003 (Adjusted R Squared = -.011)
l R Squared = .002 (Adjusted R Squared = -.011)
m R Squared = .009 (Adjusted R Squared = -.005)
n R Squared = .006 (Adjusted R Squared = -.007)
o R Squared = .019 (Adjusted R Squared = .005)
p R Squared = .019 (Adjusted R Squared = .006)
q R Squared = .007 (Adjusted R Squared = -.007)
r R Squared = .015 (Adjusted R Squared = .001)
s R Squared = .010 (Adjusted R Squared = -.004)
t R Squared = .027 (Adjusted R Squared = .013)
u R Squared = .025 (Adjusted R Squared = .012)
v R Squared = .023 (Adjusted R Squared = .009)
w R Squared = .011 (Adjusted R Squared = -.003)

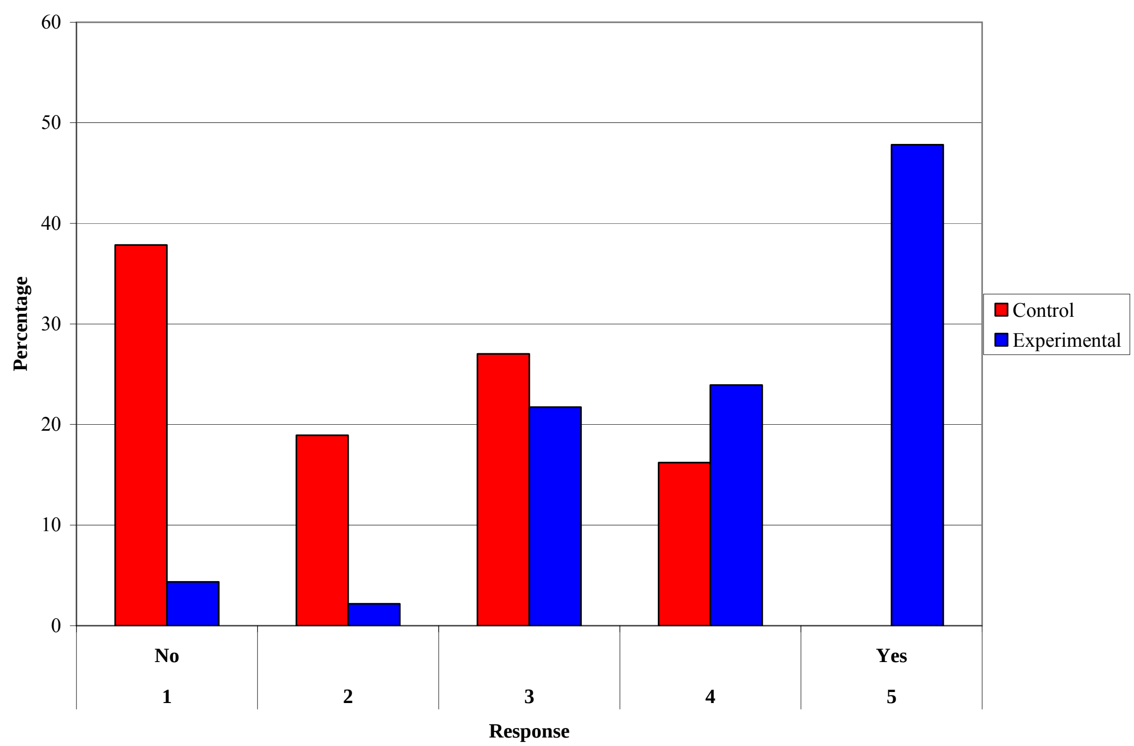
Table 93 continues on the next page

Table 93, continued

x R Squared = .015 (Adjusted R Squared = .002)
y R Squared = .035 (Adjusted R Squared = .022)
z R Squared = .001 (Adjusted R Squared = -.012)
aa R Squared = .014 (Adjusted R Squared = .001)
bb R Squared = .017 (Adjusted R Squared = .003)
cc R Squared = .024 (Adjusted R Squared = .010)
dd R Squared = .033 (Adjusted R Squared = .019)
ee R Squared = .393 (Adjusted R Squared = .384)

The analysis shows a difference in only one question, q52, “Would you recommend this course to a friend?” A histogram depicting the difference in response between the two groups is shown in Figure 4.

Figure 4: Histogram of “Would You Recommend This Course to a Friend?”, Different Instructor



Drop and Withdraw Data

The number of students who either dropped or withdrew from the control and experimental groups, excluding the PENS students, is shown in Table 94.

Table 94: Drops and Withdraws, Different Instructor

	Q	W	Total Dropped	Students	% Dropped
Control	36	11	47	322	14.6%
Experimental	2	0	2	123	1.6%

Consistent with the pattern of previous semesters, the number of students who dropped the course with either a "Q" or "W" is higher in the control group than it is in the experimental group. For Fall 2000, as shown in Table 95, a total of 455 students were enrolled in the experimental and control courses at the twelfth class day.

Table 95: Drop-Withdraw Cases for the Control and Experimental Groups, Fall 2000

Case Processing Summary

	Cases					
	Valid		Missing		Total	
	N	Percent	N	Percent	N	Percent
Course * Total	445	100.0%	0	.0%	445	100.0%

Of these 445 students, 123 were enrolled in the experimental course and 322 were enrolled in the control course, as shown in Table 96.

Table 96: Drop – Withdraw Count for the Control and Experimental Groups, Different Instructor

Course * Total Crosstabulation

Count

		Total		
		Finished Course	Dropped or Withdrawn	Total
Course	Control	275	47	322
	Experimental	121	2	123
Total		396	49	445

A χ^2 analysis is then performed to determine statistical significance. An α level of 0.05 is selected. The null hypothesis is that there is no difference in the drop and withdraw rate of the students in the experimental course as compared to that of students in the control course. If the observed significance is less than 0.05, the null hypothesis is rejected in favor of the alternative hypothesis, which is that the drop and withdraw rates between the two courses are different. The χ^2 analysis is shown in Table 97.

Table 97: χ^2 analysis on Drop – Withdraw Data for the Control and Experimental Groups, Different Instructor

Chi-Square Tests

	Value	df	Asymp. Sig. (2-sided)	Exact Sig. (2-sided)	Exact Sig. (1-sided)
Pearson Chi-Square	15.280[b]	1	.000		
Continuity Correction[a]	13.985	1	.000		
Likelihood Ratio	20.491	1	.000		
Fisher's Exact Test				.000	.000
Linear-by-Linear Association	15.246	1	.000		
N of Valid Cases	445				

a. Computed only for a 2x2 table

b. 0 cells (.0%) have expected count less than 5. The minimum expected count is 13.54.

According to the analysis, we reject the null hypothesis as the observed significance (0.000 for the Pearson Chi-Square) is smaller than the desired α level of 0.05 in favor of the alternative hypothesis, which is that there is a difference in the drop rate between the two courses. Thus, students in the control section in Fall 2000 are more likely to drop or withdraw than students in the experimental course.

Longitudinal Studies

As with drop and withdraw data, we compare the control and experimental groups. A breakdown of the grade distribution in Fall 2000 appears in Table 98.

Table 98: Final Course Grades, Different Instructor

	A	B	C	CR	D	F	Q	W	Students	% Success
Control	52	97	62	1	40	23	36	11	322	65.8%
Experimental	43	57	19	0	2	0	2	0	123	96.8%

Only students who were successful in completing their laboratory course are considered for the longitudinal studies.

Enrollment in Research Courses

Data from the registrar provides us with insight on which students took subsequent upper division research courses in Chemistry or Biology. Table 99 summarizes the number of successful students who took research courses in Chemistry or Biology after having been enrolled in either the control or experimental course in Fall 2000.

Table 99: Biology and Chemistry Research Enrollment for the Control and Experimental Groups, Different Instructor

	Took Biology or Chemistry Research	**Did Not Take Biology or Chemistry Research**	**Successful Students**	**% Taking Research**
Control	24	188	212	11.3%
Experimental	20	99	119	16.8%
Total	44	287	331	13.3%

A χ^2 analysis is then performed to determine if students from one of the two laboratory courses is more likely to enroll in Biology or Chemistry research courses. An α level of 0.05 is selected. The null hypothesis is that there is no difference in the number of students who subsequently enroll in Biology or Chemistry research courses in the experimental course as compared to students in the control course. If the observed significance is less than 0.05, the null hypothesis is rejected in favor of the alternative hypothesis, which is that students in one course enroll more frequently in subsequent

Biology or Chemistry research courses than students in the other course. A summary of the enrollment information is found in Table 100.

Table 100: Biology and Chemistry Research Course Enrollment in the Control and Experimental Groups, Different Instructor

Course * ChemBio Crosstabulation

Count

		ChemBio		Total
		Did Not Take Chem or Bio Upper Div Research	Took Chem or Bio Upper Div Research	
Course	Control	188	24	212
	Experimental	99	20	119
Total		287	44	331

To determine statistical significance, a χ^2 analysis is performed and shown in Table 101.

Table 101: χ^2 analysis on Biology and Chemistry Research Course Enrollment in the Control and Experimental Groups, Different Instructor

Chi-Square Tests

	Value	df	Asymp. Sig. (2-sided)	Exact Sig. (2-sided)	Exact Sig. (1-sided)
Pearson Chi-Square	1.990[b]	1	.158		
Continuity Correction[a]	1.543	1	.214		
Likelihood Ratio	1.939	1	.164		
Fisher's Exact Test				.178	.108
Linear-by-Linear Association	1.984	1	.159		
N of Valid Cases	331				

a. Computed only for a 2x2 table

b. 0 cells (.0%) have expected count less than 5. The minimum expected count is 15.82.

Based on the observed significance, we fail to reject the null hypothesis and conclude that students in the control and experimental groups are equally likely to enroll in Biology or Chemistry research courses subsequent to their having successfully completed their General Chemistry laboratory.

Considering any upper division research course within the realm of the College of Natural Sciences, Table 102 summarizes the enrollment data for the control and experimental groups in Fall 2000.

Table 102: Natural Sciences Research Enrollment, Different Instructor

	Took Upper Division Research	**Did Not Take Upper Division Research**	**Successful Students**	**% Taking Research**
Control	31	181	212	14.6%
Experimental	25	94	119	21.0%
Total	56	275	331	16.9%

A χ^2 analysis is then performed to determine if one group of students is more likely to participate in an upper division Natural Sciences research course. An α level of 0.05 is selected. The null hypothesis is that there is no difference in the number of students who subsequently enroll in upper division Natural Sciences research courses in the experimental course as compared to students in the control course. If the observed significance is less than 0.05, the null hypothesis is rejected in favor of the alternative hypothesis, which is that students in one course enroll more frequently in subsequent upper division Natural Sciences research courses than students in the other course. A comparison of the control and experimental groups is found in Table 103.

Table 103: Upper Division Natural Sciences Research Course Enrollment in the Control and Experimental Groups, Different Instructor

Course * AllUpperDiv Crosstabulation

Count

		AllUpperDiv: Did Not Take an Upper Div Research Course	AllUpperDiv: Took an Upper Div Research Course	Total
Course	Control	181	31	212
	Experimental	94	25	119
Total		275	56	331

The χ^2 analysis is shown in Table 104.

Table 104: χ^2 analysis on Upper Division Natural Sciences Research Course Enrollment in the Control and Experimental Groups, Different Instructor

Chi-Square Tests

	Value	df	Asymp. Sig. (2-sided)	Exact Sig. (2-sided)	Exact Sig. (1-sided)
Pearson Chi-Square	2.211[b]	1	.137		
Continuity Correction[a]	1.780	1	.182		
Likelihood Ratio	2.161	1	.142		
Fisher's Exact Test				.169	.092
Linear-by-Linear Association	2.204	1	.138		
N of Valid Cases	331				

a. Computed only for a 2x2 table

b. 0 cells (.0%) have expected count less than 5. The minimum expected count is 20.13.

As in the case of considering only Biology and Chemistry research, we fail to reject the null hypothesis as the observed significance of 0.137 for the Pearson Chi-

Square exceeds the desired α level of 0.05. We conclude that students in the control and experimental groups are equally likely to enroll in upper division Natural Sciences research courses subsequent to their having successfully completed their General Chemistry laboratory.

Retention in Science and Engineering Majors

Defining science and engineering majors as before, the enrollment on the twelfth class day, by college, of successful students in the control and experimental groups in Fall 2000 is outlined in Table 105.

Table 105: Enrollment by College, Different Instructor

	Control	Experimental	Total
Architecture	0	0	0
Business	2	7	9
Communication	3	2	5
Education	1	2	3
Engineering	27	3	30
Fine Arts	2	1	3
Liberal Arts	17	10	27
Natural Sciences	156	90	246
Nursing	4	4	8
Pharmacy	0	0	0
Social Work	0	0	0
Total	212	119	331

As Table 105 shows, 246 (74.3%) of the 331 successful students were in the College of Natural Sciences at the beginning of their laboratory experience. An additional 30 (9.1%) of the successful students were in the College of Engineering. Turning our attention to these 276 students, Table 106 shows the number of students who began as Natural Science majors and who were retained as Natural Science, Engineering, or Pharmacy majors in Fall 2000 for the two student groups.

Table 106: Natural Sciences Retention, Fall 2000

	At start of Laboratory	**Ending Science**	**Ending Eng.**	**Ending Pharm.**	**Total Retained**	**% Retained**
Control	156	118	4	3	125	80.1%
Experimental	90	70	0	2	72	80.0%

Likewise, Table 107 shows retention data for Engineering majors in Fall 2000.

Table 107: Engineering Retention, Different Instructor

	At start of Laboratory	**Ending Science**	**Ending Eng.**	**Ending Pharm.**	**Total Retained**	**% Retained**
Control	27	8	16	0	24	88.9%
Experimental	3	2	0	0	2	66.7%

In sum, 80.8% of successful students are retained as Science and Engineering majors, as shown in Table 108.

Table 108: Total Natural Sciences and Engineering Retention, Different Instructor

	At start of Laboratory	Ending Science	Ending Eng.	Ending Pharm.	Total Retained	% Retained
Control	183	126	20	3	149	81.4%
Experimental	93	72	0	2	74	79.6%
Total	276	198	20	5	223	80.8%

A χ^2 analysis is then performed to compare the control and experimental groups to evaluate any differences between these groups with respect to retention as Science or Engineering majors. An α level of 0.05 is selected. The null hypothesis is that there is no difference in the retention rate as Science, Engineering, and Pharmacy majors for students between the groups being compared. If the observed significance is less than 0.05, the null hypothesis is rejected in favor of the alternative hypothesis, which is that there is a difference in the retention rates between the students in the two courses. A summary of the retention data is found in Table 109.

Table 109: Summary of Retention Data in the Control and Experimental Groups, Different Instructor

Course * Retention Crosstabulation

Count

		Retention		Total
		Not Retained	Retained	
Course	Control	34	149	183
	Experimental	19	74	93
Total		53	223	276

The χ^2 analysis on the retention data is shown in Table 110.

Table 110: χ^2 analysis on Retention Data in the Control and Experimental Groups, Different Instructor

Chi-Square Tests

	Value	df	Asymp. Sig. (2-sided)	Exact Sig. (2-sided)	Exact Sig. (1-sided)
Pearson Chi-Square	.136[b]	1	.712		
Continuity Correction[a]	.043	1	.836		
Likelihood Ratio	.135	1	.713		
Fisher's Exact Test				.748	.414
Linear-by-Linear Association	.136	1	.713		
N of Valid Cases	276				

a. Computed only for a 2x2 table

b. 0 cells (.0%) have expected count less than 5. The minimum expected count is 17.86.

Based on the observed significance for the Pearson Chi-Square, we fail to reject the null hypothesis and conclude that students in the control and experimental groups are equally likely to be retained as Natural Sciences, Engineering, or Pharmacy majors.

EFFECT OF THE EXPERIMENTAL COURSE ON AN AT-RISK STUDENT GROUP

Students in the Partnership for Excellence in the Natural Sciences (PENS) appeared in the experimental course twice over the study period. One section of PENS students, comprising 17 individuals, appeared in Fall 2000, while in Spring 2001, two sections with a total of 41 students took part in the experimental course. This group of students was perceived by the University to be at risk for not being able to graduate with major in the Natural Sciences. Unlike other students who selected their laboratory course on their own and, in principle, could select either the control or experimental course at any time it was offered, PENS students were assigned specific sections unique to them. Hence, this group of students is different than other students in the experimental course.

As these students only appeared in the experimental course, their fates are compared to other students in the experimental course during the Fall 2000-Spring 2001 timeframe.

Survey Data

PENS students received the same survey as other students in both the experimental and control courses. In an effort to maximize the number of surveys analyzed, data from Fall 2000 and Spring 2001 are combined for analysis, although the full set of survey data appears in Appendices J (for Fall 2000) and K (for Spring 2001). Combining these two semesters, a summary of the survey responses appears in Table 111, below.

Table 111: Survey Data for Experimental versus PENS

New #	Statement	Experimental	PENS
	IMPACT ON LEARNING		
10	Activities: Lab Lecture	3.106 ± 1.114	2.769 ± 1.165
11	Activities: Wet Lab	3.868 ± 0.998	3.462 ± 1.290
12	Activities: Exams	3.417 ± 0.955	3.212 ± 1.194
13	Activities: Quizzes	3.099 ± 1.031	3.019 ± 1.213
14	Activities: Homework/Exercises	3.265 ± 1.062	2.942 ± 1.243
	IMPACT ON CONFIDENCE		
15	Activities: Lab Lecture	3.255 ± 1.054	2.647 ± 1.180
16	Activities: Wet Lab	3.682 ± 1.061	3.137 ± 1.429
17	Activities: Exams	3.444 ± 1.056	3.137 ± 1.312
18	Activities: Quizzes	3.192 ± 1.063	2.980 ± 1.304

Table 111 continues on the next page

Table 111, continued

New #	Statement	Experimental	PENS
19	Activities: Homework/Exercises	3.226 ± 1.022	2.961 ± 1.113
	IMPACT ON ENTHUSIASM		
20	Activities: Lab Lecture	2.527 ± 1.208	2.314 ± 1.191
21	Activities: Wet Lab	3.127 ± 1.244	2.529 ± 1.376
22	Activities: Exams	2.567 ± 1.155	2.235 ± 1.142
23	Activities: Quizzes	2.351 ± 1.109	2.294 ± 1.154
24	Activities: Homework/Exercises	2.497 ± 1.069	2.314 ± 1.208
	CONFIDENCE IN YOUR ABILITY TO…		
25	Understand Key Concepts of Chemistry	3.848 ± 0.806	3.686 ± 0.948
26	Solve Chemistry Problems	3.737 ± 0.874	3.712 ± 0.997
27	Understand the Chemistry Underlying Lab Experiments	3.533 ± 0.927	3.077 ± 1.007
28	Perform Lab Experiments	3.868 ± 0.789	3.769 ± 1.002
29	Visualize Key Concepts of Chemistry	3.563 ± 0.861	3.346 ± 0.988
30	Apply your Knowledge of Chemistry to the Real World	3.278 ± 0.925	3.173 ± 0.985
31	Understand Other Areas of Science	3.947 ± 0.728	4.038 ± 0.907
32	Succeed in Another Chemistry Course	3.755 ± 0.879	3.865 ± 0.971
33	Succeed in a Chemistry-Related Discipline	3.464 ± 0.922	3.519 ± 1.057
	INTEREST IN..		
34	Studying Chemistry in General	2.881 ± 1.119	2.942 ± 1.211

Table 111 continues on the next page

Table 111, continued

New #	Statement	Experimental	PENS
35	Taking More Chemistry	2.722 ± 1.276	2.808 ± 1.284
36	Pursuing a Chemistry-Related Major	2.285 ± 1.288	2.423 ± 1.500
37	Pursuing a Science-Related Field	4.258 ± 0.969	4.192 ± 1.085
38	Working with Others to Learn Science	3.813 ± 1.071	3.692 ± 1.229
39	Chemistry in Industry	2.358 ± 1.098	2.308 ± 1.213
40	Chemistry in Medicine	3.887 ± 1.192	3.885 ± 1.182
41	Chemistry in the Environment	2.881 ± 1.216	2.846 ± 1.195
42	Science in General	4.099 ± 1.106	4.115 ± 0.963
	IMPRESSIONS OF LECTURE		
43	I enjoyed the formal laboratory (1 hour) lectures.	2.675 ± 1.164	2.500 ± 1.129
44	The organization of the lectures was important for my learning.	3.099 ± 1.088	2.981 ± 1.336
45	The applications of chemistry discussed in this course made certain concepts easier to understand.	3.464 ± 0.998	3.077 ± 1.169
46	The applications of chemistry discussed in this course made learning chemistry interesting.	3.265 ± 1.088	2.846 ± 1.211
	IMPRESSIONS OF LABS		
47	I enjoyed the labs.	3.197 ± 1.213	2.673 ± 1.410
48	I understood the chemistry behind the labs before I did them.	2.941 ± 1.111	2.462 ± 1.075
49	Eventually I understood the chemistry behind the labs.	3.914 ± 0.963	3.596 ± 1.225

Table 111 continues on the next page

Table 111, continued

New #	Statement	Experimental	PENS
50	The labs helped me understand important concepts in this course.	3.656 ± 0.917	3.212 ± 1.242
51	Enough time was allowed for labs.	3.987 ± 1.162	2.942 ± 1.420
	GENERAL QUESTION		
52	Would you recommend this course to a friend?	3.689 ± 1.292	2.500 ± 1.350

As with previous analyses, a MANOVA is analyzed to assess differences, if any, in student reaction. In this case, the student groups come from (possibly) different populations but are evaluating the same experience. First, an overall MANOVA is performed to confirm that there is a difference between the two student groups. An α level of 0.05 is selected, and an observed significance less than this value indicates a difference in student opinion as measured by the survey. The result of this test is shown in Table 112.

Table 112: Overall MANOVA, Experimental versus PENS

Multivariate Tests[b]

Effect		Value	F	Hypothesis df	Error df	Sig.
Intercept	Pillai's Trace	.980	168.814[a]	43.000	146.000	.000
	Wilks' Lambda	.020	168.814[a]	43.000	146.000	.000
	Hotelling's Trace	49.719	168.814[a]	43.000	146.000	.000
	Roy's Largest Root	49.719	168.814[a]	43.000	146.000	.000
Q1	Pillai's Trace	.387	2.141[a]	43.000	146.000	.000
	Wilks' Lambda	.613	2.141[a]	43.000	146.000	.000
	Hotelling's Trace	.631	2.141[a]	43.000	146.000	.000
	Roy's Largest Root	.631	2.141[a]	43.000	146.000	.000

a. Exact statistic

b. Design: Intercept+Q1

The result of this analysis suggests that there is a difference in how students in the two groups responded to the survey. With this difference confirmed, an item-by-item analysis is appropriate, and the results of this analysis are shown in Table 113. Of the 207 surveys collected, 140 in the Experimental group and 50 in the PENS group had all items marked and were evaluated. Uncompleted surveys were not analyzed. As before, a Bonferroni correction was applied to control the Type I error rate as 43 items on the survey were analyzed. The null hypothesis is that there is no difference in how students responded to each individual item on the survey. Should the observed significance be less than 0.00116, the null hypothesis is rejected in favor of the alternative hypothesis, which is that there is a difference in student opinion on that survey item.

Table 113: Survey Results, Experimental versus PENS

Tests of Between-Subjects Effects

Source	Dependent Variable	Type III Sum of Squares	df	Mean Square	F	Sig.
Corrected Model	Q10	3.160(a)	1	3.160	2.457	.11870
	Q11	5.811(b)	1	5.811	4.843	.02897
	Q12	1.647(c)	1	1.647	1.568	.21199
	Q13	.000(d)	1	.000	.000	.98729
	Q14	3.068(a)	1	3.068	2.449	.11927
	Q15	9.962(e)	1	9.962	8.700	.00359
	Q16	11.495(f)	1	11.495	8.318	.00438
	Q17	3.347(g)	1	3.347	2.585	.10953
	Q18	.926(h)	1	.926	.727	.39490
	Q19	2.250(i)	1	2.250	2.025	.15638
	Q20	1.119(h)	1	1.119	.767	.38217
	Q21	13.012(j)	1	13.012	7.725	.00600
	Q22	3.573(g)	1	3.573	2.605	.10822
	Q23	.033(d)	1	.033	.026	.87285
	Q24	.861(k)	1	.861	.715	.39873
	Q25	1.138(c)	1	1.138	1.591	.20879
	Q26	.139(l)	1	.139	.175	.67619
	Q27	6.857(m)	1	6.857	7.919	.00541

Table 113 continues on the next page

Table 113, continued

Source	Dependent Variable	Type III Sum of Squares	df	Mean Square	F	Sig.
	Q28	.506(k)	1	.506	.685	.40894
	Q29	2.276(n)	1	2.276	2.873	.09174
	Q30	.262(o)	1	.262	.292	.58968
	Q31	.047(d)	1	.047	.078	.77991
	Q32	.146(l)	1	.146	.176	.67495
	Q33	.009(d)	1	.009	.010	.92186
	Q34	.289(l)	1	.289	.218	.64135
	Q35	.469(o)	1	.469	.290	.59096
	Q36	.977(p)	1	.977	.533	.46643
	Q37	.152(q)	1	.152	.151	.69776
	Q38	.328(l)	1	.328	.266	.60646
	Q39	.009(d)	1	.009	.007	.93310
	Q40	.173(q)	1	.173	.124	.72546
	Q41	.051(d)	1	.051	.034	.85377
	Q42	.015(d)	1	.015	.013	.91083
	Q43	.623(r)	1	.623	.468	.49493
	Q44	.033(d)	1	.033	.025	.87510
	Q45	4.662(s)	1	4.662	4.132	.04349
	Q46	5.360(t)	1	5.360	4.184	.04221
	Q47	10.972(u)	1	10.972	6.682	.01050
	Q48	8.949(v)	1	8.949	7.465	.00689
	Q49	2.743(a)	1	2.743	2.489	.11632
	Q50	6.323(w)	1	6.323	6.029	.01498
	Q51	42.293(x)	1	42.293	27.009	**.00000**
	Q52	52.674(y)	1	52.674	30.308	**.00000**
Intercept	Q10	1279.370	1	1279.370	994.742	.000
	Q11	1972.548	1	1972.548	1644.060	.000
	Q12	1571.668	1	1571.668	1496.783	.000
	Q13	1378.611	1	1378.611	1165.567	.000
	Q14	1401.889	1	1401.889	1119.103	.000
	Q15	1273.794	1	1273.794	1112.380	.000
	Q16	1702.863	1	1702.863	1232.174	.000
	Q17	1576.484	1	1576.484	1217.584	.000
	Q18	1415.558	1	1415.558	1111.096	.000
	Q19	1401.240	1	1401.240	1260.971	.000
	Q20	868.151	1	868.151	595.250	.000
	Q21	1169.559	1	1169.559	694.382	.000
	Q22	859.994	1	859.994	626.892	.000
	Q23	803.486	1	803.486	622.318	.000
	Q24	860.503	1	860.503	715.143	.000

Table 113 continues on the next page

Table 113, continued

Source	Dependent Variable	Type III Sum of Squares	df	Mean Square	F	Sig.
	Q25	2070.001	1	2070.001	2894.644	.000
	Q26	2007.360	1	2007.360	2526.744	.000
	Q27	1562.057	1	1562.057	1803.787	.000
	Q28	2126.400	1	2126.400	2880.910	.000
	Q29	1707.876	1	1707.876	2155.400	.000
	Q30	1530.009	1	1530.009	1706.046	.000
	Q31	2336.889	1	2336.889	3894.075	.000
	Q32	2115.219	1	2115.219	2563.524	.000
	Q33	1776.641	1	1776.641	1883.845	.000
	Q34	1252.836	1	1252.836	943.621	.000
	Q35	1125.501	1	1125.501	695.181	.000
	Q36	805.946	1	805.946	439.280	.000
	Q37	2639.521	1	2639.521	2622.483	.000
	Q38	2091.359	1	2091.359	1700.208	.000
	Q39	798.578	1	798.578	620.123	.000
	Q40	2234.910	1	2234.910	1595.723	.000
	Q41	1187.419	1	1187.419	795.781	.000
	Q42	2465.194	1	2465.194	2103.942	.000
	Q43	984.749	1	984.749	739.555	.000
	Q44	1357.444	1	1357.444	1014.185	.000
	Q45	1564.114	1	1564.114	1386.382	.000
	Q46	1353.613	1	1353.613	1056.563	.000
	Q47	1250.382	1	1250.382	761.511	.000
	Q48	1032.107	1	1032.107	860.880	.000
	Q49	2079.480	1	2079.480	1887.034	.000
	Q50	1710.744	1	1710.744	1631.169	.000
	Q51	1739.556	1	1739.556	1110.912	.000
	Q52	1360.001	1	1360.001	782.515	.000
Q1	Q10	3.160	1	3.160	2.457	.119
	Q11	5.811	1	5.811	4.843	.029
	Q12	1.647	1	1.647	1.568	.212
	Q13	.000	1	.000	.000	.987
	Q14	3.068	1	3.068	2.449	.119
	Q15	9.962	1	9.962	8.700	.004
	Q16	11.495	1	11.495	8.318	.004
	Q17	3.347	1	3.347	2.585	.110
	Q18	.926	1	.926	.727	.395
	Q19	2.250	1	2.250	2.025	.156
	Q20	1.119	1	1.119	.767	.382
	Q21	13.012	1	13.012	7.725	.006

Table 113 continues on the next page

Table 113, continued

Source	Dependent Variable	Type III Sum of Squares	df	Mean Square	F	Sig.
	Q22	3.573	1	3.573	2.605	.108
	Q23	.033	1	.033	.026	.873
	Q24	.861	1	.861	.715	.399
	Q25	1.138	1	1.138	1.591	.209
	Q26	.139	1	.139	.175	.676
	Q27	6.857	1	6.857	7.919	.005
	Q28	.506	1	.506	.685	.409
	Q29	2.276	1	2.276	2.873	.092
	Q30	.262	1	.262	.292	.590
	Q31	.047	1	.047	.078	.780
	Q32	.146	1	.146	.176	.675
	Q33	.009	1	.009	.010	.922
	Q34	.289	1	.289	.218	.641
	Q35	.469	1	.469	.290	.591
	Q36	.977	1	.977	.533	.466
	Q37	.152	1	.152	.151	.698
	Q38	.328	1	.328	.266	.606
	Q39	.009	1	.009	.007	.933
	Q40	.173	1	.173	.124	.725
	Q41	.051	1	.051	.034	.854
	Q42	.015	1	.015	.013	.911
	Q43	.623	1	.623	.468	.495
	Q44	.033	1	.033	.025	.875
	Q45	4.662	1	4.662	4.132	.043
	Q46	5.360	1	5.360	4.184	.042
	Q47	10.972	1	10.972	6.682	.010
	Q48	8.949	1	8.949	7.465	.007
	Q49	2.743	1	2.743	2.489	.116
	Q50	6.323	1	6.323	6.029	.015
	Q51	42.293	1	42.293	27.009	.000
	Q52	52.674	1	52.674	30.308	.000
Error	Q10	241.793	188	1.286		
	Q11	225.563	188	1.200		
	Q12	197.406	188	1.050		
	Q13	222.363	188	1.183		
	Q14	235.506	188	1.253		
	Q15	215.280	188	1.145		
	Q16	259.816	188	1.382		
	Q17	243.416	188	1.295		
	Q18	239.516	188	1.274		

Table 113 continues on the next page

Table 113, continued

Source	Dependent Variable	Type III Sum of Squares	df	Mean Square	F	Sig.
	Q19	208.913	188	1.111		
	Q20	274.191	188	1.458		
	Q21	316.651	188	1.684		
	Q22	257.906	188	1.372		
	Q23	242.730	188	1.291		
	Q24	226.213	188	1.203		
	Q25	134.441	188	.715		
	Q26	149.356	188	.794		
	Q27	162.806	188	.866		
	Q28	138.763	188	.738		
	Q29	148.966	188	.792		
	Q30	168.601	188	.897		
	Q31	112.821	188	.600		
	Q32	155.123	188	.825		
	Q33	177.301	188	.943		
	Q34	249.606	188	1.328		
	Q35	304.373	188	1.619		
	Q36	344.923	188	1.835		
	Q37	189.221	188	1.006		
	Q38	231.251	188	1.230		
	Q39	242.101	188	1.288		
	Q40	263.306	188	1.401		
	Q41	280.523	188	1.492		
	Q42	220.280	188	1.172		
	Q43	250.330	188	1.332		
	Q44	251.630	188	1.338		
	Q45	212.101	188	1.128		
	Q46	240.856	188	1.281		
	Q47	308.691	188	1.642		
	Q48	225.393	188	1.199		
	Q49	207.173	188	1.102		
	Q50	197.171	188	1.049		
	Q51	294.386	188	1.566		
	Q52	326.741	188	1.738		
Total	Q10	1973.000	190			
	Q11	2907.000	190			
	Q12	2288.000	190			
	Q13	1999.000	190			
	Q14	2127.000	190			
	Q15	2008.000	190			

Table 113 continues on the next page

Table 113, continued

Source	Dependent Variable	Type III Sum of Squares	df	Mean Square	F	Sig.
	Q16	2641.000	190			
	Q17	2369.000	190			
	Q18	2110.000	190			
	Q19	2087.000	190			
	Q20	1433.000	190			
	Q21	1992.000	190			
	Q22	1439.000	190			
	Q23	1285.000	190			
	Q24	1370.000	190			
	Q25	2864.000	190			
	Q26	2758.000	190			
	Q27	2312.000	190			
	Q28	2921.000	190			
	Q29	2430.000	190			
	Q30	2166.000	190			
	Q31	3113.000	190			
	Q32	2861.000	190			
	Q33	2463.000	190			
	Q34	1842.000	190			
	Q35	1728.000	190			
	Q36	1351.000	190			
	Q37	3617.000	190			
	Q38	2960.000	190			
	Q39	1275.000	190			
	Q40	3169.000	190			
	Q41	1821.000	190			
	Q42	3406.000	190			
	Q43	1551.000	190			
	Q44	2010.000	190			
	Q45	2339.000	190			
	Q46	2097.000	190			
	Q47	2078.000	190			
	Q48	1685.000	190			
	Q49	2984.000	190			
	Q50	2538.000	190			
	Q51	2923.000	190			
	Q52	2475.000	190			
Corrected Total	Q10	244.953	189			
	Q11	231.374	189			
	Q12	199.053	189			

Table 113 continues on the next page

Table 113, continued

Source	Dependent Variable	Type III Sum of Squares	df	Mean Square	F	Sig.
	Q13	222.363	189			
	Q14	238.574	189			
	Q15	225.242	189			
	Q16	271.311	189			
	Q17	246.763	189			
	Q18	240.442	189			
	Q19	211.163	189			
	Q20	275.311	189			
	Q21	329.663	189			
	Q22	261.479	189			
	Q23	242.763	189			
	Q24	227.074	189			
	Q25	135.579	189			
	Q26	149.495	189			
	Q27	169.663	189			
	Q28	139.268	189			
	Q29	151.242	189			
	Q30	168.863	189			
	Q31	112.868	189			
	Q32	155.268	189			
	Q33	177.311	189			
	Q34	249.895	189			
	Q35	304.842	189			
	Q36	345.900	189			
	Q37	189.374	189			
	Q38	231.579	189			
	Q39	242.111	189			
	Q40	263.479	189			
	Q41	280.574	189			
	Q42	220.295	189			
	Q43	250.953	189			
	Q44	251.663	189			
	Q45	216.763	189			
	Q46	246.216	189			
	Q47	319.663	189			
	Q48	234.342	189			
	Q49	209.916	189			
	Q50	203.495	189			
	Q51	336.679	189			
	Q52	379.416	189			

Table 113 continues on the next page

Table 113, continued

a R Squared = .013 (Adjusted R Squared = .008)
b R Squared = .025 (Adjusted R Squared = .020)
c R Squared = .008 (Adjusted R Squared = .003)
d R Squared = .000 (Adjusted R Squared = -.005)
e R Squared = .044 (Adjusted R Squared = .039)
f R Squared = .042 (Adjusted R Squared = .037)
g R Squared = .014 (Adjusted R Squared = .008)
h R Squared = .004 (Adjusted R Squared = -.001)
i R Squared = .011 (Adjusted R Squared = .005)
j R Squared = .039 (Adjusted R Squared = .034)
k R Squared = .004 (Adjusted R Squared = -.002)
l R Squared = .001 (Adjusted R Squared = -.004)
m R Squared = .040 (Adjusted R Squared = .035)
n R Squared = .015 (Adjusted R Squared = .010)
o R Squared = .002 (Adjusted R Squared = -.004)
p R Squared = .003 (Adjusted R Squared = -.002)
q R Squared = .001 (Adjusted R Squared = -.005)
r R Squared = .002 (Adjusted R Squared = -.003)
s R Squared = .022 (Adjusted R Squared = .016)
t R Squared = .022 (Adjusted R Squared = .017)
u R Squared = .034 (Adjusted R Squared = .029)
v R Squared = .038 (Adjusted R Squared = .033)
w R Squared = .031 (Adjusted R Squared = .026)
x R Squared = .126 (Adjusted R Squared = .121)
y R Squared = .139 (Adjusted R Squared = .134)

Only on 2 questions is a difference in student opinion found: q51, “enough time was allowed for labs” and q52, “Would you recommend this course to a friend?” In both cases, students in the experimental group responded to these questions in a more positive manner.

Drop and Withdraw Data

As has been performed on the other comparisons in this dissertation, an analysis of student persistence in the experimental course CH 204AV is presented here. As PENS students appeared in the CH 204AV in two semesters, the data for each individual semester are displayed individually and then collectively for analysis. The drop and withdraw data for Fall 2000 for the Experimental and PENS students is shown in Table 114.

Table 114: Drops and Withdraws, Fall 2000

	Q	W	Total Dropped	Students	% Dropped
Experimental	2	0	2	123	1.6%
PENS	0	0	0	17	0%

Parallel data for Spring 2001 were obtained and are displayed in Table 115. Of the 8 sections of CH 204AV offered in Spring 2001, 2 were earmarked for PENS students.

Table 115: Drops and Withdraws, Spring 2001

	Q	W	Total Dropped	Students	% Dropped
Experimental	5	2	7	135	5.2%
PENS	0	1	1	41	2.4%

The combination of these two semesters is shown in Table 116.

Table 116: Drops and Withdraws, Experimental versus PENS

	Q	W	Total Dropped	Students	% Dropped
Experimental	7	2	9	258	3.5%
PENS	0	1	1	58	1.7%

To determine if students in the Experimental group are more likely to drop the CH 204AV course, a χ^2 analysis is performed. The α level is again set to 0.05, and the null hypothesis is that there is no difference in the drop rate between the Experimental and

PENS students. An observed significance of less than 0.05 indicates that the alternative hypothesis must be true, that students in the Experimental group drop the course more frequently than PENS students. The result of the analysis is shown in Table 117.

Table 117: χ^2 analysis on Drop – Withdraw Data for the Control and Experimental Groups, Experimental versus PENS

Chi-Square Tests

	Value	df	Asymp. Sig. (2-sided)	Exact Sig. (2-sided)	Exact Sig. (1-sided)
Pearson Chi-Square	.481[b]	1	.488		
Continuity Correction[a]	.078	1	.781		
Likelihood Ratio	.554	1	.457		
Fisher's Exact Test				.696	.424
Linear-by-Linear Association	.479	1	.489		
N of Valid Cases	316				

a. Computed only for a 2x2 table

b. 1 cells (25.0%) have expected count less than 5. The minimum expected count is 1. 84.

According to the analysis, we fail to reject the null hypothesis as the observed significance (0.488 for the Pearson Chi-Square) is larger than the desired α level of 0.05. Thus, there is no difference in the drop rate between Experimental and PENS students in the experimental course CH 204AV.

Longitudinal Studies

Data on the subsequent enrollment patterns of Experimental and PENS students were collected in Summer 2005, at which time virtually all of these students would have finished their undergraduate careers at The University of Texas at Austin. Of particular interest is retention in a Science or Engineering major, as defined before, and enrollment in a research course. These analyses are properly done on students who completed CH 204AV successfully. Most students were successful in doing so, as Table 118 depicts for Fall 2000.

Table 118: Final Course Grades, Fall 2000

	A	B	C	CR	D	F	Q	W	Students	% Success
Experimental	43	57	19	0	2	0	2	0	123	96.7%
PENS	3	7	7	0	0	0	0	0	17	100%

Similarly, Table 119 shows this data for Spring 2001.

Table 119: Final Course Grades, Spring 2001

	A	B	C	CR	D	F	Q	W	Students	% Success
Experimental	56	50	16	0	4	2	5	2	135	90.4%
PENS	11	17	10	0	2	0	0	1	41	92.7%

Combining this information for both semesters shows us a composite of the success rates of PENS students versus Experimental students in the same time frame, displayed in Table 120.

Table 120: Final Course Grades, Experimental versus PENS

	A	B	C	CR	D	F	Q	W	Students	% Success
Experimental	99	107	35	0	6	2	7	2	258	93.4%
PENS	14	24	17	0	2	0	0	1	58	94.8%

It is upon these groups of successful students that our longitudinal studies are performed.

Enrollment in Research Courses

Our first interest is determining if PENS students differ from the Experimental students in terms of enrolling in a subsequent research course in Chemistry or Biology, as defined before. This information is complied for Fall 2000 in Table 121.

Table 121: Biology and Chemistry Research Enrollment for Experimental versus PENS, Fall 2000

	Took Biology or Chemistry Research	Did Not Take Biology or Chemistry Research	Successful Students	% Taking Research
Experimental	20	99	119	16.8%
PENS	0	17	17	0%
Total	20	116	136	14.7%

For Spring 2001, three PENS students pursued upper division research courses in Biology or Chemistry. Data are tabulated in Table 122.

Table 122: Biology and Chemistry Research Enrollment for Experimental versus PENS, Spring 2001

	Took Biology or Chemistry Research	**Did Not Take Biology or Chemistry Research**	**Successful Students**	**% Taking Research**
Experimental	16	106	122	13.1%
PENS	3	35	38	7.9%
Total	19	141	160	11.9%

Combining these two semesters in which PENS students were enrolled in CH 204AV for comparison with typical students taking the experimental course, Table 123 summarizes the result.

Table 123: Biology and Chemistry Research Enrollment, Experimental versus PENS

	Took Biology or Chemistry Research	**Did Not Take Biology or Chemistry Research**	**Successful Students**	**% Taking Research**
Experimental	36	205	241	14.9%
PENS	3	52	55	5.5%
Total	39	257	296	13.2%

A χ^2 analysis is then performed to determine if students from the experimental group is more likely to enroll in Biology or Chemistry research courses than students in the PENS group. An α level of 0.05 is selected. The null hypothesis is that there is no difference in the number of students who subsequently enroll in Biology or Chemistry research courses; however, if the observed significance is less than 0.05, the null hypothesis is rejected in favor of the alternative hypothesis, which is that students in the experimental group enroll more frequently in subsequent Biology or Chemistry research courses than PENS students. A summary of the enrollment information is found in Table 124.

Table 124: Biology and Chemistry Research Course Enrollment, Experimental versus PENS

Course * ChemBio Crosstabulation

Count

		ChemBio		
		Did Not Take Chem or Bio Upper Div Research	Took Chem or Bio Upper Div Research	Total
Course	Experimental	205	36	241
	PENS	52	3	55
Total		257	39	296

To determine statistical significance, a χ^2 analysis is performed and shown in Table 125.

Table 125: χ^2 analysis on Biology and Chemistry Research Course Enrollment, Experimental versus PENS

Chi-Square Tests

	Value	df	Asymp. Sig. (2-sided)	Exact Sig. (2-sided)	Exact Sig. (1-sided)
Pearson Chi-Square	3.520[b]	1	.061		
Continuity Correction[a]	2.740	1	.098		
Likelihood Ratio	4.200	1	.040		
Fisher's Exact Test				.076	.041
Linear-by-Linear Association	3.508	1	.061		
N of Valid Cases	296				

a. Computed only for a 2x2 table

b. 0 cells (.0%) have expected count less than 5. The minimum expected count is 7. 25.

Based on the observed significance, we fail to reject the null hypothesis and conclude that PENS students are equally likely as typical students in the experimental course to enroll in Biology or Chemistry research courses subsequent to their having successfully completed their General Chemistry laboratory.

Broadening our consideration to any upper division research course in the Natural Sciences, we present data on subsequent research course enrollment in the Natural Science for students in the PENS group and typical experimental course students in Fall 2000 in Table 126.

Table 126: Upper Division Research Enrollment for Experimental versus PENS, Fall 2000

	Took Upper Division Research	Did Not Take Upper Division Research	Successful Students	% Taking Research
Experimental	25	94	119	21.0%
PENS	0	17	17	0%
Total	25	116	136	18.4%

Only three PENS students pursued upper division research courses in Spring 2001, and all three did so in Biology or Chemistry. Data for Spring 2001 is displayed in Table 127.

Table 127: Upper Division Research Enrollment for Experimental versus PENS, Spring 2001

	Took Upper Division Research	Did Not Take Upper Division Research	Successful Students	% Taking Research
Experimental	19	103	122	15.6%
PENS	3	35	38	7.9%
Total	22	138	160	13.8%

The merger of these two semesters is shown in Table 128.

Table 128: Natural Sciences Research Enrollment for Experimental versus PENS

	Took Upper Division Research	**Did Not Take Upper Division Research**	**Successful Students**	**% Taking Research**
Experimental	44	197	241	18.3%
PENS	3	52	55	5.5%
Total	47	249	296	15.9%

A χ^2 analysis is performed to determine if one group of students is more likely to participate in an upper division Natural Sciences research course. An α level of 0.05 is selected. The null hypothesis is that there is no difference in the numbers of students who subsequently enroll in upper division Natural Sciences research course. If the observed significance is less than 0.05, the null hypothesis is rejected in favor of the alternative hypothesis, which is that typical students in the experimental course enroll more frequently in subsequent upper division Natural Sciences research courses than PENS students. A summary of the enrollment information is found in Table 129.

Table 129: Upper Division Natural Sciences Research Course Enrollment for Experimental versus PENS

Course * AllUpperDiv Crosstabulation

Count

		AllUpperDiv		
		Did Not Take an Upper Div Research Course	Took an Upper Div Research Course	Total
Course	Experimental	197	44	241
	PENS	52	3	55
Total		249	47	296

The χ^2 analysis is shown in Table 130.

Table 130: χ^2 analysis on Upper Division Natural Sciences Research Course Enrollment for Experimental versus PENS

Chi-Square Tests

	Value	df	Asymp. Sig. (2-sided)	Exact Sig. (2-sided)	Exact Sig. (1-sided)
Pearson Chi-Square	5.495[b]	1	.019		
Continuity Correction[a]	4.578	1	.032		
Likelihood Ratio	6.721	1	.010		
Fisher's Exact Test				.023	.011
Linear-by-Linear Association	5.477	1	.019		
N of Valid Cases	296				

a. Computed only for a 2x2 table

b. 0 cells (.0%) have expected count less than 5. The minimum expected count is 8.73.

Unlike the case of considering only Biology and Chemistry research, we reject the null hypothesis as the observed significance of 0.019 for the Pearson Chi-Square is less than the desired α level of 0.05. We conclude that typical students in the experimental course are more likely to enroll in upper division Natural Sciences research courses subsequent to their having successfully completed their General Chemistry laboratory than PENS students.

Retention in Science and Engineering Majors

One of the chief aims of the PENS program was not only to have these at-risk students successfully finish an undergraduate degree, but to do so with a major in Natural Sciences. We now consider the role, if any, that the experimental course may have had in achieving that goal.

Defining science and engineering majors as before, the enrollment on the twelfth class day, by college, of successful students in the experimental and PENS groups in Fall 2000 is outlined in Table 131.

Table 131: Enrollment by College, Fall 2000

	Experimental	PENS	Total
Architecture	0	0	0
Business	7	0	7
Communication	2	0	2
Education	2	0	2
Engineering	3	1	4
Fine Arts	1	0	1
Liberal Arts	10	1	11
Natural Sciences	90	15	105
Nursing	4	0	4
Pharmacy	0	0	0
Social Work	0	0	0
Total	119	17	136

Similar data for Spring 2001 was obtained and is shown in Table 132.

Table 132: Spring 2001 Enrollment by College

	Experimental	PENS	Total
Architecture	0	0	0
Business	2	0	2
Communication	2	0	2
Education	0	0	0
Engineering	5	0	5
Fine Arts	1	1	2
Liberal Arts	9	0	9
Natural Sciences	102	37	139
Nursing	0	0	0
Pharmacy	1	0	1
Social Work	0	0	0
Total	122	38	160

Combining these two semesters, we derive Table 133, which shows the total enrollment, by college, of successful students in the time period in which PENS students took the experimental course.

Table 133: Enrollment by College, Experimental versus PENS

	Experimental	**PENS**	**Total**
Architecture	0	0	0
Business	9	0	9
Communication	4	0	4
Education	2	0	2
Engineering	8	1	9
Fine Arts	2	1	3
Liberal Arts	19	1	20
Natural Sciences	192	52	244
Nursing	4	0	4
Pharmacy	1	0	1
Social Work	0	0	0
Total	241	55	296

The large majority of students, 244 (82.4%) of the 296 successful students, were in the College of Natural Sciences at the beginning of their laboratory experience, as shown in Table 133. A much smaller number, 9 (3.0%) of the successful students, were in the College of Engineering. Considering these 253 students, Table 134 shows the number of students who began as Natural Science majors and who were retained as Natural Science, Engineering, or Pharmacy majors in Fall 2000 for typical experimental and PENS students.

Table 134: Natural Sciences Retention, Fall 2000

	At start of Laboratory	Ending Science	Ending Eng.	Ending Pharm.	Total Retained	% Retained
Experimental	90	70	0	2	72	80.0%
PENS	15	8	0	1	9	60.0%

In a similar manner, Table 135 shows retention data for Engineering majors in Fall 2000.

Table 135: Engineering Retention, Fall 2000

	At start of Laboratory	Ending Science	Ending Eng.	Ending Pharm.	Total Retained	% Retained
Experimental	3	2	0	0	2	66.7%
PENS	1	0	1	0	1	100%

In sum, 77.1% of successful students are retained as Science and Engineering majors, as shown in Table 136.

Table 136: Total Natural Sciences and Engineering Retention, Fall 2000

	At start of Laboratory	Ending Science	Ending Eng.	Ending Pharm.	Total Retained	% Retained
Experimental	93	72	0	2	74	79.6%
PENS	16	8	1	1	10	62.5%
Total	109	80	1	3	84	77.1%

Likewise, we analyze data obtained for Spring 2001. First, we consider Natural Sciences retention, shown in Table 137.

Table 137: Natural Sciences Retention, Spring 2001

	At start of Laboratory	Ending Science	Ending Eng.	Ending Pharm.	Total Retained	% Retained
Experimental	102	80	1	6	87	85.3%
PENS	37	26	0	3	29	78.4%

Table 138 shows retention data for the small number of Engineering majors in Spring 2001.

Table 138: Engineering Retention, Spring 2001

	At start of Laboratory	Ending Science	Ending Eng.	Ending Pharm.	Total Retained	% Retained
Experimental	5	1	4	0	5	100%
PENS	0	0	0	0	0	N/A

Combining the totals for Science and Engineering from Spring 2001, 84.0% of successful students are retained as Science and Engineering majors, as shown in Table 139.

Table 139: Total Natural Sciences and Engineering Retention, Spring 2001

	At start of Laboratory	Ending Science	Ending Eng.	Ending Pharm.	Total Retained	% Retained
Experimental	107	81	5	6	92	86.0%
PENS	37	26	0	3	29	78.4%
Total	144	107	5	9	121	84.0%

Lastly, data from Fall 2000 and Spring 2001 are merged for analysis. The summation is shown in Table 140.

Table 140: Total Natural Sciences and Engineering Retention, Experimental versus PENS

	At start of Laboratory	Ending Science	Ending Eng.	Ending Pharm.	Total Retained	% Retained
Experimental	200	153	5	8	166	83.0%
PENS	53	34	1	4	39	73.6%
Total	253	187	6	12	205	81.0%

χ^2 analyses are then performed to compare the typical experimental and PENS groups to evaluate any differences between those groups with respect to retention as Science or Engineering majors. An α level of 0.05 is selected. The null hypothesis is that there is no difference in the retention rate as Science, Engineering, and Pharmacy majors for students between the groups being compared. If the observed significance is less than 0.05, the null hypothesis is rejected in favor of the alternative hypothesis, which is that there is a difference in the retention rates between the students in the two courses. A summary of the retention data is found in Table 141.

Table 141: Summary of Retention Data, Experimental versus PENS

Course * Retention Crosstabulation

Count

		Retention		
		Not Retained	Retained	Total
Course	Experimental	34	166	200
	PENS	14	39	53
Total		48	205	253

The χ^2 analysis on the retention data is shown in Table 142.

Table 142: χ^2 analysis on Retention Data, Experimental versus PENS

Chi-Square Tests

	Value	df	Asymp. Sig. (2-sided)	Exact Sig. (2-sided)	Exact Sig. (1-sided)
Pearson Chi-Square	2.416[b]	1	.120		
Continuity Correction[a]	1.842	1	.175		
Likelihood Ratio	2.272	1	.132		
Fisher's Exact Test				.166	.090
Linear-by-Linear Association	2.406	1	.121		
N of Valid Cases	253				

a. Computed only for a 2x2 table

b. 0 cells (.0%) have expected count less than 5. The minimum expected count is 10. 06.

Based on the observed significance for the Pearson Chi-Square, we fail to reject the null hypothesis and conclude that typical experimental students and PENS students are equally likely to be retained as Natural Sciences, Engineering, or Pharmacy majors.

SUMMARY OF FINDINGS

In this course of this study, several groups of students were compared in hopes of understanding how the experimental course CH 204AV impacted them, both in terms of an immediate reaction to the course (by way of a survey) and in terms of a long-term effect as measured by subsequent enrollment patterns. Ultimately, five group comparisons were made on 5 sets of criteria. The findings are summarized in Table 143, below.

Table 143: Summary of Findings

Group Comparison	Survey	Drop-Withdraw Incidence	Incidence of Chemistry and Biology Research Courses	Incidence of Upper Division Research Courses	Retention in Science and Engineering
Control versus Experimental (random distribution)	No difference observed	No difference observed	No difference observed	No difference observed	No difference observed
Control versus Experimental (self-selected enrollment)	Differences on many survey items (in favor of Experimental course)	Less frequently in Experimental course	No difference observed	No difference observed	No difference observed
Control versus Experimental (same TA)	Difference on three survey items	No comparison possible	No difference observed	No difference observed	No difference observed
Control versus Experimental (different experimental instructor)	Difference on one survey item (in favor of Experimental course)	Less frequently in Experimental course	No difference observed	No difference observed	No difference observed
Experimental versus PENS	Difference on two survey items (in favor of Experimental course)	No difference observed	No difference observed	More frequently in Experimental course	No difference observed

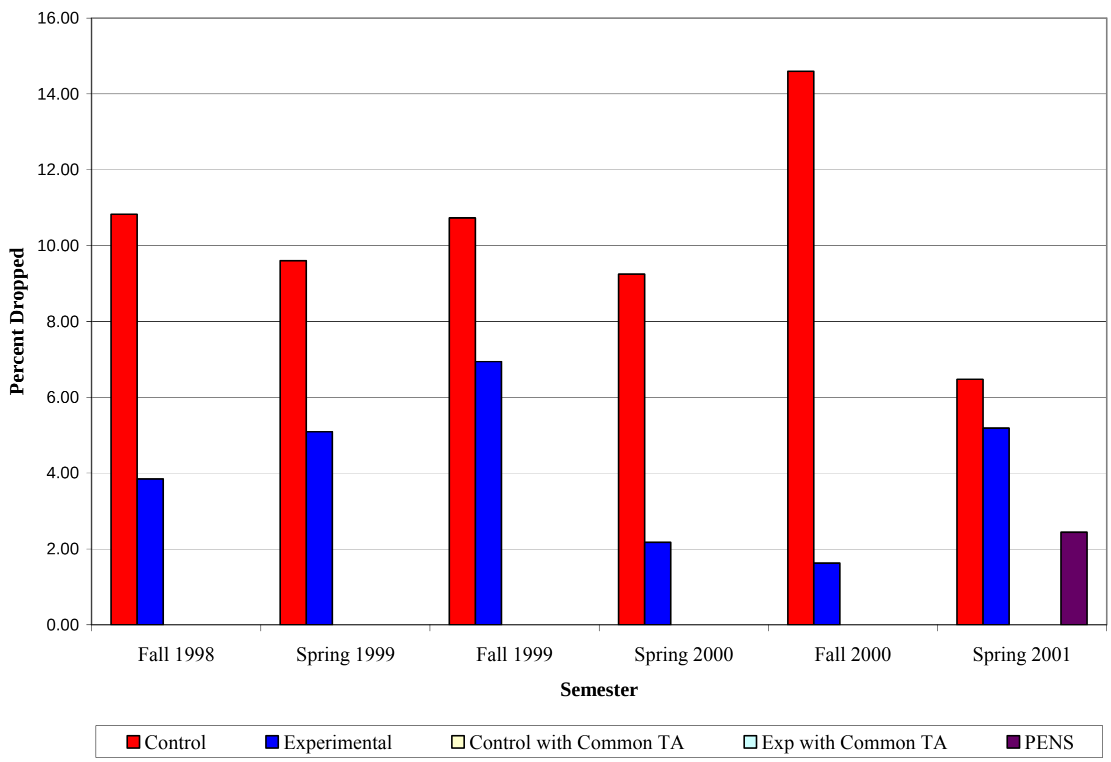
Survey Data

In general, wide differences in student opinion were only found in the primary comparison we wanted to make, that between the control group and the experimental group, as we defined them before. In other cases, relatively few differences were found, although one question that typically showed a difference was q52, "Would you recommend this course to a friend?" In each case in which a significant difference of opinion was found on this question, the experimental group responded more positively to this question.

Drop-Withdraw Data

The incidence of dropping the control course was always higher than that of the experimental course. While in Fall 1998 a significant difference was not found, the semester-to-semester trend is suggestive of a pattern, as depicted in Figure 5.

Figure 5: Drops and Withdraws, by Group and Semester

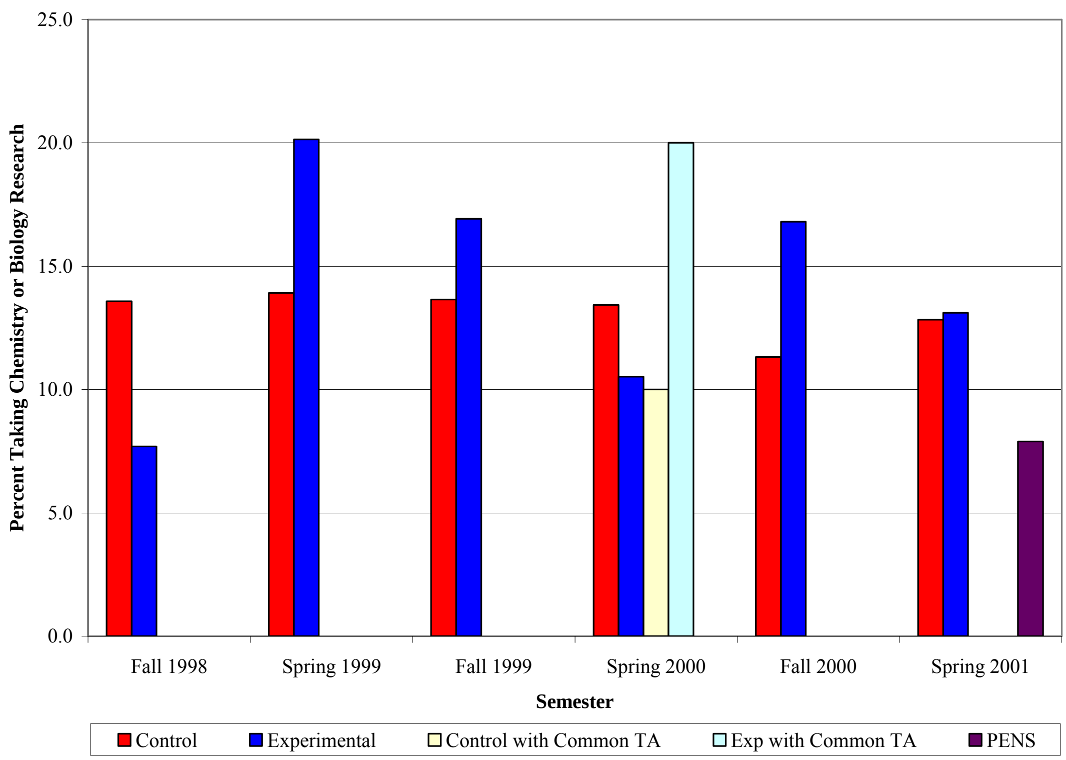


For the primary comparison of control versus experimental, both with the original instructor and with the different instructor, a significant difference in the drop rate was found.

Enrollment in Subsequent Chemistry and Biology Research Courses

No difference in the incidence of enrolling in a chemistry or biology research course was found in any of the comparisons we made. The data is presented graphically, by semester and group, in Figure 6.

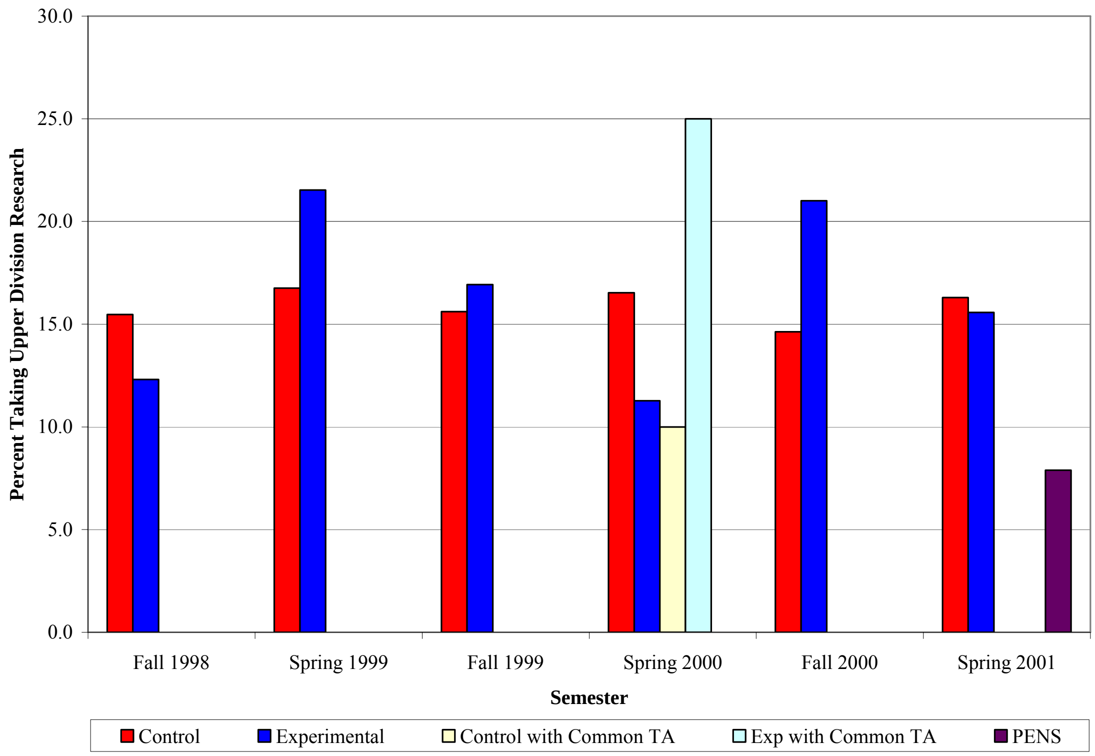
Figure 6: Enrollment in Subsequent Chemistry and Biology Research Courses



Enrollment in Subsequent Natural Sciences Upper Division Research Courses

The percentages of students of enrolling in upper division research courses was found to be the same for virtually all of the comparisons except for the comparison of typical students in the experimental group compared to PENS students also taking the experimental course. A histogram of the enrollment data is shown in Figure 7.

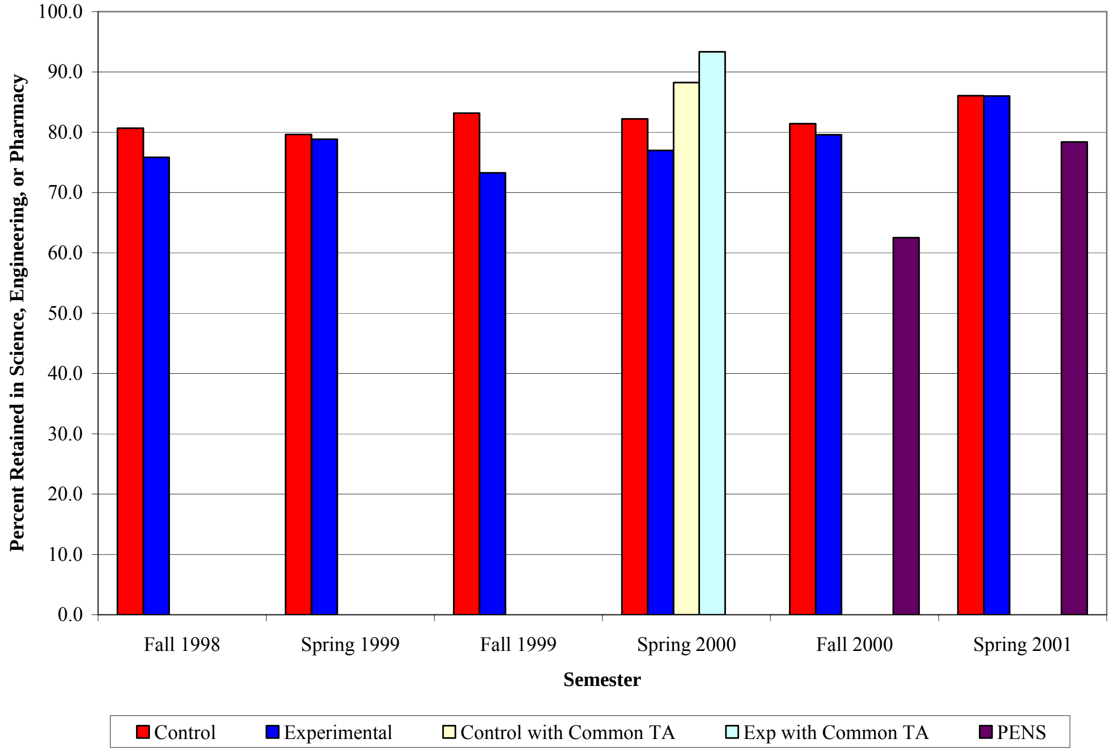
Figure 7: Enrollment in Upper Division Research Courses



Retention in Science and Engineering Majors

No differences were found in the retention rates in Science, Engineering, or Pharmacy in any of the comparisons that were made as a part of this study. Retention data on a semester-by-semester basis is depicted in Figure 8.

Figure 8: Retention in Science, Engineering, or Pharmacy Majors



Chapter 4: Discussion

This dissertation began with the proposition that General Chemistry laboratory courses should be taught in the manner that Liebig taught his beginning chemistry students: as an introduction to chemical research. Using Cognitive Apprenticeship Theory as a model for the processes in a chemical research environment, CH 204AV, this course was successfully taught at The University of Texas at Austin from Spring 1998 through Spring 2005. Having collected data during seven semesters in which this course was offered, we are now in a position to evaluate the Liebig-premise and to make recommendations for the future of laboratory instruction in chemistry. Five comparisons were made, and the conclusions of these comparisons are presented first here. Afterwards, the implications of these conclusions are framed in terms of the four research questions that were posed of the experimental course at the beginning of this dissertation.

GROUP COMPARISONS

Fall 1998: Control versus Experimental when the Groupings are Truly Random

In this first semester in which the experimental course CH 204AV was taught to a larger audience, no difference was observed between the control and experimental groups in any of the variables we attempted to measure. While many individual survey items were suggestive of a difference between the two groups, the survey was only distributed to only four sections in the control group, and only 15 students in the control group completed the survey. The relatively small number of surveys received negatively impacted our ability to observe any difference between the control and experimental groups. Likewise, the drop and withdraw data also suggested a difference between the two groups (and, indeed, followed the general pattern observed in other semesters), but we likely did not have enough subjects to observe any difference when using a χ^2 analysis necessitated by the nature of the analysis.

Another issue associated with this first offering of this course to a typical General Chemistry laboratory audience is that the course was still very much in development at that point; it was not a mature course as the control course was at that point. Possibly it was not until later that we would have been able to implement the ideas of Cognitive Apprenticeship in such a way as to receive any benefit from them.

The failure in observing any difference between the control and experimental groups at this point does cause some concern. Since beyond this point in time, students were aware of the existence of the experimental course or were simply assigned to the course, as in the PENS program, the obvious question of whether the experimental course met any of its goals given a random student enrollment is legitimate. However, as a pilot study in developing a new course for a larger audience, and given the *suggestion* (even if not fully realized or observed) that there may be some student benefit(s) in the new course, a wider offering and analysis of the experimental course followed in subsequent semesters.

Spring 1999 Onward: Control versus Experimental

Beginning in Spring 1999, the catalog description of the experimental course included the phrase, "Intended for Life Science Students." The inclusion of this phrase, with the intent of attracting students with a natural interest in the course material, allowed students to self-select the experimental course (or, the control course) if they observed the phrase. No doubt many students also did what one of the questions on the survey posed, "Would you recommend this course to a friend?", which also would lead to some non-randomness in the students in the two courses. The effect of a non-random distribution of students in the control and experimental courses would make any analysis less reliable; as a means of reducing this effect, a very strict standard of significance was chosen for survey items and the use of a distribution-free test statistic for the research course enrollment and retention data. The result of the nature of how students appeared in the control and experimental courses is that any conclusion drawn from the data should be approached with some caution.

However, if students signed up for the experimental course as a result of their *interest* in the focus on life sciences, one might expect to observe differences in key "Interest" questions posed in the survey. Indeed, on 2 of the 9 "Interest" questions, a difference is observed, and perhaps it is telling that q40, "Chemistry in Medicine" is one of these two, in favor of the experimental course. The other "Interest" question in which a difference was observed was q34, "Studying Chemistry in General.", perhaps a measure of the general appeal of the content of the experimental course. "But the failure to observe any difference in all of the other "Interest" questions causes us to wonder: aside from the *content* of the experimental course that would appeal to a segment of the General Chemistry laboratory audience and thus may have led to some imbalance in terms of the number of life science students (and, as a consequence, in other areas as well) in the two courses, were the students in the two groups different at the beginning of their General Chemistry laboratory experience?

Evidence supporting the idea that the control and experimental group were not different at the onset of their laboratory experience comes from the research course enrollment and, particularly, retention data on the two groups. No differences were found between the two groups in either of these factors. These results suggest that students in the two courses were equally capable of success in their General Chemistry laboratory course, and any differences observed in them during the time of their General Chemistry laboratory experience must be attributable to something within their laboratory course.

This observation provides us confidence that analyses between the control and experimental groups are appropriate.

While relatively few differences were found in "Interest" questions between the two groups, on 8 of the 9 "Confidence" questions, a significant difference is observed. Notably, in all of the "Confidence" questions which addressed chemistry specifically (understand key concepts of chemistry, solve chemistry problems, understand the chemistry underlying lab experiments, visualize key concepts of chemistry, apply your knowledge of chemistry to the real world, success in another chemistry course, succeed in a chemistry-related discipline), the experimental group responded more positively. This series of responses, taken together, suggests that a carefully-constructed laboratory experience can enhance student confidence in the subject at hand. A significant difference was also found in "Confidence" in the ability to "perform lab experiments" in favor of the experimental group, likely due to the structure of the experimental course: students performed experiments that were related to each other and could approach each laboratory session with the expectation that they had some experience in the chemistry at play. The only question in which no difference was found in "understand other areas of science", understandable because students recognize success in one area of science does not immediately suggest success in other areas. The large number of differences within "Confidence" questions suggests that something within the structure of the experimental course provides students with the confidence in being able to succeed in their General Chemistry laboratory course.

Additional evidence that the experimental course enhanced confidence in being successful comes from drop-withdraw data. In every semester in which this study was performed, a smaller percentage of students dropped or withdrew from the experimental course as compared to students in the control course. This difference was shown to be statistically significant in the comparison of control students with experimental students.

Among the remaining survey questions, students in the control group and experimental group responded in a similar fashion (no observed difference) to questions addressing the lecture component of the laboratory course (Impact on Learning, Impact on Confidence, Impact on Enthusiasm, I enjoyed the lectures, the organization of the lectures was important for my learning). Clearly, the laboratory experience itself, and not the lecture associated with the laboratory experience, differentiates the control and experimental groups. Students in the experimental group responded more positively to statements about the applications of chemistry in the course (made certain concepts easier to understand, made learning interesting), perhaps due to the life-science focus of the class. Other questions addressing various components of the course experience (wet lab, exams, quizzes, homework/exercises) all favored the experimental course.

In the end, it appears to be the laboratory experience itself that caused students to report higher confidence in being able to be successful. All questions addressing the nature of the laboratory experience (I enjoyed the labs, I understood the chemistry behind the labs before I did them, eventually I understood the chemistry behind the labs, the labs helped me understand important concepts in the course, enough time was allowed for labs) displayed a significant difference in response between the two groups, all in favor of the experimental course. The survey culminates in a question that pursues the general value of the laboratory course, “Would you recommend this course to a friend?” Students in the experimental course respond to this question with a resounding yes, while students in the control course are equally negative.

Does the Teaching Assistant Make the Difference? Control versus Experimental when the Same TA Teaches Both Courses

In Spring 2000, one teaching assistant was assigned to teach one section of the control course and one section of the experimental course. Ordinarily, this arrangement would be viewed as being undesirable for the graduate student assigned to be a teaching assistant as it requires preparation for two courses instead of the conventional one. This unusual arrangement allowed us to consider the impact of the teaching assistant (TA) has on the course. Central to the idea of teaching a course using the Cognitive Apprenticeship model is that an expert provides his/her experience in terms of the thought processes required to complete cognitive tasks, such as designing laboratory experiments. Since in the laboratory course, the primary contact for the students is the TA, the TA bears a great deal of responsibility for making the approach work. Unfortunately, however, this arrangement only happened in one semester and as such, a relatively small number of students (20 in each group) were involved in this aspect of the CH 204AV laboratory assessment.

In the end, very little difference was observed between the control and experimental students with regard to the variables we chose to study. Given the relatively small number of students involved, it is not surprising that we were not able to discern any differences in the subsequent enrollment patterns of the students in the two courses. Additionally, no student dropped or withdrew from either of the courses, which made impossible a comparison of the incidence of dropping out of the laboratory course. The survey demonstrated a difference on 3 questions, two in favor of the experimental course ("Confidence in your ability to succeed in a chemistry-related discipline" and "The applications of chemistry discussed in this course made certain concepts easier to understand"), both of which were observed in the larger control versus experimental comparison, and one in favor of the control course, "Interest in chemistry in Industry", which was not observed before. The difference in response on this one question is difficult to explain; perhaps it is due to some atypical distribution of students in the two sections under study. As only 30 surveys were completed between the two groups, it is conceivable that we simply did not have enough subjects to really observe the differences between the two groups that were observed before.

However, taking the survey analysis at face value, another explanation is that there was no difference between the control and experimental groups under this TA's supervision. This conclusion would be at odds with the difference in the two groups that we observed before and highlights an important point about trying to change the way laboratory courses are taught: teaching a course according to the principles of Cognitive Apprenticeship requires discipline and some experience as an instructor. No doubt we never realized all of the benefit of teaching the experimental course in this manner since we were reliant on (in many cases, including this one) relatively inexperienced teaching assistants. It is not difficult to imagine the teaching assistant in charge of the two sections at hand approaching them in a very similar, if not identical, manner. Any difference we might have observed would be primarily due to some factor(s) other than the pedagogical approach of the TA, perhaps the structure of the course or the influence of other people involved in the course. If we had been able to perform a comparison between the two courses with the same, more experienced, TA several other times in an effort to increase the number of subjects, we might have been able to draw a better conclusion on how large a role the teaching assistant played in the apparent success of the experimental course. As it is, this question remains largely unresolved.

The Effect of the Instructor: Control versus Experimental when a Different Instructor Teaches the Experimental Course

In Fall 2000, as part of a study to assess the long-term viability of the experimental course, the head teaching assistant assumed the responsibility of teaching the experimental course, although the original instructor, having a faculty appointment, remained on as the instructor of record for the course and acted in a supervisory manner. In many ways, the parameters that we considered in comparing the control and experimental courses provided us with the same results as before: a significant difference was found in the drop rates, with students in the control course being more likely to drop their laboratory course as compared to students in the experimental course, and no difference was found in the incidence of enrolling in subsequent research courses or in the retention rate in Science and Engineering. On the survey, a difference was found in only one of the questions, which was a question in which a difference was ordinarily observed, "Would you recommend this course to a friend?" Given that 74 surveys were completed, enough surveys should have been collected to observe a difference between the two groups, and the lack of difference between the two groups is suggestive that the identity of the instructor is important.

Indeed, even as the experimental course was being taught, the instructional staff felt that the experimental course had lost some of the richness that it had under the original instructor. The original instructor of the course had spent the bulk of his career in the content area of the experimental course and consequently was able to add personal experience and anecdotes to the lecture portion of the laboratory course; while the head teaching assistant was able to competently convey the content of the experimental course, the lecture portion of the course became less personal and more sterile. One of the great strengths of the experimental course, the relation of the laboratory course to the personal real-life work experience of the instructor, was lost in the process. With a weakened link to the "real world", the situated learning which is an element of Cognitive Apprenticeship theory becomes weakened as well, and subsequent benefits from teaching this course in this manner would be minimized. In this context, it is not difficult to imagine students in the experimental course not reporting higher “Confidence” or “Interest” on various survey items as compared to students in the control course. The structure of the experimental course, however, remained intact. That structure likely accounts for the difference in drop rates between the two courses and the difference in response on the one survey question.

This particular aspect of the experimental course experience was evaluated in the fall. Students taking the laboratory course in the fall were taking it either (at least) one semester behind their General Chemistry lecture experience or were taking it concurrently with their second-half portion of General Chemistry, in which case they would be taking General Chemistry one semester late relative to the “typical” student. Our experience suggested that students taking General Chemistry laboratory in the fall were not as academically strong as students taking laboratory in the spring, and it is conceivable that the lack of difference we observed on the survey may be indicative of subtly different student group in the fall semesters. Notably, in the comparison of students in Fall 1998, no difference was observed on the survey between the control and experimental groups at that time as well with the original instructor of the experimental course in place. To fully assess the impact of the instructor on the experimental course, an experiment in a spring semester should have been performed in order to evaluate any difference between semesters. However, our “gut feeling” at the time told us that the experimental course was diminished by the change in instructor, even without the survey analysis in hand, and so this aspect of the experimental course experience was not repeated.

The Effect of the Experimental Course on an At-Risk Student Group

In Fall 2000 and again in Spring 2001, the experimental course was chosen as the General Chemistry laboratory experience for students in the Partnership for Excellence in the Natural Sciences (PENS). Participants in the PENS program were primarily first-generation college students who had attended high schools traditionally underrepresented at The University. As such, these students were perceived as being at-risk. Special sections of introductory courses in Natural Sciences, such as General Chemistry, were arranged for these students in an effort to place them in smaller classes in the hope of increasing interactions between PENS students with each other and with University faculty. Additionally, a tutor was designated for each course within the PENS suite of introductory courses so that students had an additional instructional resource available to themselves that other students within The University ordinarily would not have. Prior to Fall 2000, no General Chemistry laboratory section was set aside for PENS students and PENS students were individually placed in different sections of the control laboratory course. This arrangement was ultimately viewed as being unsuitable by the College of Natural Sciences, and as testament to The University's high regard for the experimental course, sections of the experimental course were chosen to host PENS students.

Regrettably for purposes of this study, no sections of the control course were ever designated for PENS students. To best draw a conclusion about the impact of the experimental course on different student groups, a comparison between PENS students in the control course with PENS students in the experimental course should have been arranged. This comparison was beyond our capability to organize. Instead, to evaluate the impact of the experimental course on student groups, a comparison between "typical" experimental course students and PENS students in the experimental course is presented here.

Students in the PENS group presented a new challenge for the experimental course. A fair question at the outset was if PENS students could be successful in the experimental course. Comparing the drop and withdraw rates between "typical" experimental students with their PENS counterparts shows no difference between the two student groups. However, an inspection of the grade distribution in Table 120 shows that “typical” students in the experimental group received higher marks than PENS students, consistent with the idea that PENS students were somewhat academically weaker than typical students at The University. The important observation here, though, is that PENS students were as likely to finish their laboratory course successfully as other University students.

With respect to subsequent enrollment in research courses, PENS students appear to be less likely to take upper division research courses than other students in Natural Sciences and Engineering at The University. As, typically, only advanced undergraduate students might pursue a research project, this pattern may be the result of PENS students, on average, being academically weaker than “typical” students.

The survey demonstrated differences on two questions: q51, “Enough time was allowed for labs”, and q52, “Would you recommend this course to a friend?”, with “typical” students in the experimental course responding more favorably to these items. PENS students evidently found the experimental course challenging and likely struggled to understand the concepts behind the laboratory exercises; their struggle with respect to time required to conceptualize laboratory processes and overall impression of the experimental course is reflected in their responses to these two questions. Notably, however, no difference was found on the “Interest” and “Confidence” questions between the two groups, perhaps suggestive of the idea that the same benefit of enhanced confidence afforded to the “typical” experimental students was provided to PENS students as well. Without a comparison of the control course to the experimental course for PENS students, though, this idea remains speculative.

OVERALL CONCLUSIONS

At this point, it is instructive to reframe the experience of the experimental course in terms of the four overall research questions posed of it early in this dissertation. The experimental course itself, with a renewed focus on the value of the laboratory experience, and variations on the experimental course (in terms of the instructional staff and population it serves) provides us some insight on how the laboratory experience impacts students and what the role of the laboratory might be. An analysis of the four research questions follows here.

Interest in Science

The first research question asked if students in the experimental course are more likely to become interested in science as a result of their enrollment in the course. The experimental course was designed to appeal to and meet the needs of life science students taking a General Chemistry laboratory course. Given the greater appreciation of the importance of chemistry to understand and explain biological phenomena, it was not unreasonable to structure an introductory chemistry laboratory course with the life sciences in mind. By focusing on chemistry relevant to students in the life sciences, we anticipated that the students in the experimental course might report enhanced interest in chemistry and in the sciences in general. This expectation is partially borne out by the comparison of control and experimental students as the survey data show a difference in two interest questions: studying chemistry in general and chemistry in medicine. The enhanced interest in studying chemistry in general is an encouraging result, not easily explained by a previous interest in chemistry as it pertains to life sciences, and may be directly due to the influence of the course: tailoring an experience to a students' perceived interest may heighten interest in the subject area in general.

However, in none of the other interest questions was a significant difference found. No difference was found between the control and experimental groups on questions addressing the issue of a career in chemistry (q36, pursuing a chemistry-related major) or in science (q37, pursuing a science-related field) or interest in science in general (q42). It appears as though students enjoyed the application of chemistry to their perceived interest at the time of taking the experimental course but did not anticipate it impacting their ultimate career choice.

This aspect of the survey data is echoed in the long-term effects of the General Chemistry laboratory experience. We find that students are no more likely to pursue research courses in the sciences nor be retained as science and engineering majors as a result of having taken the experimental course. Each of these results suggests that the experimental course was not able to increase the level of interest in science and engineering in students relative to students in the control course. However, there may be a limit to the number of available research spaces, and if one exists, may cause us not to be able to see any difference in student *desire* to enroll in those research courses. Notably, the same percentage (16.4%) of students in both the control and experimental courses pursued a research course after their General Chemistry laboratory experience, suggestive of the idea that all of the available slots were occupied. Confounding the issue, other factors, such as interest in the lecture course (if one exists) may be equally important, if not more so, in confirming a student's desire to continue along a path towards a career in the sciences.

Even if students may not have become more interested in a science career as a result of having been enrolled in the experimental course, the observation that students appear to enjoy a selection of experiments customized to their perceived interest and do not appear to be negatively impacted by the choice in the long term is an important one.

This observation frees instructors to design laboratory courses around whatever chemistry they feel can be interesting to (and appropriate for) introductory students and have instrumentation and equipment to support. Indeed, it may be that the most important factor in eliciting student interest may be a laboratory course which draws from the instructor's own career experience. In such a course, students can feel the excitement inherit in scientific discovery both for themselves and vicariously through the instructor. However, to share this scientific journey with students, the course has to be structured in the same way that the instructor follows in his/her own line of work. Students in the experimental course reported higher interest in studying chemistry in general as a result. The obvious implication of this observation is that *any* content, within any overlap of instructor experience and student perceived interests, may be suitable for introductory chemistry laboratory courses as long as that content is accessible to introductory students and if it is structured in a way that follows the natural rhythm of chemical research.

In comparing typical students in the experimental group with the PENS group, we find no difference in how students respond to survey items related to interest and little difference in terms of their incidence of retention in Science, Engineering, or Pharmacy or enrollment in research courses. PENS students are less likely to pursue upper division research courses, but this may be the result of their having a much more structured program than other undergraduates. It appears, in terms of interest in chemistry and science in general, that PENS students in the experimental course are very much like other undergraduates who took the experimental course.

Confidence in Success

The second research question asked if students in the experimental course are more likely to feel that they can be successful in a science career. Students play out the beginning stages of their careers in introductory courses such as General Chemistry laboratory. An important lesson these courses teach them, among other things, is what career paths are viable options for them. If a student feels that he/she may be unsuccessful in a course, it may be because he/she has either not made the requisite effort to be successful, a condition which is reparable, or may have little aptitude in the area, which is a more difficult problem to solve. Whatever the cause(s), students have an "out": they may elect to drop these courses. In laboratory courses, however, students reasonably expect to finish the course successfully if they only come to class and meet the requirements of the course, since evaluation in laboratory instruction is largely based on performance in the laboratory setting. It seems reasonable then that laboratory courses should not have large drop rates, unless students are performing poorly in the associated lecture course (if one exists) and they are required to drop the laboratory course. In fact, the experimental course and the control course each have a relatively small attrition rate (4.9% and 8.7%, respectively, in the overall comparison of control versus experimental). In every semester in which a comparison between the control and experimental course was made, the drop rate in the experimental course was always lower, as shown in Figure 5. If students are dropping one laboratory course more frequently than the other, there must be an underlying cause. The lower drop rate in the experimental course could be interpreted as a higher level of confidence in finishing the laboratory course successfully, as compared to the control course. The survey data reinforces this hypothesis. The survey indicates a generally positive feeling towards the experimental course, particularly in the area of student confidence, in which virtually every (with one notable exception as described before) item within the Confidence section indicated higher confidence among students in the experimental course. The survey data also demonstrate that students in the experimental course would be more willing to recommend the course to a friend.

Taken together, these factors may merely be a reflection of the general feeling of confidence that students had about the laboratory experience in the experimental course.

This enhanced feeling of confidence is no doubt brought about by the structure imposed by the Cognitive Apprenticeship model. While it is likely that we were not able to derive all of the benefits that the model provides in that our teaching assistant "experts" were (mostly) beginning graduate students with limited teaching experience, the underlying structure of the course necessitated by the model certainly added to the feeling of confidence that students in the experimental course evidently felt. The experiments were designed to follow the natural rhythm of chemical research by focusing on a narrow problem in depth, rather than having a series of unrelated experiments, as would be common in a typical General Chemistry laboratory course. Each week's experience in the experimental course drew something from all of the previous work in the course, so that students could feel as though they were applying old knowledge to new problems. The process can be described as a spiral: starting with a small, central idea, students built upon their experience not only upward but outward as new, related ideas were introduced. This iterative process naturally encourages confidence in being able to understand and succeed in chemistry, not only because students worked from a position of experience in each week's experiment, but also because they knew they were performing experiments much as a practicing chemist would in the course of his/her work.

The higher level of confidence students felt benefited not only the students in the experimental course, but the University as well. A lower drop rate positively impacts the University's finances, as fewer resources (not only in the cost of chemicals, disposal, and laboratory equipment, but also in personnel and space utilization) are consumed.

Enrollment in Research Courses

The third research question investigates if students in the experimental course are more likely to pursue further research courses. The experimental course was created in the anticipation of attracting a larger number of students into pursuing research, as evidenced by taking a research course, later in their academic careers. The longitudinal data obtained suggest that this expectation was not realized; students in the experimental and control courses were equally likely to take research courses later. Several factors may account for this result. The number of research positions available at The University has a natural limit, and not every student who may be interested in pursuing research may have the opportunity to do so, as described earlier. Within the Department of Chemistry and Biochemistry, in particular, the few research positions that exist for undergraduates are likely to be offered to chemistry majors, who ordinarily would not have taken either the experimental or control courses, but rather a laboratory course designed especially for chemistry and chemical engineering majors. There simply may not have been a large enough number of students able to pursue a research course to perceive any difference in the incidence of their doing so.

Persistence as Science Majors

The final research question posed asked if students are more likely to persist as science majors as a result of having been enrolled in the experimental course. Engaging students in research is commonly believed to be a powerful recruiting tool for many disciplines, including chemistry. With this idea in mind, we expected that the experimental course would ultimately lead to higher retention in the sciences and engineering relative to the control course. The longitudinal data obtained, however, do not support this expectation, as no difference in science and engineering retention is found between students in the experimental and control groups. Important to this result, of course, is that the research experience in which the experimental group participated was in the context of a standard introductory laboratory course; they did not have access to the personalized attention that a handful of advanced undergraduate students under a faculty mentor have. Thus, if it is because of the larger personal investment that faculty must make in each research student that makes the research experience more powerful, the effect would be diminished in a standard laboratory course involving a large number of students, no matter how well designed or intentioned the course was.

Achievement in the lecture course rather than in the laboratory course might be an important factor in determining which introductory students may be retained as science or engineering majors. Laboratory courses typically have small attrition rates and high grade distributions and as such may not provide much feedback to students regarding their ability to be successful in a chosen field. The problem here may be one of perception: laboratory courses should provide students with some expectation of what work in different fields is like and hence might provide some justification to select one career track over another. Introductory students may not have enough experience to appreciate this point of view. Perhaps only after a few years of study in an area can students make a mature judgment in this regard.

SUGGESTIONS FOR FUTURE WORK

While this study has provided some insight into the nature of the laboratory experience on students, some questions remain unresolved. Here we propose some ideas for future work to build upon what we have discovered.

The study, as conceived and carried out, was strictly quantitative, *i.e.*, we only looked at measurables: survey responses and numbers of students in one condition or another. While such study designs can be instructive, often they cannot provide much information on *why* a particular phenomenon occurs. The study would have benefited from a qualitative component, in which some students were interviewed, in order to further understand some of the observations we made. In particular, we do not know, from the data collected, whether the confidence in the ability to be successful the students in the experimental course reported persisted beyond the timeframe of the laboratory course. Measures of confidence were established during the time students were enrolled in the laboratory courses under study; although any initial feeling of confidence may have been helpful to students while they were taking these laboratory courses, it is unknown whether students carried this confidence into later courses. Of particular interest would be whether students taking research courses later in their careers would still feel this confidence brought on by their introduction to laboratory work in chemistry; if so, the experimental course will have served an important purpose in these students' professional development. Interviewing these students would likely be very instructive.

Additionally, beyond the sheer numbers of students who pursued a research course later in their careers, there is the question of how well they were prepared for such an experience. Students in the experimental course should have been at an advantage relative to the students in the control group in this regard, as their course was designed with this goal in mind. However, little is known of how well any of these students felt prepared for advanced research once they reached that point in their academic careers. A follow-up study, in which students in both the experimental and control groups would be interviewed on their impressions of the advanced research experience, may provide some insight on the effectiveness of the research-based introductory chemistry laboratory toward preparing students for later research work. If students are better prepared for research as a result of having been taught using this method, the approach will indeed be justified, even if larger numbers of students do not participate in that research.

The study also left out a group of students who may have been useful to include: those who were in the lecture course but who were not in an associated laboratory course. While these students are obligated to eventually take the introductory laboratory course if they remain in a science-oriented track, a comparison of survey responses between students who were either enrolled in laboratory or not as they took the associated lecture course could determine if laboratory courses act as a means to interest students in a science career. Conceivably, both laboratory courses could have acted in this way for students, just equally so, but since the comparison was made between the two courses without the benefit of a baseline of no laboratory instruction at all, we do not currently know if the two laboratory courses might have increased interest in a science career for the two groups of students.

The survey instrument was not validated, and it may not have been capable of detecting some of the affective characteristics it was intended to measure. However, since the survey data and the longitudinal data obtained pointed to the same conclusions, the survey instrument appears to be reliable for this particular study. Still, a validated survey instrument designed to measure affective characteristics such as interest, confidence, *etc*., would be a very valuable tool for future work, given a great deal of the value of the laboratory experience for students appears to be in the affective domain.

A wider study of the impact of the teaching assistant on the experimental course would have been useful; as the primary instructional contact for students at a large institution such as The University of Texas at Austin, the teaching assistant undoubtedly plays an important role in a student's laboratory experience. A more experienced instructor, one who can approach different courses in different ways, would be required to make a better assessment of this factor.

SUMMARY

The chemistry laboratory experience is perhaps unique among all courses that students pursue in higher education. The memory of the laboratory course remains vivid in the minds of students who take it well after the experience is over, even for those students who ultimately pursue career paths outside of the sciences. Whether it is because of the hands-on approach laboratory work always involves, the feelings of success and failure, the camaraderie of working in the laboratory with other students, the one-on-one contact with the instructor of the laboratory, or some combination of all these things and perhaps more, the laboratory course represents the nature of chemistry to the students who have the opportunity to take it. The world of chemistry does in fact contain these elements, and in this way the laboratory course does accurately reflect the nature of chemistry. What remains is to make the *work* of the teaching laboratory authentic and true to the nature of chemistry as well.

One of the common rationales for laboratory instruction is that it exists to support instruction in the lecture component of the course, as H.I Schlesinger argued, "to illustrate and clarify principles discussed in the classroom, by providing actual contact with materials."[10] In fact, many laboratory courses are designed with this idea in mind, with laboratory experiences coordinated in time with lecture topics. As the lecture course is an overview of many topics, this approach necessitates a "cafeteria-style" laboratory course in which many apparently unrelated laboratory experiences are "cobbled together" into one course. The control laboratory course in this study was designed to follow this very common scheme. The experimental laboratory course, being research-based and with a focus on a narrow topic, could not be taught under the cafeteria-style approach of traditional laboratory instruction. The experimental course in this study was instead designed to be a stand-alone course, with very little reference to the associated lecture. It would seem then that students in the control course would see connections to the lecture course whereas students in the experimental course would not. In the few semesters in which this question was specifically addressed, students in the control group were not more likely to say that "the labs related well to the CH 302 lecture material." This may simply be related to the already established literature precedent that laboratory content does not appear to improve student performance in the lecture[29–34]: students apparently compartmentalize their learning and do not readily connect laboratory and lecture concepts.

While this observation may be perceived as deeply discouraging, it also provides an opportunity: students are not likely to be harmed by choosing experiments that are not immediately related to lecture material. Indeed, if the survey responses are accurate, students in the experimental course were not at a disadvantage in the lecture course relative to students in the control course. If this is so, instructors should not feel bound to the canon that laboratory exercises need be chosen based on lecture topics; the laboratory, evidently from the student's point of view, is an entirely separate course. Indeed, for courses involving large numbers of students, the coordination of lecture and laboratory topics become extremely difficult from a logistic point of view and the two components become separate courses, *de facto*. Once instructors accept this point of view, it provides them an opportunity to take on innovative approaches to laboratory work; freed of the imposed (and artificial) time constraints from the lecture course, instructors can pursue projects with students, allowing them to experience first-hand how chemists approach problems to which chemistry can provide answers. The chief benefit of this point of view to instructors is that they can structure laboratory courses based on their own experience as chemists, providing the "personal touch" that is part of any mentor/mentee relationship. This approach strikes at the heart of chemical research, which is likely to be more intellectually stimulating than a series of experiments performed by rote, not only to the instructor, but certainly also to the student. Perhaps students in the experimental course indicated as much when they reported more interest in studying chemistry in general.

The failure of students to make a connection between the lecture and laboratory course is telling. Students are reminding us that the two venues in which chemical knowledge is attained are indeed different. The lecture course is not unlike a history course; it documents what we already know about the discipline and how we came to know it. The laboratory course also has this character, but it also holds the promise of revealing what we do not yet know. It is this ability that makes the laboratory course unique and powerful, and ultimately, true to the nature of chemistry. Chemistry, in Liebig's time and in ours, continues to be the science of transformation and change, reflected not only in the phenomena chemists study, but indeed in the discipline itself. It will continue to be so for all generations which follow us. Laboratory courses do chemistry a disservice when they cannot be the mechanism for change, for in the end, they are the only means that chemistry can rely on to play that role.

It may be that the most important role of the teaching laboratory is to prepare the next group of students to be chemistry's agents of change. Having them skilled in the ability to do research, as Liebig found nearly 200 years ago, is the most reliable way to make sure the work of chemistry goes on. The experimental course in this study showed that introductory chemistry students can be successful in a research-based laboratory program and, from it, derive a feeling a confidence about their ability to perform laboratory experiments. Furthermore, the benefits of such a laboratory program are attainable by all students, including those who might be considered at-risk. As the students in the experimental course look forward to the future with confidence, the laboratory experience has served its purpose well.

Appendix A: Spring 1998 and Fall 1998 Survey

End of Semester
Alternate CH204 Course Survey[1]

Chemistry 204 Consent Form for Students

Dr. Kent Stewart is conducting a survey of all the students completing the Alternate CH204. The survey is designed to assist Dr. Stewart in understanding the effects of various course innovations on students' learning experiences and may lead to improvements in the teaching of chemistry nationwide.

The survey should take about ten minutes to complete. All student responses will be held strictly confidential. Dr. Stewart will generalize about student responses so as to obscure the identity of any particular students before reporting any survey findings. Dr. Stewart may publish papers based on the results of this survey, but these materials will contain no information that would identify particular students.

Participation is completely voluntary. (Students choosing not to participate may simply return a blank survey). Refusal to participate will have no effect on your grade. There are no formal benefits or risks associated with participation.

Any questions you have you may ask now, or you may call Dr. Kent Stewart at 471-7732. I have read the above and give my consent to participate in the study.

Signature _________________________________ Date ____________
STUDENT I.D. number ____________________
(Do not put your student I.D. on the upper left corner of the "bubble" sheet)

Dr. Stewart thanks you for participating in this survey. The questions in the survey are intended to help him understand your experiences in alternate CH204. Your thoughtful responses to the questions in this survey will help him to evaluate and improve the course offering.

Extra copies of this consent form can be obtained at front of the room where this class is being held.

---

[1] This form is modified from one developed by The Learning through Evaluation, Adaptation and Dissemination (LEAD) Center, University of Wisconsin Madison for the education reform project, "New Traditions: Revitalizing the Curriculum" as taken from their web site on April 20, 1998.

<u>BACKGROUND</u>:

1) Major: ____

(Students filled responses, which were then coded by hand to reflect the following descriptions)

	fill in…
CHEMISTRY AND BIOCHEMISTRY	**1**
LIFE SCIENCES, HEALTH SCIENCES, BUT NOT BIOCHEMISTRY	**2**
ENGINEERING, INCLUDING CHEMICAL ENGINEERING	**3**
ALL OTHER SCIENCES, INCLUDING PHYSICS AND COMPUTER SCIENCES	**4**
ALL OTHER MAJORS	**5**

2) <u>sex</u>:

for...	female	male
fill in...	**1**	**2**

3) <u>citizenship</u>:

for...	**U.S.**	**other**
fill in...	**1**	**2**

4) <u>U.S. ethnic codes</u> for…

	fill in…
WHITE (NOT HISPANIC) OR OTHER	**0**
CAMBODIAN, LAOTIAN, VIETNAMESE AFTER 1975	**1**
OTHER ASIAN OR PACIFIC ISLANDER	**2**
AMERICAN INDIAN OR ALASKAN NATIVE	**3**
HISPANIC/LATINO	**4**
BLACK/AFRICAN-AMERICAN	**5**

5) <u>college rank</u>:

for...	no college rank	freshman	sophomore	junior	senior
fill in...	**1**	**2**	**3**	**4**	**5**

6) <u>semesters of high school chemistry</u>: 0 1 2 3 over 3 **(fill in bubble 4)**

7) <u>semesters of college level chemistry completed</u>: 0 1 2 3 4 5 6 7 8 over 8 **(fill in bubble 9)**

For each group of factors below please fill in a number on the bubble sheet to indicate the ***relative impact*** of each factor on your ***<u>LEARNING</u>*** overall in this course.

<u>PEOPLE</u>		***relative impact on your <u>LEARNING</u> overall***							
		not applicable	**negative**			**neutral**			**positive**
professor	**8)**	0	1	2	3	4	5	6	7
TA/lab instructor	**9)**	0	1	2	3	4	5	6	7
friends/informal groups	**10)**	0	1	2	3	4	5	6	7
course organized groups	**11)**	0	1	2	3	4	5	6	7
other people specify here: ______________	**12)**	0	1	2	3	4	5	6	7

ACTIVITIES		*relative impact on your LEARNING overall*							
		not applicable	**negative**			**neutral**			**positive**
lecture	**13)**	0	1	2	3	4	5	6	7
lab	**14)**	0	1	2	3	4	5	6	7
discussion/problem sessions	**15)**	0	1	2	3	4	5	6	7
exams	**16)**	0	1	2	3	4	5	6	7
quizzes	**17)**	0	1	2	3	4	5	6	7
homework/exercises	**18)**	0	1	2	3	4	5	6	7
other activities specify here: ________________	**19)**	0	1	2	3	4	5	6	7

MATERIALS		*relative impact on your LEARNING overall*							
		not applicable	**negative**			**neutral**			**positive**
lecture handouts	**20)**	0	1	2	3	4	5	6	7
laboratory handouts	**21)**	0	1	2	3	4	5	6	7
computer materials	**22)**	0	1	2	3	4	5	6	7
other materials specify here: ________________	**23)**	0	1	2	3	4	5	6	7

For each group of factors below please fill in a number on the bubble sheet to indicate the ***relative impact*** of each factor on your ***CONFIDENCE*** in your ability to understand and do chemistry.

PEOPLE		*relative impact on your CONFIDENCE*							
		not applicable	**negative**			**neutral**			**positive**
professor	**24)**	0	1	2	3	4	5	6	7
TA/lab instructor	**25)**	0	1	2	3	4	5	6	7
friends/informal groups	**26)**	0	1	2	3	4	5	6	7
course organized groups	**27)**	0	1	2	3	4	5	6	7
other people specify here: ________________	**28)**	0	1	2	3	4	5	6	7

ACTIVITIES		*relative impact on your* ***CONFIDENCE***							
		not applicable	**negative**			**neutral**			**positive**
lecture	**29)**	0	1	2	3	4	5	6	7
lab	**30)**	0	1	2	3	4	5	6	7
discussion/problem sessions	**31)**	0	1	2	3	4	5	6	7
exams	**32)**	0	1	2	3	4	5	6	7
quizzes	**33)**	0	1	2	3	4	5	6	7
homework/exercises	**34)**	0	1	2	3	4	5	6	7
other activities specify here: ___________	**35)**	0	1	2	3	4	5	6	7

MATERIALS		*relative impact on your* ***CONFIDENCE***							
		not applicable	**negative**			**neutral**			**positive**
lecture handouts	**36)**	0	1	2	3	4	5	6	7
laboratory handouts	**37)**	0	1	2	3	4	5	6	7
computer materials	**38)**	0	1	2	3	4	5	6	7
other materials specify here: ___________	**39)**	0	1	2	3	4	5	6	7

For each group of factors below please fill in a number on the bubble sheet to indicate the ***relative impact*** of each factor on your ***ENTHUSIASM*** for learningchemistry.

PEOPLE		*relative impact on your* ***ENTHUSIASM***							
		not applicable	**negative**			**neutral**			**positive**
professor	**40)**	0	1	2	3	4	5	6	7
TA/lab instructor	**41)**	0	1	2	3	4	5	6	7
friends/informal groups	**42)**	0	1	2	3	4	5	6	7
course organized groups	**43)**	0	1	2	3	4	5	6	7
other people specify here: ___________	**44)**	0	1	2	3	4	5	6	7

ACTIVITIES		*relative impact on your __ENTHUSIASM__*							
		not applicable	**negative**			**neutral**			**positive**
lecture	**45)**	0	1	2	3	4	5	6	7
lab	**46)**	0	1	2	3	4	5	6	7
discussion/problem sessions	**47)**	0	1	2	3	4	5	6	7
exams	**48)**	0	1	2	3	4	5	6	7
quizzes	**49)**	0	1	2	3	4	5	6	7
homework/exercises	**50)**	0	1	2	3	4	5	6	7
other activities specify here: ___________________	**51)**	0	1	2	3	4	5	6	7

MATERIALS		*relative impact on your __ENTHUSIASM__*							
		not applicable	**negative**			**neutral**			**positive**
lecture handouts	**52)**	0	1	2	3	4	5	6	7
laboratory handouts	**53)**	0	1	2	3	4	5	6	7
computer materials	**54)**	0	1	2	3	4	5	6	7
other materials specify here: ___________________	**55)**	0	1	2	3	4	5	6	7

Please compare your ***__CONFIDENCE__*** levels ***__BEFORE__*** and ***__AFTER__*** taking this course.
(Fill in a number on the bubble sheet for each row.)

CONFIDENCE IN YOUR ABILITY TO...			**confidence level**				
			low				**high**
understand key concepts of chemistry………………	**56)**	**before**	0	1	2	3	4	5
	57)	**after**	0	1	2	3	4	5
solve chemistry problems…………………………...	**58)**	**before**	0	1	2	3	4	5
	59)	**after**	0	1	2	3	4	5
understand the chemistry underlying lab experiments	**60)**	**before**	0	1	2	3	4	5
	61)	**after**	0	1	2	3	4	5
perform lab experiments…………………………….	**62)**	**before**	0	1	2	3	4	5
	63)	**after**	0	1	2	3	4	5
visualize key concepts of chemistry…………..........	**64)**	**before**	0	1	2	3	4	5
	65)	**after**	0	1	2	3	4	5
apply your knowledge of chemistry to the real world	**66)**	**before**	0	1	2	3	4	5
	67)	**after**	0	1	2	3	4	5
understand other areas of science..............................	**68)**	**before**	0	1	2	3	4	5
	69)	**after**	0	1	2	3	4	5
succeed in another chemistry course.........................	**70)**	**before**	0	1	2	3	4	5
	71)	**after**	0	1	2	3	4	5
succeed in a chemistry-related discipline..................	**72)**	**before**	0	1	2	3	4	5
	73)	**after**	0	1	2	3	4	5

Please compare your ***INTEREST*** levels ***BEFORE*** and ***AFTER*** taking this course.
(Fill in a number on the bubble sheet for each row.)

CONFIDENCE IN YOUR ABILITY TO...			**confidence level**					
			low					**high**
studying chemistry in general……….………………	**74)**	**before**	0	1	2	3	4	5
	75)	**after**	0	1	2	3	4	5
taking more chemistry…….…………………………...	**76)**	**before**	0	1	2	3	4	5
	77)	**after**	0	1	2	3	4	5
pursuing a chemistry-related major…………………	**78)**	**before**	0	1	2	3	4	5
	79)	**after**	0	1	2	3	4	5
pursuing a science-related field…………………….	**80)**	**before**	0	1	2	3	4	5
	81)	**after**	0	1	2	3	4	5
working with others to learn science...………..........	**82)**	**before**	0	1	2	3	4	5
	83)	**after**	0	1	2	3	4	5
chemistry in industry………………………………..	**84)**	**before**	0	1	2	3	4	5
	85)	**after**	0	1	2	3	4	5
chemistry in agriculture………..................................	**86)**	**before**	0	1	2	3	4	5
	87)	**after**	0	1	2	3	4	5
chemistry in medicine……………..........................	**88)**	**before**	0	1	2	3	4	5
	89)	**after**	0	1	2	3	4	5
chemistry in athletics………………………………..	**90)**	**before**	0	1	2	3	4	5
	91)	**after**	0	1	2	3	4	5
chemistry in the environment…………...................	**92)**	**before**	0	1	2	3	4	5
	93)	**after**	0	1	2	3	4	5
science in general……………………………………	**94)**	**before**	0	1	2	3	4	5
	95)	**after**	0	1	2	3	4	5

For each row please fill in **one** number on the bubble sheet which best represents your view.

	LECTURE	**strongly disagree**					**strongly agree**
96)	I enjoyed the formal laboratory (1 hour) lectures.	0	1	2	3	4	5
97)	The organization of the lectures was important for my learning.	0	1	2	3	4	5
98)	The professor was concerned about my learning chemistry.	0	1	2	3	4	5
99)	The professor made students feel comfortable asking questions.	0	1	2	3	4	5
100)	The applications of chemistry discussed in this course made certain concepts easier to understand.	0	1	2	3	4	5
101)	The applications of chemistry discussed in this course made learning chemistry interesting.	0	1	2	3	4	5

	EXAMS	**strongly disagree**					**strongly agree**
102)	The lectures and assigned work adequately prepared me for exams.	0	1	2	3	4	5
103)	Taking the exams increased my understanding of the course material.	0	1	2	3	4	5
104)	I sometimes developed new insights from taking the exams.	0	1	2	3	4	5

	LABS	**strongly disagree**					**strongly agree**
105)	I enjoyed the labs.	0	1	2	3	4	5
106)	I understood the chemistry behind the labs before I did them.	0	1	2	3	4	5
107)	Eventually I understood the chemistry behind the labs.	0	1	2	3	4	5
108)	The labs helped me understand important concepts in this course.	0	1	2	3	4	5
109)	The labs related well to the CH 302 lecture material.	0	1	2	3	4	5
110)	Enough time was allowed for labs.	0	1	2	3	4	5
111)	The lab instructor was helpful.	0	1	2	3	4	5

GENERAL: (Fill in the appropriate response)

			hours per week				
112)	**Average hours per week spent on this course:**	**For…**	**0-5**	**5-10**	**10-15**	**15-20**	**Over 20**
		Fill in…	1	2	3	4	5

		no					**highly recommend**
113)	**Would you recommend this course to a friend?**	0	1	2	3	4	5

Additional items coded:

114) Chemistry lab enrollment	**fill in…**
CH 204	**1**
CH 204 AV	**2**

115) Wet Lab Day: for…	**fill in…**
TUESDAY (OR TUESDAY/ THURSDAY)	**1**
WEDNESDAY (OR MONDAY/ WEDNESDAY)	**2**
THURSDAY	**3**
FRIDAY	**4**

116) Wet Lab Time:	**for...**	mornings	afternoons
	fill in...	**1**	**2**

Please complete this item. (in the space provided below).

The three most important aspects of this course for my learning were…

1)

2)

3)

THANK YOU!

Appendix B: Spring 1999 Survey

Introductory Chemistry Laboratory Course Survey[1] Consent Form for Students

Dr. Kent Stewart and Mike Elliott are conducting a survey of all the students completing introductory Chemistry laboratory courses at the University of Texas. The survey is designed to assist us in understanding the effects of various course innovations on students' learning experiences and may lead to improvements in the teaching of chemistry nationwide.

The survey should take about ten minutes to complete. All student responses will be held strictly confidential. We will generalize about student responses so as to obscure the identity of any particular students before reporting any survey findings. We may publish papers based on the results of this survey, but these materials will contain no information that would identify particular students. Participation is completely voluntary. (Students choosing not to participate may simply return a blank survey). Refusal to participate will have no effect on your grade. There are no formal benefits or risks associated with participation. Any questions you have you may ask now, or you may call Dr. Kent Stewart or Mike Elliott at 471-7732. I have read the above and give my consent to participate in the study.

Signature _______________________________ Date ___________
STUDENT I.D. number ___________________
(Do not put your student I.D. on the upper left corner of the "bubble" sheet)

Dr. Stewart and Mike Elliott thank you for participating in this survey. The questions in the survey are intended to help us understand your experiences in alternate CH204. Your thoughtful responses to the questions in this survey will help us to evaluate and improve the course offering.

Extra copies of this consent form can be obtained at front of the room where this class is being held.

Please Answer: The two most important aspects of this course for my learning were…
1)

2)

Please fill in your responses on the separate bubble sheet

[1] This form is modified from one developed by The Learning through Evaluation, Adaptation and Dissemination (LEAD) Center, University of Wisconsin Madison for the education reform project, "New Traditions: Revitalizing the Curriculum" as taken from their web site on April 20, 1998.

BACKGROUND:

1) Chemistry lab enrollment

	fill in…
CH 204	**1**
CH 204 AV TUESDAY/WEDNESDAY WET LABS	**2**
CH 204 AV THURSDAY/FRIDAY WET LABS	**3**
CH 317	**4**

2) Major: ____

(Coded by hand to reflect the following descriptions)

	fill in…
CHEMISTRY AND BIOCHEMISTRY	**1**
LIFE SCIENCES, HEALTH SCIENCES, BUT NOT BIOCHEMISTRY	**2**
ENGINEERING, INCLUDING CHEMICAL ENGINEERING	**3**
ALL OTHER SCIENCES, INCLUDING PHYSICS AND COMPUTER SCIENCES	**4**
ALL OTHER MAJORS	**5**

3) sex:

for...	female	male
fill in...	**1**	**2**

4) U.S. ethnic codes for…

	fill in…
WHITE (NOT HISPANIC) OR OTHER	**1**
ASIAN OR PACIFIC ISLANDER	**2**
AMERICAN INDIAN OR ALASKAN NATIVE	**3**
HISPANIC/LATINO	**4**
BLACK/AFRICAN-AMERICAN	**5**

5) college rank:

for...	freshman	sophomore	junior	senior	all other situations
fill in...	**1**	**2**	**3**	**4**	**5**

6) semesters of high school chemistry: 1 2 3 over 3 **(fill in bubble 4)** none **(fill in bubble 5)**

7) semesters of college level chemistry completed: 1 2 3 over 3 **(fill in bubble 4)** none **(fill in bubble 5)**

For each group of factors below please fill in a number on the bubble sheet to indicate the ***relative impact*** of each factor on your ***LEARNING*** overall in this course.

		relative impact on your ***LEARNING*** overall				
	ACTIVITIES	**negative**		**neutral**		**positive**
8)	lecture	1	2	3	4	5
9)	lab	1	2	3	4	5
10)	computer lab	1	2	3	4	5
11)	exams	1	2	3	4	5
12)	quizzes	1	2	3	4	5
13)	homework/exercises	1	2	3	4	5

		relative impact on your ***LEARNING*** overall				
	MATERIALS	**negative**		**neutral**		**positive**
14)	lecture handouts	1	2	3	4	5
15)	laboratory handouts	1	2	3	4	5
16)	computer materials	1	2	3	4	5

For each group of factors below please fill in a number on the bubble sheet to indicate the ***relative impact*** of each factor on your ***CONFIDENCE*** in your ability to understand and do chemistry.

	ACTIVITIES	***relative impact*** on your ***CONFIDENCE*** **negative**		**neutral**		**positive**
17)	lecture	1	2	3	4	5
18)	lab	1	2	3	4	5
19)	computer lab	1	2	3	4	5
20)	exams	1	2	3	4	5
21)	quizzes	1	2	3	4	5
22)	homework/exercises	1	2	3	4	5

	MATERIALS	***relative impact*** on your ***CONFIDENCE*** **negative**		**neutral**		**positive**
23)	lecture handouts	1	2	3	4	5
24)	laboratory handouts	1	2	3	4	5
25)	computer materials	1	2	3	4	5

For each group of factors below please fill in a number on the bubble sheet to indicate the ***relative impact*** of each factor on your ***ENTHUSIASM*** for learning chemistry.

relative impact on your ***ENTHUSIASM***

	ACTIVITIES	**negative**		**neutral**		**positive**
26)	lecture	1	2	3	4	5
27)	lab	1	2	3	4	5
28)	computer lab	1	2	3	4	5
29)	exams	1	2	3	4	5
30)	quizzes	1	2	3	4	5
31)	homework/exercises	1	2	3	4	5

	MATERIALS	***relative impact*** on your ***ENTHUSIASM*** **negative**		**neutral**		**positive**
32)	lecture handouts	1	2	3	4	5
33)	laboratory handouts	1	2	3	4	5
34)	computer materials	1	2	3	4	5

Please compare your ***CONFIDENCE*** levels ***BEFORE*** and ***AFTER*** taking this course.
(Fill in a number on the bubble sheet for each row.)

CONFIDENCE IN YOUR ABILITY TO...			**confidence level**				
			low				**high**
understand key concepts of chemistry………………	**35)**	**before**	1	2	3	4	5
	36)	**after**	1	2	3	4	5
solve chemistry problems…………………………...	**37)**	**before**	1	2	3	4	5
	38)	**after**	1	2	3	4	5
understand the chemistry underlying lab experiments	**39)**	**before**	1	2	3	4	5
	40)	**after**	1	2	3	4	5
perform lab experiments…………………………….	**41)**	**before**	1	2	3	4	5
	42)	**after**	1	2	3	4	5
visualize key concepts of chemistry………..........	**43)**	**before**	1	2	3	4	5
	44)	**after**	1	2	3	4	5
apply your knowledge of chemistry to the real world	**45)**	**before**	1	2	3	4	5
	46)	**after**	1	2	3	4	5
understand other areas of science..............................	**47)**	**before**	1	2	3	4	5
	48)	**after**	1	2	3	4	5
succeed in another chemistry course.........................	**49)**	**before**	1	2	3	4	5
	50)	**after**	1	2	3	4	5
succeed in a chemistry-related discipline..................	**51)**	**before**	1	2	3	4	5
	52)	**after**	1	2	3	4	5

Please compare your ***INTEREST*** levels ***BEFORE*** and ***AFTER*** taking this course.
(Fill in a number on the bubble sheet for each row.)

INTEREST IN...			**interest level**				
			low				**high**
studying chemistry in general………….……………	**53)**	**before**	1	2	3	4	5
	54)	**after**	1	2	3	4	5
taking more chemistry…….………………………...	**55)**	**before**	1	2	3	4	5
	56)	**after**	1	2	3	4	5
pursuing a chemistry-related major…………………	**57)**	**before**	1	2	3	4	5
	58)	**after**	1	2	3	4	5
pursuing a science-related field…………………….	**59)**	**before**	1	2	3	4	5
	60)	**after**	1	2	3	4	5
working with others to learn science...………...........	**61)**	**before**	1	2	3	4	5
	62)	**after**	1	2	3	4	5
chemistry in industry………………………………..	**63)**	**before**	1	2	3	4	5
	64)	**after**	1	2	3	4	5
chemistry in the environment...................................	**65)**	**before**	1	2	3	4	5
	66)	**after**	1	2	3	4	5
chemistry in medicine……………...........................	**67)**	**before**	1	2	3	4	5
	68)	**after**	1	2	3	4	5
science in general……………………………………	**69)**	**before**	1	2	3	4	5
	70)	**after**	1	2	3	4	5

For each row please fill in **one** number on the bubble sheet which best represents your view.

	LECTURE	**strongly disagree**				**strongly agree**
71)	I enjoyed the formal laboratory (1 hour) lectures.	1	2	3	4	5
72)	The organization of the lectures was important for my learning.	1	2	3	4	5
73)	The applications of chemistry discussed in this course made certain concepts easier to understand.	1	2	3	4	5
74)	The applications of chemistry discussed in this course made learning chemistry interesting.	1	2	3	4	5

	EXAMS	**strongly disagree**				**strongly agree**
75)	The lectures and assigned work adequately prepared me for exams.	1	2	3	4	5
76)	Taking the exams increased my understanding of the course material.	1	2	3	4	5
77)	I sometimes developed new insights from taking the exams.	1	2	3	4	5

	LABS	**strongly disagree**				**strongly agree**
78)	I enjoyed the labs.	1	2	3	4	5
79)	The organization of the labs was important for my learning.					
80)	I understood the chemistry behind the labs before I did them.	1	2	3	4	5
81)	Eventually I understood the chemistry behind the labs.	1	2	3	4	5
82)	The labs helped me understand important concepts in this course.	1	2	3	4	5
83)	The labs related well to the CH 302 lecture material.	1	2	3	4	5
84)	Enough time was allowed for labs.	1	2	3	4	5

GENERAL: (Fill in the appropriate response)

					hours per week		
85)	**Average hours per week spent on this course:**	**For…**	**0**	**1-5**	**5-10**	**10-15**	**Over 20**
		Fill in…	1	2	3	4	5

		no				**highly recommend**
86)	**Would you recommend this course to a friend?**	1	2	3	4	5

Additional items coded:

87) <u>Wet Lab Day</u>: for… **fill in…**

for…	fill in…
TUESDAY (OR TUESDAY/ THURSDAY)	**1**
WEDNESDAY (OR MONDAY/ WEDNESDAY)	**2**
THURSDAY	**3**
FRIDAY	**4**

88) <u>Wet Lab Time</u>:

for...	mornings	afternoons
fill in...	**1**	**2**

Please complete this item. (in the space provided below).

The three most important aspects of this course for my learning were…

1)

2)

3)

THANK YOU!

Appendix C: Fall 1999, Spring 2000, and Fall 2000 Survey

Introductory Chemistry Laboratory Course Survey[1] Consent Form for Students

Dr. Kent Stewart and Mike Elliott are conducting a survey of students completing introductory Chemistry laboratory courses at The University of Texas. The survey is designed to assist us in understanding the effects of various course innovations on students' learning experiences and may lead to improvements in the teaching of chemistry nationwide.

The survey should take about fifteen minutes to complete. All student responses will be held strictly confidential. We will generalize about student responses so as to obscure the identity of any particular students before reporting any survey findings. We may publish papers based on the results of this survey, but these materials will contain no information that would identify particular students. Participation is completely voluntary. (Students choosing not to participate may simply return a blank survey). Refusal to participate will have no effect on your grade. There are no formal benefits or risks associated with participation. Any questions you have you may ask now, or you may call Dr. Kent Stewart or Mike Elliott at 471-7732. I have read the above and give my consent to participate in the study.

Signature ________________________________ Date ____________
STUDENT I.D. number ____________________
(Please also put your student I.D. on the upper left corner of the "bubble" sheet)

Circle your laboratory enrollment:

CH 204 CH204AV CH317

Dr. Stewart and Mike Elliott thank you for participating in this survey. The questions in the survey are intended to help us understand your experiences in your General Chemistry laboratory course. Your thoughtful responses to the questions in this survey will help us to evaluate and improve course offerings.

Extra copies of this consent form can be obtained at front of the room where this class is being held.

Please Answer: The two most important aspects of this course for my learning were...
1)
2)

<u>Please fill in your responses on the separate bubble sheet</u>

Lab Survey April 24, 2000

---

[1] This form is modified from one developed by The Learning through Evaluation, Adaptation and Dissemination (LEAD) Center, University of Wisconsin Madison for the education reform project, "New Traditions: Revitalizing the Curriculum" as taken from their web site on April 20, 1998.

BACKGROUND:

1) Chemistry lab enrollment **fill in…**

CH 204	**1**
CH 204 AV	**2**
CH 317	**3**

2) Wet Lab Day: **for…** **fill in…**

TUESDAY (OR TUESDAY/ THURSDAY)	**1**
WEDNESDAY (OR MONDAY/ WEDNESDAY)	**2**
THURSDAY	**3**
FRIDAY	**4**

3) Wet Lab Time:

for...	mornings	afternoons
fill in...	**1**	**2**

4) Major: **for…** **fill in…**

CHEMISTRY AND BIOCHEMISTRY	**1**
LIFE SCIENCES, HEALTH SCIENCES, BUT NOT BIOCHEMISTRY	**2**
ENGINEERING, INCLUDING CHEMICAL ENGINEERING	**3**
ALL OTHER SCIENCES, INCLUDING PHYSICS AND COMPUTER SCIENCES	**4**
ALL OTHER MAJORS	**5**

5) sex:

for...	female	male
fill in...	**1**	**2**

6) U.S. ethnic codes **for...** **fill in...**

WHITE (NOT HISPANIC) OR OTHER	**1**
ASIAN OR PACIFIC ISLANDER	**2**
AMERICAN INDIAN OR ALASKAN NATIVE	**3**
HISPANIC/LATINO	**4**
BLACK/AFRICAN-AMERICAN	**5**

7) college rank:

for...	freshman	sophomore	junior	senior	all other situations
fill in...	**1**	**2**	**3**	**4**	**5**

8) semesters of high school chemistry: **1 2 3** over 3 **(fill in bubble 4)** none **(fill in bubble 5)**

9) semesters of college level chemistry completed: **1 2 3** over 3 **(fill in bubble 4)** none **(fill in bubble 5)**

Please rate your ***CONFIDENCE*** levels in the areas below.
(Fill in a number on the bubble sheet for each row.)

CONFIDENCE IN YOUR ABILITY TO...		confidence level				
		low				high
understand key concepts of chemistry..........................	**10)**	1	2	3	4	5
solve chemistry problems..	**11)**	1	2	3	4	5
understand the chemistry underlying lab experiments	**12)**	1	2	3	4	5
perform lab experiments..	**13)**	1	2	3	4	5
visualize key concepts of chemistry.............................	**14)**	1	2	3	4	5
apply your knowledge of chemistry to the real world	**15)**	1	2	3	4	5
understand other areas of science.................................	**16)**	1	2	3	4	5
succeed in another chemistry course.............................	**17)**	1	2	3	4	5
succeed in a chemistry-related discipline.....................	**18)**	1	2	3	4	5

Please rate your ***INTEREST*** levels in the areas below.
(Fill in a number on the bubble sheet for each row.)

INTEREST IN….		INTEREST LEVEL				
		low				high
studying chemistry in general.......................………..	**19)**	1	2	3	4	5
taking more chemistry…..	**20)**	1	2	3	4	5
pursuing a chemistry-related major…………………..	**21)**	1	2	3	4	5
pursuing a science-related field....................................	**22)**	1	2	3	4	5
working with others to learn science.............................	**23)**	1	2	3	4	5
chemistry in industry………………………………….	**24)**	1	2	3	4	5
chemistry in the environment……................................	**25)**	1	2	3	4	5
chemistry in medicine……………...............................	**26)**	1	2	3	4	5
science in general………………………....................	**27)**	1	2	3	4	5

28) When did you take CH 302 (or its equivalent)?	**Fill in...**
THIS TERM (FALL 1999)	**1**
LAST TERM (SPRING 1999 OR SUMMER 1999)	**2**
FALL 1998	**3**
PRIOR TO FALL 1998	**4**
I PLACED OUT OF CH 302	**5**

		No/ not at all				**Yes/ very much so**
Did your General Chemistry lecture experience help you in your laboratory course?.......................…………..………	**29)**	1	2	3	4	5
Did you use the General Chemistry textbook to help solve problems in your laboratory course?....................................	**30)**	1	2	3	4	5
Do you see value in taking laboratory courses?.…………..	**31)**	1	2	3	4	5

For each group of factors below please fill in a number on the bubble sheet to indicate the ***relative impact*** of each factor on your ***LEARNING*** overall in this course. (Leave blank any factors you did not participate in.)

	ACTIVITIES	***relative impact*** on your ***LEARNING*** overall **negative**		**neutral**		**positive**
32)	lab lecture	1	2	3	4	5
33)	wet lab	1	2	3	4	5
34)	computer lab	1	2	3	4	5
35)	exams	1	2	3	4	5
36)	quizzes	1	2	3	4	5
37)	homework/exercises	1	2	3	4	5

For each group of factors below please fill in a number on the bubble sheet to indicate the ***relative impact*** of each factor on your ***CONFIDENCE*** in your ability to understand and do chemistry. (Leave blank any factors you did not participate in.)

	ACTIVITIES	***relative impact*** on your ***CONFIDENCE*** **negative**		**neutral**		**positive**
38)	lab lecture	1	2	3	4	5
39)	wet lab	1	2	3	4	5
40)	computer lab	1	2	3	4	5
41)	exams	1	2	3	4	5
42)	quizzes	1	2	3	4	5
43)	homework/exercises	1	2	3	4	5

For each group of factors below please fill in a number on the bubble sheet to indicate the ***relative impact*** of each factor on your ***ENTHUSIASM*** for learning chemistry. (Leave blank any factors you did not participate in.)

	ACTIVITIES	***relative impact*** on your ***ENTHUSIASM*** **negative**		**neutral**		**positive**
44)	lab lecture	1	2	3	4	5
45)	wet lab	1	2	3	4	5
46)	computer lab	1	2	3	4	5
47)	exams	1	2	3	4	5
48)	quizzes	1	2	3	4	5
49)	homework/exercises	1	2	3	4	5

For each row please fill in **one** number on the bubble sheet which best represents your view.

	LECTURE	**strongly disagree**				**strongly agree**
50)	I enjoyed the formal laboratory (1 hour) lectures.	1	2	3	4	5
51)	The organization of the lectures was important for my learning.	1	2	3	4	5
52)	The applications of chemistry discussed in this course made certain concepts easier to understand.	1	2	3	4	5
53)	The applications of chemistry discussed in this course made learning chemistry interesting.	1	2	3	4	5

	LABS	**strongly disagree**				**strongly agree**
54)	I enjoyed the labs.	1	2	3	4	5
55)	The organization of the labs was important for my learning.	1	2	3	4	5
56)	I understood the chemistry behind the labs before I did them.	1	2	3	4	5
57)	Eventually I understood the chemistry behind the labs.	1	2	3	4	5
58)	The labs helped me understand important concepts in this course.	1	2	3	4	5
59)	The labs related well to the CH 302 lecture material.	1	2	3	4	5
60)	Enough time was allowed for labs.	1	2	3	4	5

<u>GENERAL</u>: (Fill in the appropriate response)

		hours per week				
61) Average hours per week spent on this course:	**For…**	**0**	**1-5**	**5-10**	**15-20**	**Over 20**
	Fill in…	1	2	3	4	5

	no				**highly recommend**
62) Would you recommend this course to a friend?	1	2	3	4	5

Appendix D: Spring 2001 Survey

Introductory Chemistry Laboratory Course Survey[1] Consent Form for Students

Dr. Kent Stewart and Mike Elliott are conducting a survey of students completing introductory Chemistry laboratory courses at The University of Texas. The survey is designed to assist us in understanding the effects of various course innovations on students' learning experiences and may lead to improvements in the teaching of chemistry nationwide.

The survey should take about fifteen minutes to complete. All student responses will be held strictly confidential. We will generalize about student responses so as to obscure the identity of any particular students before reporting any survey findings. We may publish papers based on the results of this survey, but these materials will contain no information that would identify particular students. Participation is completely voluntary. (Students choosing not to participate may simply return a blank survey). Refusal to participate will have no effect on your grade. There are no formal benefits or risks associated with participation. Any questions you have you may ask now, or you may call Dr. Kent Stewart or Mike Elliott at 471-7732. I have read the above and give my consent to participate in the study.

Signature ________________________________ Date ____________

Circle your laboratory enrollment:

CH 204 CH204AV CH317

Dr. Stewart and Mike Elliott thank you for participating in this survey. The questions in the survey are intended to help us understand your experiences in your General Chemistry laboratory course. Your thoughtful responses to the questions in this survey will help us to evaluate and improve course offerings.

Extra copies of this consent form can be obtained at front of the room where this class is being held.

Lab Survey April 30, 2001

[1] This form is modified from one developed by The Learning through Evaluation, Adaptation and Dissemination (LEAD) Center, University of Wisconsin Madison for the education reform project, "New Traditions: Revitalizing the Curriculum" as taken from their web site on April 20, 1998.

Please Answer: The two most important aspects of this course for my learning were...
1)

2)

The three things that helped me most in getting through this course were...
1)

2)

3)

<u>The survey continues on the following page:</u>

<u>Please fill in your responses on the separate bubble sheet</u>

<u>BACKGROUND</u>:

1) Chemistry lab enrollment	**fill in…**
CH 204	**1**
CH 204 AV	**2**
CH 317	**3**

2) <u>Wet Lab Day</u>: for…	**fill in…**
TUESDAY (OR TUESDAY/THURSDAY)	**1**
WEDNESDAY (OR MONDAY/ WEDNESDAY)	**2**
THURSDAY	**3**
FRIDAY	**4**

3) <u>Wet Lab Time</u>:		
for...	mornings	afternoons
fill in...	**1**	**2**

4) <u>Major</u>: for…	**fill in…**
CHEMISTRY AND BIOCHEMISTRY	**1**
LIFE SCIENCES, HEALTH SCIENCES, BUT NOT BIOCHEMISTRY	**2**
ENGINEERING, INCLUDING CHEMICAL ENGINEERING	**3**
ALL OTHER SCIENCES, INCLUDING PHYSICS AND COMPUTER SCIENCES	**4**
ALL OTHER MAJORS	**5**

5) <u>sex</u>:		
for...	female	male
fill in...	**1**	**2**

6) <u>U.S. ethnic codes</u> for...	**fill in...**
WHITE (NOT HISPANIC) OR OTHER	**1**
ASIAN OR PACIFIC ISLANDER	**2**
AMERICAN INDIAN OR ALASKAN NATIVE	**3**
HISPANIC/LATINO	**4**
BLACK/AFRO-AMERICAN	**5**

7) <u>college rank</u>:

for...	freshman	sophomore	junior	senior	all other situations
fill in...	**1**	**2**	**3**	**4**	**5**

8) <u>semesters of high school chemistry</u>: 1 2 3 over 3 **(fill in bubble 4)** none **(fill in bubble 5)**

9) <u>semesters of college level chemistry completed</u>: 1 2 3 over 3 **(fill in bubble 4)** none **(fill in bubble 5)**

Please rate your ***CONFIDENCE*** levels in the areas below.
(Fill in a number on the bubble sheet for each row.)
CONFIDENCE IN YOUR ABILITY TO...

		confidence level				
		low				**high**
understand key concepts of chemistry..........................	**10)**	1	2	3	4	5
solve chemistry problems..	**11)**	1	2	3	4	5
understand the chemistry underlying lab experiments	**12)**	1	2	3	4	5
perform lab experiments...	**13)**	1	2	3	4	5
visualize key concepts of chemistry.............................	**14)**	1	2	3	4	5
apply your knowledge of chemistry to the real world	**15)**	1	2	3	4	5
understand other areas of science.................................	**16)**	1	2	3	4	5
succeed in another chemistry course.............................	**17)**	1	2	3	4	5
succeed in a chemistry-related discipline.....................	**18)**	1	2	3	4	5

Please rate your ***INTEREST*** levels in the areas below.
(Fill in a number on the bubble sheet for each row.)
INTEREST IN….

		INTEREST LEVEL				
		low				**high**
studying chemistry in general...................…….…..	**19)**	1	2	3	4	5
taking more chemistry…...	**20)**	1	2	3	4	5
pursuing a chemistry-related major…………………..	**21)**	1	2	3	4	5
pursuing a science-related field....................................	**22)**	1	2	3	4	5
working with others to learn science.............................	**23)**	1	2	3	4	5
chemistry in industry……………………………….	**24)**	1	2	3	4	5
chemistry in the environment……................................	**25)**	1	2	3	4	5
chemistry in medicine……………...............................	**26)**	1	2	3	4	5
science in general………………………......................	**27)**	1	2	3	4	5

28) When did you take CH 302 (or its equivalent)?	**Fill in...**
THIS TERM (SPRING 2001)	**1**
LAST TERM (FALL 2000)	**2**
SUMMER 2000	**3**
PRIOR TO SUMMER 2000	**4**
I PLACED OUT OF CH 302	**5**

		No/ not at all				**Yes/ very much so**
Did your General Chemistry lecture experience help you in your laboratory course?......................…………..………	**29)**	1	2	3	4	5
Did you use the General Chemistry textbook to help solve problems in your laboratory course?....................................	**30)**	1	2	3	4	5
Do you see value in taking laboratory courses?…………..	**31)**	1	2	3	4	5
How closely do the skills presented in this lab match your academic and/or career goals?..............…………..………	**32)**	1	2	3	4	5

	no				**highly recommend**
33) Would you recommend this course to a friend?	1	2	3	4	5

For each group of factors below please fill in a number on the bubble sheet to indicate the ***relative impact*** of each factor on your ***LEARNING*** overall in this course. (Leave blank any factors you did not participate in.)

	ACTIVITIES	***relative impact*** on your ***LEARNING*** overall **negative**		**neutral**		**positive**
34)	lab lecture	1	2	3	4	5
35)	wet lab	1	2	3	4	5
36)	computer lab	1	2	3	4	5
37)	exams	1	2	3	4	5
38)	quizzes	1	2	3	4	5
39)	homework/exercises	1	2	3	4	5

For each group of factors below please fill in a number on the bubble sheet to indicate the ***relative impact*** of each factor on your ***CONFIDENCE*** in your ability to understand and do chemistry. (Leave blank any factors you did not participate in.)

	ACTIVITIES	***relative impact*** on your ***CONFIDENCE*** **negative**		**neutral**		**positive**
40)	lab lecture	1	2	3	4	5
41)	wet lab	1	2	3	4	5
42)	computer lab	1	2	3	4	5
43)	exams	1	2	3	4	5
44)	quizzes	1	2	3	4	5
45)	homework/exercises	1	2	3	4	5

For each group of factors below please fill in a number on the bubble sheet to indicate the ***relative impact*** of each factor on your ***ENTHUSIASM*** for learning chemistry. (Leave blank any factors you did not participate in.)

	ACTIVITIES	***relative impact*** on your ***ENTHUSIASM*** **negative**		**neutral**		**positive**
46)	lab lecture	1	2	3	4	5
47)	wet lab	1	2	3	4	5
48)	computer lab	1	2	3	4	5
49)	exams	1	2	3	4	5
50)	quizzes	1	2	3	4	5
51)	homework/exercises	1	2	3	4	5

For each row please fill in **one** number on the bubble sheet which best represents your view.

	LECTURE	**strongly disagree**				**strongly agree**
52)	I enjoyed the formal laboratory (1 hour) lectures.	1	2	3	4	5
53)	The organization of the lectures was important for my learning.	1	2	3	4	5
54)	The applications of chemistry discussed in this course made certain concepts easier to understand.	1	2	3	4	5
55)	The applications of chemistry discussed in this course made learning chemistry interesting.	1	2	3	4	5

The survey continues on the following page.

	LABS	strongly disagree				strongly agree
56)	I enjoyed the labs.	1	2	3	4	5
57)	The organization of the labs was important for my learning.	1	2	3	4	5
58)	I understood the chemistry behind the labs before I did them.	1	2	3	4	5
59)	Eventually I understood the chemistry behind the labs.	1	2	3	4	5
60)	The labs helped me understand important concepts in this course.	1	2	3	4	5
61)	The labs related well to the CH 302 lecture material.	1	2	3	4	5
62)	Enough time was allowed for labs.	1	2	3	4	5

GENERAL: (Fill in the appropriate response)

63) Average hours per week spent on this course:	**For…**	**0**	**1-5**	**5-10**	**15-20**	**Over 20**
	Fill in…	1	2	3	4	5

64) What one resource was most important in helping you understand the concepts presented in this course?

For…	Fill in...
THE INSTRUCTOR/PROFESSOR/HEAD TA OF THE COURSE	**1**
THE TA ASSIGNED TO YOUR SECTION	**2**
OTHER STUDENTS IN THE COURSE	**3**
THE LAB MANUAL	**4**
THE CH 302 TEXTBOOK	**5**

65) What one resource was most important in helping you complete the experiments in this course?

For…	Fill in...
THE INSTRUCTOR/PROFESSOR/HEAD TA OF THE COURSE	**1**
THE TA ASSIGNED TO YOUR SECTION	**2**
OTHER STUDENTS IN THE COURSE	**3**
THE LAB MANUAL	**4**
THE CH 302 TEXTBOOK	**5**

66) What one resource was most important in helping you prepare the laboratory reports in this course?

For…	Fill in...
THE INSTRUCTOR/PROFESSOR/HEAD TA OF THE COURSE	**1**
THE TA ASSIGNED TO YOUR SECTION	**2**
OTHER STUDENTS IN THE COURSE	**3**
THE LAB MANUAL	**4**
THE CH 302 TEXTBOOK	**5**

Appendix E: Statements on the Survey

The following table shows the numbering used in all versions of the survey and how these versions were compiled into a common numbering scheme for purposes of analysis.

Table A1: Statements on the Survey

Statement	Item Numbers				
	Version of Survey				New #
	A	B	C	D	
BACKGROUND					
Chemistry Lab Enrollment	114	1	1	1	1
Wet Lab Day	115	87	2	2	2
Wet Lab Time	116	88	3	3	3
Major	1	2	4	4	4
Sex	2	3	5	5	5
Citizenship	3	–	–	–	–
U.S. Ethnic Codes	4	4	6	6	6
College Rank	5	5	7	7	7
Semesters of High School Chemistry	6	6	8	8	8
Semesters of College Level Chemistry Completed	7	7	9	9	9
IMPACT ON LEARNING					
People: Professor	8	–	–	–	–
People: TA/Lab Instructor	9	–	–	–	–

Table A1 continues on the following page

Table A1, continued

Statement	Item Numbers				
	Version of Survey				New #
People: Friends/Informal Groups	10	–	–	–	–
People: Course Organized Groups	11	–	–	–	–
People: Other People	12	–	–	–	–
Activities: Lecture (rephrased as Lab Lecture in C, D)	13	8	32	34	10
Activities: Lab (rephrased as Wet Lab in C, D)	14	9	33	35	11
Activities: Discussion/Problem Sessions	15	–	–	–	–
Activities: Computer Labs	–	10	34	36	–
Activities: Exams	16	11	35	37	12
Activities: Quizzes	17	12	36	38	13
Activities: Homework/Exercises	18	13	37	39	14
Activities: Other Activities	19	–	–	–	–
Materials: Lecture Handouts	20	14	–	–	–
Materials: Laboratory Handouts	21	15	–	–	–
Materials: Computer Materials	22	16	–	–	–
Materials: Other Materials	23	–	–	–	–
IMPACT ON CONFIDENCE					
People: Professor	24	–	–	–	–
People: TA/Lab Instructor	25	–	–	–	–
People: Friends/Informal Groups	26	–	–	–	–

Table A1 continues on the next page

Table A1, continued

Statement	Item Numbers				
	Version of Survey				New #
People: Course Organized Groups	27	–	–	–	–
People: Other People	28	–	–	–	–
Activities: Lecture (rephrased as Lab Lecture in C, D)	29	17	38	40	15
Activities: Lab (rephrased as Wet Lab in C, D)	30	18	39	41	16
Activities: Discussion/Problem Sessions	31	–	–	–	–
Activities: Computer Labs	–	19	40	42	–
Activities: Exams	32	20	41	43	17
Activities: Quizzes	33	21	42	44	18
Activities: Homework/Exercises	34	22	43	45	19
Activities: Other Activities	35	–	–	–	–
Materials: Lecture Handouts	36	23	–	–	–
Materials: Laboratory Handouts	37	24	–	–	–
Materials: Computer Materials	38	25	–	–	–
Materials: Other Materials	39	–	–	–	–
IMPACT ON ENTHUSIASM					
People: Professor	40	–	–	–	–
People: TA/Lab Instructor	41	–	–	–	–
People: Friends/Informal Groups	42	–	–	–	–
People: Course Organized Groups	43	–	–	–	–

Table A1 continues on the next page

Table A1, continued

Statement	Item Numbers				
	Version of Survey				New #
People: Other People	44	–	–	–	–
Activities: Lecture (rephrased as Lab Lecture in C, D)	45	26	44	46	20
Activities: Lab (rephrased as Wet Lab in C, D)	46	27	45	47	21
Activities: Discussion/Problem Sessions	47	–	–	–	–
Activities: Computer Labs	–	28	46	48	–
Activities: Exams	48	29	47	49	22
Activities: Quizzes	49	30	48	50	23
Activities: Homework/Exercises	50	31	49	51	24
Activities: Other Activities	51	–	–	–	–
Materials: Lecture Handouts	52	32	–	–	–
Materials: Laboratory Handouts	53	33	–	–	–
Materials: Computer Materials	54	34	–	–	–
Materials: Other Materials	55	–	–	–	–
CONFIDENCE IN ABILITY TO					
Understand Key Concepts of Chemistry (before)	56	35	–	–	–
Understand Key Concepts of Chemistry (after)	57	36	10	10	25
Solve Chemistry Problems (before)	58	37	–	–	–
Solve Chemistry Problems (after)	59	38	11	11	26

Table A1 continues on the next page

Table A1, continued

Statement	Item Numbers				
	Version of Survey				New #
Understand the Chemistry Underlying Lab Experiments (before)	60	39	–	–	–
Understand the Chemistry Underlying Lab Experiments (after)	61	40	12	12	27
Perform Lab Experiments (before)	62	41	–	–	–
Perform Lab Experiments (after)	63	42	13	13	28
Visualize Key Concepts of Chemistry (before)	64	43	–	–	–
Visualize Key Concepts of Chemistry (after)	65	44	14	14	29
Apply your Knowledge of Chemistry to the Real World (before)	66	45	–	–	–
Apply your Knowledge of Chemistry to the Real World (after)	67	46	15	15	30
Understand Areas of Science (before)	68	47	–	–	–
Understand Areas of Science (after)	69	48	16	16	31
Succeed in Another Chemistry Course (before)	70	49	–	–	–
Succeed in Another Chemistry Course (after)	71	50	17	17	32
Succeed in a Chemistry–Related Discipline (before)	72	51	–	–	–
Succeed in a Chemistry–Related Discipline (after)	73	52	18	18	33
INTEREST IN					
Studying Chemistry in General (before)	74	53	–	–	–
Studying Chemistry in General (after)	75	54	19	19	34

Table A1 continues on the next page

Table A1, continued

Statement	Item Numbers: Version of Survey				New #
Taking More Chemistry (before)	76	55	–	–	–
Taking More Chemistry (after)	77	56	20	20	35
Pursuing a Chemistry–Related Major (before)	78	57	–	–	–
Pursuing a Chemistry–Related Major (after)	79	58	21	21	36
Pursuing a Science–Related Field (before)	80	59	–	–	–
Pursuing a Science–Related Field (after)	81	60	22	22	37
Working with Others to Learn Science (before)	82	61	–	–	–
Working with Others to Learn Science (after)	83	62	23	23	38
Chemistry in Industry (before)	84	63	–	–	–
Chemistry in Industry (after)	85	64	24	24	39
Chemistry in Agriculture (before)	86	–	–	–	–
Chemistry in Agriculture (after)	87	–	–	–	–
Chemistry in Medicine (before)	88	67	–	–	–
Chemistry in Medicine (after)	89	68	26	26	40
Chemistry in Athletics (before)	90	–	–	–	–
Chemistry in Athletics (after)	91	–	–	–	–
Chemistry in the Environment (before)	92	65	–	–	–
Chemistry in the Environment (after)	93	66	25	25	41
Science in General (before)	94	69	–	–	–
Science in General (after)	95	70	27	27	42

Table A1 continues on the next page

Table A1, continued

Statement	Item Numbers Version of Survey				New #
IMPRESSIONS OF LECTURE					
I enjoyed the lectures. (Rephrased as I enjoyed the formal laboratory (1 hour) lectures for B, C, D)	96	71	50	52	43
The organization of the lectures was important for my learning.	97	72	51	53	44
The professor was concerned about my learning chemistry.	98	–	–	–	–
The professor made students feel comfortable asking questions.	99	–	–	–	–
The applications of chemistry discussed in this course made certain concepts easier to understand.	100	73	52	54	45
The applications of chemistry discussed in this course made learning chemistry interesting.	101	74	53	55	46
IMPRESSIONS OF EXAMS					
The lectures and assigned work adequately prepared me for exams.	102	75	–	–	–
Taking the exams increased my understanding of the course material.	103	76	–	–	–
I sometimes developed new insights from taking the exams.	104	77	–	–	–
IMPRESSIONS OF LABS					
I enjoyed the labs.	105	78	54	56	47
The organization of the labs was important for my learning.	–	79	55	57	–

Table A1 continues on the next page

Table A1, continued

Statement	Item Numbers				
	Version of Survey				New #
I understood the chemistry behind the labs before I did them.	106	80	56	58	48
Eventually I understood the chemistry behind the labs.	107	81	57	59	49
The labs helped me understand important concepts in this course.	108	82	58	60	50
The labs related well to the lecture material.	109	83	–	–	–
The labs related well to the CH 302 lecture material.	–	–	59	61	–
Enough time was allowed for labs.	110	84	60	62	51
The lab instructor was helpful.	111	–	–	–	–
GENERAL QUESTIONS					
Average hours each week spent on this course	112	85	61	63	–
Would you recommend this course to a friend?	113	86	62	33	52
When did you take CH 302 (or its equivalent)?	–	–	28	28	–
Did your General Chemistry lecture experience help you in your laboratory course?	–	–	29	29	–
Did you use the General Chemistry textbook to help solve problems in your laboratory course?	–	–	30	30	–
Do you see value in taking laboratory courses?	–	–	31	31	–
How closely do the skills presented in this lab match your academic and/or career goals?	–	–	–	32	–

Table A1 continues on the next page

Table A1, continued

	Item Numbers				
Statement	**Version of Survey**				**New #**
What one resource was most important in helping you understand the concepts presented in this course?	–	–	–	64	–
What one resource was most important in helping you complete the experiments in this course?	–	–	–	65	–
What one resource was most important in helping you prepare the laboratory reports in this course?	–	–	–	66	–

Appendix F: Survey Responses, Fall 1998

Presented below is the complete set of responses for the survey distributed in Fall 1998. The original survey numbering is shown here.

Table A2: Survey Responses for Survey Items 8-55, Fall 1998

Item	Statement	Control	Experimental	New #
	IMPACT ON LEARNING			
8	People: Professor	3.281 ± 2.159	4.908 ± 1.465	
9	People: TA/Lab Instructor	5.375 ± 1.579	6.385 ± 0.744	
10	People: Friends/Informal Groups	5.689 ± 1.520	5.516 ± 1.238	
11	People: Course Organized Groups	3.786 ± 1.595	5.016 ± 1.204	
12	People: Other People	4.607 ± 1.792	4.711 ± 1.113	
13	Activities: Lecture	4.435 ± 1.734	4.177 ± 1.553	10
14	Activities: Lab	4.729 ± 1.783	5.766 ± 0.938	11
15	Activities: Discussion/Problem Sessions	5.189 ± 1.488	5.491 ± 1.297	
16	Activities: Exams	4.061 ± 1.870	5.391 ± 1.280	12
17	Activities: Quizzes	3.955 ± 1.904	5.203 ± 1.250	13
18	Activities: Homework/Exercises	4.182 ± 1.920	5.500 ± 1.168	14
19	Activities: Other Activities	3.438 ± 1.548	5.167 ± 1.298	
20	Materials: Lecture Handouts	4.579 ± 1.734	5.381 ± 1.224	
21	Materials: Laboratory Handouts	4.723 ± 1.542	5.508 ± 1.176	
22	Materials: Computer Materials	4.136 ± 1.850	4.841 ± 1.516	
23	Materials: Other Materials	4.111 ± 1.451	4.741 ± 1.318	

Table A2 continues on the next page

Table A2, continued

Item	Statement	Control	Experimental	New #
	IMPACT ON CONFIDENCE			
24	People: Professor	3.429 ± 2.063	4.781 ± 1.527	
25	People: TA/Lab Instructor	5.298 ± 1.350	6.077 ± 1.020	
26	People: Friends/Informal Groups	5.512 ± 1.437	5.356 ± 1.214	
27	People: Course Organized Groups	4.407 ± 1.185	5.180 ± 1.204	
28	People: Other People	4.238 ± 1.513	4.885 ± 1.211	
29	Activities: Lecture	4.213 ± 1.641	4.476 ± 1.490	15
30	Activities: Lab	4.458 ± 1.901	5.387 ± 1.486	16
31	Activities: Discussion/Problem Sessions	4.447 ± 1.622	5.379 ± 1.424	
32	Activities: Exams	3.485 ± 2.017	4.938 ± 1.661	17
33	Activities: Quizzes	3.795 ± 1.837	4.723 ± 1.709	18
34	Activities: Homework/Exercises	3.816 ± 1.887	5.000 ± 1.560	19
35	Activities: Other Activities	4.167 ± 0.408	4.833 ± 1.339	
36	Materials: Lecture Handouts	4.225 ± 1.702	5.016 ± 1.476	
37	Materials: Laboratory Handouts	4.067 ± 1.601	5.159 ± 1.461	
38	Materials: Computer Materials	3.886 ± 1.701	4.869 ± 1.597	
39	Materials: Other Materials	3.583 ± 1.240	5.040 ± 1.338	
	IMPACT ON ENTHUSIASM			
40	People: Professor	3.133 ± 2.177	5.000 ± 1.705	
41	People: TA/Lab Instructor	4.896 ± 1.893	5.985 ± 1.053	
42	People: Friends/Informal Groups	4.739 ± 1.744	4.984 ± 1.208	
43	People: Course Organized Groups	3.968 ± 1.426	4.969 ± 1.333	

Table A2 continues on the next page

Table A2, continued

Item	Statement	Control	Experimental	New #
44	People: Other People	3.778 ± 1.801	4.833 ± 1.308	
45	Activities: Lecture	3.652 ± 1.741	4.254 ± 1.685	20
46	Activities: Lab	4.234 ± 2.013	5.302 ± 1.613	21
47	Activities: Discussion/Problem Sessions	4.083 ± 1.680	4.950 ± 1.523	
48	Activities: Exams	3.250 ± 1.867	4.554 ± 1.687	22
49	Activities: Quizzes	3.143 ± 1.855	4.462 ± 1.687	23
50	Activities: Homework/Exercises	3.277 ± 1.850	4.594 ± 1.571	24
51	Activities: Other Activities	3.400 ± 1.350	4.739 ± 1.356	
52	Materials: Lecture Handouts	3.850 ± 1.626	4.532 ± 1.576	
53	Materials: Laboratory Handouts	3.717 ± 1.587	4.758 ± 1.575	
54	Materials: Computer Materials	3.619 ± 1.592	4.583 ± 1.598	
55	Materials: Other Materials	3.357 ± 1.447	4.857 ± 1.236	

Questions 56-73, involving student interest, and 74-95 on student confidence are shown for the control group in Tables A3 and A4.

Table A3: Student Self-Reported Confidence in Ability in the Control Group, Fall 1998

Items	**Statement**	**Before**	**After**	**Change**
56,57	Understand Key Concepts of Chemistry	3.109 ± 1.178	3.478 ± 1.027	0.370
58,59	Solve Chemistry Problems	2.935 ± 1.237	3.422 ± 1.158	0.487
60,61	Understand the Chemistry Underlying Lab Experiments	2.435 ± 1.294	3.478 ± 1.260	1.043
62,63	Perform Lab Experiments	2.522 ± 1.516	3.889 ± 1.112	1.367
64,65	Visualize Key Concepts of Chemistry	2.644 ± 1.131	3.489 ± 1.058	0.844
66,67	Apply your Knowledge of Chemistry to the Real World	2.457 ± 1.187	3.239 ± 1.303	0.783
68,69	Understand Other Areas of Science	2.630 ± 1.103	3.043 ± 1.228	0.413
70, 71	Succeed in Another Chemistry Course	2.978 ± 1.220	3.304 ± 1.245	0.326
72,73	Succeed in a Chemistry-Related Discipline	2.800 ± 1.272	3.178 ± 1.173	0.378

Table A4: Student Self-Reported Interest in Science Areas in the Control Group, Fall 1998

Items	Statement	Before	After	Change
74, 75	Studying Chemistry in General	2.894 ± 1.339	3.106 ± 1.220	0.213
76, 77	Taking More Chemistry	2.978 ± 1.273	2.915 ± 1.231	-0.063
78, 79	Pursuing a Chemistry-Related Major	2.489 ± 1.640	2.277 ± 1.741	-0.213
80, 81	Pursuing a Science-Related Field	3.681 ± 1.163	3.681 ± 1.321	0.000
82, 83	Working with Others to Learn Science	3.085 ± 1.139	3.809 ± 1.209	0.723
84, 85	Chemistry in Industry	2.196 ± 1.408	2.085 ± 1.282	-0.111
86, 87	Chemistry in Agriculture	1.723 ± 1.330	1.702 ± 1.397	-0.021
88, 89	Chemistry in Medicine	3.213 ± 1.573	3.511 ± 1.586	0.298
90, 91	Chemistry in Athletics	2.064 ± 1.538	2.261 ± 1.612	0.197
92, 93	Chemistry in the Environment	2.511 ± 1.428	2.617 ± 1.497	0.106
94, 95	Science in General	3.489 ± 1.300	3.638 ± 1.293	0.149

The same survey responses are presented for the experimental group in Tables A5 and A6.

Table A5: Student Self-Reported Confidence in Ability in the Experimental Group, Fall 1998

Items	Statement	Before	After	Change
56,57	Understand Key Concepts of Chemistry	2.800 ± 1.175	3.754 ± 1.031	0.954
58,59	Solve Chemistry Problems	2.923 ± 1.005	3.708 ± 1.011	0.785
60,61	Understand the Chemistry Underlying Lab Experiments	2.354 ± 1.217	4.016 ± 0.852	1.662
62,63	Perform Lab Experiments	2.308 ± 1.413	3.954 ± 1.082	1.646
64,65	Visualize Key Concepts of Chemistry	2.538 ± 1.324	3.631 ± 0.961	1.092
66,67	Apply your Knowledge of Chemistry to the Real World	2.292 ± 1.221	3.446 ± 1.186	1.154
68,69	Understand Other Areas of Science	2.892 ± 1.239	3.692 ± 0.951	0.800
70, 71	Succeed in Another Chemistry Course	2.908 ± 1.284	3.492 ± 1.239	0.585
72,73	Succeed in a Chemistry-Related Discipline	2.785 ± 1.244	3.400 ± 1.321	0.615

Table A6: Student Self-Reported Interest in Science Areas in the Experimental Group, Fall 1998

Items	Statement	Before	After	Change
74, 75	Studying Chemistry in General	2.585 ± 1.345	3.077 ± 1.315	0.492
76, 77	Taking More Chemistry	2.385 ± 1.259	2.815 ± 1.467	0.431
78, 79	Pursuing a Chemistry-Related Major	2.046 ± 1.525	2.092 ± 1.627	0.046
80, 81	Pursuing a Science-Related Field	3.646 ± 1.351	4.000 ± 1.118	0.354
82, 83	Working with Others to Learn Science	3.077 ± 1.291	3.662 ± 1.253	0.585
84, 85	Chemistry in Industry	2.077 ± 1.407	2.400 ± 1.589	0.323
86, 87	Chemistry in Agriculture	1.815 ± 1.357	2.015 ± 1.441	0.200
88, 89	Chemistry in Medicine	3.391 ± 1.341	3.938 ± 1.180	0.547
90, 91	Chemistry in Athletics	2.431 ± 1.541	2.892 ± 1.562	0.462
92, 93	Chemistry in the Environment	2.415 ± 1.467	3.000 ± 1.521	0.585
94, 95	Science in General	3.723 ± 1.218	4.123 ± 0.910	0.400

The remaining survey responses are presented in Table A7.

Table A7: Survey Responses for Survey Items 96-113, Fall 1998

Item	Statement	Control	Experimental	New #
	IMPRESSIONS OF LECTURE			
96	I enjoyed the lectures.	2.000 ± 1.549	2.308 ± 1.560	43
97	The organization of the lectures was important for my learning.	2.739 ± 1.769	2.708 ± 1.476	44
98	The professor was concerned about my learning chemistry.	2.283 ± 1.846	3.846 ± 1.337	
99	The professor made students feel comfortable asking questions.	2.600 ± 1.912	3.703 ± 1.477	
100	The applications of chemistry discussed in this course made certain concepts easier to understand.	2.644 ± 1.612	3.323 ± 1.324	45
101	The applications of chemistry discussed in this course made learning chemistry interesting.	2.591 ± 1.661	3.246 ± 1.287	46
	IMPRESSIONS OF EXAMS			
102	The lectures and assigned work adequately prepared me for exams.	2.214 ± 1.601	3.723 ± 1.375	
103	Taking the exams increased my understanding of the course material.	2.357 ± 1.605	3.538 ± 1.404	
104	I sometimes developed new insights from taking the exams.	2.357 ± 1.635	3.277 ± 1.398	
	IMPRESSIONS OF LABS			
105	I enjoyed the labs.	2.681 ± 1.617	3.246 ± 1.347	47
106	I understood the chemistry behind the labs before I did them.	2.652 ± 1.433	2.446 ± 1.212	48
107	Eventually I understood the chemistry behind the labs.	3.370 ± 1.323	3.875 ± 0.968	49

Table A7 continues on the next page

Table A7, continued

Item	Statement	Control	Experimental	New #
108	The labs helped me understand important concepts in this course.	3.043 ± 1.429	3.723 ± 1.023	50
109	The labs related well to the lecture material.	3.068 ± 1.469	3.692 ± 1.030	
110	Enough time was allowed for labs.	3.196 ± 1.721	4.338 ± 0.889	51
111	The lab instructor was helpful.	3.978 ± 1.437	4.662 ± 0.594	
	GENERAL QUESTIONS			
112	Average hours each week spent on this course	2.500 ± 1.070	2.285 ± 0.820	
113	Would you recommend this course to a friend?	1.522 ± 1.683	3.477 ± 1.501	52

Appendix G: Survey Responses, Spring 1999

Presented below is the complete set of responses for the survey distributed in Spring 1999. The original survey numbering is shown here. The data are broken into Tables A8, A9, A10, A11, A12, and A13, corresponding to different sections of the survey.

Table A8: Survey Responses for Survey Items 8-55, Spring 1999

Item	Statement	Control	Experimental	New #
	IMPACT ON LEARNING			
8	Activities: Lecture	3.611 ± 0.964	3.397 ± 0.958	10
9	Activities: Lab	2.833 ± 1.134	4.168 ± 0.824	11
10	Activities: Computer Labs	2.139 ± 1.175	3.443 ± 1.009	
11	Activities: Exams	2.636 ± 0.822	3.817 ± 0.935	12
12	Activities: Quizzes	2.556 ± 1.054	3.611 ± 1.064	13
13	Activities: Homework/Exercises	2.861 ± 1.334	3.527 ± 1.033	14
14	Materials: Lecture Handouts	2.824 ± 1.141	4.084 ± 0.912	
15	Materials: Laboratory Handouts	2.743 ± 1.120	4.084 ± 0.860	
16	Materials: Computer Materials	2.222 ± 1.149	3.679 ± 0.888	
	IMPACT ON CONFIDENCE			
17	Activities: Lecture	3.543 ± 1.197	3.321 ± 0.994	15
18	Activities: Lab	2.971 ± 1.124	4.015 ± 0.936	16
19	Activities: Computer Lab	2.600 ± 1.193	3.557 ± 0.896	

Table A8 continues on the next page

Table A8, continued

Item	Statement	Control	Experimental	New #
20	Activities: Exams	2.742 ± 0.999	3.802 ± 0.948	17
21	Activities: Quizzes	2.629 ± 1.285	3.336 ± 1.035	18
22	Activities: Homework/Exercises	2.771 ± 1.239	3.496 ± 0.826	19
23	Materials: Lecture Handouts	2.848 ± 0.939	3.725 ± 0.961	
24	Materials: Laboratory Handouts	2.706 ± 0.938	3.771 ± 0.899	
25	Materials: Computer Materials	2.543 ± 1.039	3.534 ± 0.880	
	IMPACT ON ENTHUSIASM			
26	Activities: Lecture	2.657 ± 1.211	2.832 ± 1.204	20
27	Activities: Lab	2.571 ± 1.441	3.708 ± 1.137	21
28	Activities: Computer Lab	1.914 ± 1.011	3.038 ± 1.003	
29	Activities: Exams	2.030 ± 0.810	3.145 ± 1.164	22
30	Activities: Quizzes	1.886 ± 0.932	2.786 ± 1.157	23
31	Activities: Homework/Exercises	2.029 ± 1.071	2.939 ± 0.967	24
32	Materials: Lecture Handouts	2.455 ± 1.063	3.206 ± 0.982	
33	Materials: Laboratory Handouts	2.441 ± 1.106	3.321 ± 0.994	
34	Materials: Computer Materials	2.143 ± 1.033	3.122 ± 0.961	

Table A9: Student Self-Reported Confidence in Ability in the Control Group, Spring 1999

Items	Statement	Before	After	Change
35,36	Understand Key Concepts of Chemistry	3.571 ± 1.092	3.400 ± 0.914	-0.171
37,38	Solve Chemistry Problems	3.429 ± 1.195	3.314 ± 1.132	-0.114
39,40	Understand the Chemistry Underlying Lab Experiments	2.914 ± 1.222	3.000 ± 1.181	0.086
41,42	Perform Lab Experiments	2.824 ± 1.242	3.412 ± 1.019	0.588
43,44	Visualize Key Concepts of Chemistry	3.206 ± 1.095	3.176 ± 0.904	-0.029
45,46	Apply your Knowledge of Chemistry to the Real World	3.000 ± 1.101	2.912 ± 1.190	-0.088
47,48	Understand Other Areas of Science	3.294 ± 0.906	3.147 ± 1.019	-0.147
49,50	Succeed in Another Chemistry Course	3.500 ± 1.108	3.088 ± 1.288	-0.412
51,52	Succeed in a Chemistry-Related Discipline	3.265 ± 1.082	3.059 ± 1.013	-0.206

Table A10: Student Self-Reported Interest in Science Areas in the Control Group, Spring 1999

Items	Statement	Before	After	Change
53, 54	Studying Chemistry in General	3.471 ± 1.051	2.618 ± 1.206	-0.853
55, 56	Taking More Chemistry	3.353 ± 1.041	2.500 ± 1.237	-0.853
57, 58	Pursuing a Chemistry-Related Major	3.206 ± 1.274	2.441 ± 1.481	-0.765
59, 60	Pursuing a Science-Related Field	4.000 ± 0.985	3.618 ± 0.954	-0.382
61, 62	Working with Others to Learn Science	3.500 ± 0.896	3.412 ± 1.104	-0.088
63, 64	Chemistry in Industry	2.912 ± 1.190	2.559 ± 1.330	-0.353
65, 66	Chemistry in the Environment	3.265 ± 1.053	2.853 ± 1.234	-0.412
67, 68	Chemistry in Medicine	3.941 ± 0.952	3.500 ± 1.237	-0.441
69, 70	Science in General	3.941 ± 0.983	3.471 ± 1.107	-0.471

Table A11: Student Self-Reported Confidence in Ability in the Experimental Group, Spring 1999

Items	Statement	Before	After	Change
35,36	Understand Key Concepts of Chemistry	3.154 ± 0.960	3.900 ± 0.714	0.746
37,38	Solve Chemistry Problems	3.208 ± 1.009	3.969 ± 0.767	0.762
39,40	Understand the Chemistry Underlying Lab Experiments	2.667 ± 0.938	3.923 ± 0.886	1.256
41,42	Perform Lab Experiments	2.731 ± 1.070	4.115 ± 0.912	1.385
43,44	Visualize Key Concepts of Chemistry	2.992 ± 0.968	3.838 ± 0.833	0.846
45,46	Apply your Knowledge of Chemistry to the Real World	2.731 ± 0.955	3.700 ± 0.986	0.969
47,48	Understand Other Areas of Science	3.277 ± 0.915	3.846 ± 0.811	0.569
49,50	Succeed in Another Chemistry Course	3.163 ± 0.998	3.885 ± 0.903	0.722
51,52	Succeed in a Chemistry-Related Discipline	3.062 ± 0.971	3.669 ± 0.951	0.608

Table A12: Student Self-Reported Interest in Science Areas in the Experimental Group, Spring 1999

Items	Statement	Before	After	Change
53, 54	Studying Chemistry in General	2.862 ± 1.069	3.354 ± 1.120	0.492
55, 56	Taking More Chemistry	2.900 ± 1.099	3.169 ± 1.149	0.269
57, 58	Pursuing a Chemistry-Related Major	2.554 ± 1.233	2.808 ± 1.393	0.254
59, 60	Pursuing a Science-Related Field	3.922 ± 1.087	4.192 ± 0.973	0.270
61, 62	Working with Others to Learn Science	3.208 ± 1.098	3.762 ± 1.133	0.554
63, 64	Chemistry in Industry	2.631 ± 1.094	2.892 ± 1.283	0.262
65, 66	Chemistry in the Environment	2.915 ± 1.141	3.231 ± 1.178	0.315
67, 68	Chemistry in Medicine	3.562 ± 1.093	3.931 ± 1.149	0.369
69, 70	Science in General	3.876 ± 0.919	4.140 ± 0.882	0.264

Table A13: Survey Responses for Survey Items 71-86, Spring 1999

Item	Statement	Control	Experimental	New #
	IMPRESSIONS OF LECTURE			
71	I enjoyed the formal laboratory (1 hour) lectures.	3.147 ± 1.158	2.717 ± 1.221	43
72	The organization of the lectures was important for my learning.	3.324 ± 1.249	3.299 ± 1.129	44
73	The applications of chemistry discussed in this course made certain concepts easier to understand.	2.765 ± 1.182	3.630 ± 1.060	45
74	The applications of chemistry discussed in this course made learning chemistry interesting.	2.176 ± 1.193	3.449 ± 0.982	46
	IMPRESSIONS OF EXAMS			
75	The lectures and assigned work adequately prepared me for exams.	2.500 ± 0.984	3.921 ± 1.066	
76	Taking the exams increased my understanding of the course material.	2.438 ± 1.134	3.740 ± 1.121	
77	I sometimes developed new insights from taking the exams.	2.375 ± 0.942	2.717 ± 1.221	
	IMPRESSIONS OF LABS			
78	I enjoyed the labs.	2.412 ± 1.131	3.685 ± 1.059	47
79	The organization of the labs was important for my learning.	2.529 ± 1.285	3.795 ± 0.979	
80	I understood the chemistry behind the labs before I did them.	2.353 ± 1.228	3.024 ± 1.050	48
81	Eventually I understood the chemistry behind the labs.	2.765 ± 1.232	4.063 ± 0.856	49
82	The labs helped me understand important concepts in this course.	2.794 ± 1.122	4.000 ± 0.900	50

Table A13 continues on the next page

Table A13, continued

Item	Statement	Control	Experimental	New #
83	The labs related well to the lecture material.	3.088 ± 1.111	4.094 ± 0.921	
84	Enough time was allowed for labs.	2.886 ± 1.430	4.457 ± 0.804	51
	GENERAL QUESTIONS			
85	Average hours each week spent on this course	3.257 ± 0.886	2.913 ± 0.836	
86	Would you recommend this course to a friend?	1.618 ± 1.045	3.903 ± 1.172	52

Appendix H: Survey Responses, Fall 1999

Presented below is the complete set of responses for the survey distributed in Fall 1999. The original survey numbering is shown here.

Table A14: Survey Responses, Fall 1999

Item	Statement	Control	Experimental	New #
	CONFIDENCE IN YOUR ABILITY TO…			
10	Understand Key Concepts of Chemistry	3.541 ± 0.954	3.728 ± 0.915	25
11	Solve Chemistry Problems	3.387 ± 0.868	3.649 ± 0.839	26
12	Understand the Chemistry Underlying Lab Experiments	3.133 ± 1.031	3.457 ± 0.958	27
13	Perform Lab Experiments	3.587 ± 0.960	3.840 ± 0.965	28
14	Visualize Key Concepts of Chemistry	3.440 ± 0.962	3.511 ± 0.936	29
15	Apply your Knowledge of Chemistry to the Real World	3.040 ± 1.071	3.436 ± 0.945	30
16	Understand Other Areas of Science	3.813 ± 1.009	3.947 ± 0.847	31
17	Succeed in Another Chemistry Course	3.413 ± 1.028	3.734 ± 0.882	32
18	Succeed in a Chemistry-Related Discipline	3.027 ± 1.052	3.489 ± 0.901	33
	INTEREST IN..			
19	Studying Chemistry in General	2.635 ± 1.165	3.160 ± 1.194	34
20	Taking More Chemistry	2.373 ± 1.271	2.968 ± 1.291	35
21	Pursuing a Chemistry-Related Major	2.162 ± 1.205	2.511 ± 1.465	36
22	Pursuing a Science-Related Field	4.122 ± 1.059	4.457 ± 0.757	37

Table A14 continues on the next page

Table A14, continued

Item	Statement	Control	Experimental	New #
23	Working with Others to Learn Science	3.554 ± 1.294	3.926 ± 1.060	38
24	Chemistry in Industry	2.459 ± 1.161	2.426 ± 1.141	39
25	Chemistry in the Environment	2.919 ± 1.202	3.138 ± 1.160	41
26	Chemistry in Medicine	3.716 ± 1.360	4.053 ± 1.091	40
27	Science in General	3.919 ± 1.120	4.287 ± 0.798	42
	GENERAL QUESTIONS			
28	When did you take CH 302 (or its equivalent)?	1.562 ± 0.913	1.564 ± 0.934	
29	Did your General Chemistry lecture experience help you in your laboratory course?	2.865 ± 1.264	2.574 ± 1.266	
30	Did you use the General Chemistry textbook to help solve problems in your laboratory course?	3.230 ± 1.380	1.723 ± 1.082	
31	Do you see value in taking laboratory courses?	2.622 ± 1.321	3.691 ± 1.210	
	IMPACT ON LEARNING			
32	Activities: Lab Lecture	2.548 ± 1.179	2.925 ± 1.163	10
33	Activities: Wet Lab	3.135 ± 1.264	4.223 ± 0.996	11
34	Activities: Computer Labs	2.311 ± 1.249	3.383 ± 1.146	
35	Activities: Exams	2.609 ± 1.093	3.585 ± 1.177	12
36	Activities: Quizzes	2.595 ± 1.260	3.130 ± 1.233	13
37	Activities: Homework/Exercises	2.554 ± 1.305	3.250 ± 1.183	14
	IMPACT ON CONFIDENCE			
38	Activities: Lab Lecture	2.851 ± 1.289	2.871 ± 1.163	15
39	Activities: Wet Lab	3.000 ± 1.293	3.872 ± 1.238	16

Table A14 continues on the next page

Table A14, continued

Item	Statement	Control	Experimental	New #
40	Activities: Computer Lab	2.581 ± 1.194	3.340 ± 1.093	
41	Activities: Exams	2.645 ± 1.118	3.596 ± 1.139	17
42	Activities: Quizzes	2.808 ± 1.255	3.011 ± 1.209	18
43	Activities: Homework/Exercises	2.324 ± 1.294	3.348 ± 1.094	19
	IMPACT ON ENTHUSIASM			
44	Activities: Lab Lecture	1.851 ± 0.902	2.196 ± 1.197	20
45	Activities: Wet Lab	2.446 ± 1.416	3.660 ± 1.291	21
46	Activities: Computer Lab	1.905 ± 1.049	2.957 ± 1.172	
47	Activities: Exams	1.905 ± 1.043	2.840 ± 1.194	22
48	Activities: Quizzes	1.944 ± 1.120	2.462 ± 1.128	23
49	Activities: Homework/Exercises	1.676 ± 0.952	2.652 ± 1.032	24
	IMPRESSIONS OF LECTURE			
50	I enjoyed the formal laboratory (1 hour) lectures.	1.726 ± 0.870	2.129 ± 1.154	43
51	The organization of the lectures was important for my learning.	2.458 ± 1.373	2.871 ± 1.253	44
52	The applications of chemistry discussed in this course made certain concepts easier to understand.	2.375 ± 1.238	3.452 ± 1.079	45
53	The applications of chemistry discussed in this course made learning chemistry interesting.	2.222 ± 1.258	3.398 ± 1.095	46
	IMPRESSIONS OF LABS			
54	I enjoyed the labs.	2.270 ± 1.338	3.648 ± 1.196	47
55	The organization of the labs was important for my learning.	2.685 ± 1.373	3.747 ± 1.081	

Table A14 continues on the next page

Table A14, continued

Item	Statement	Control	Experimental	New #
56	I understood the chemistry behind the labs before I did them.	2.284 ± 1.014	2.890 ± 1.069	48
57	Eventually I understood the chemistry behind the labs.	3.014 ± 1.188	3.967 ± 0.988	49
58	The labs helped me understand important concepts in this course.	2.622 ± 1.235	3.966 ± 1.016	50
59	The labs related well to the CH 302 lecture material.	2.676 ± 1.251	2.966 ± 1.210	
60	Enough time was allowed for labs.	3.081 ± 1.450	4.337 ± 0.965	51
	GENERAL QUESTIONS			
61	Average hours each week spent on this course	3.403 ± 0.867	2.978 ± 0.848	
62	Would you recommend this course to a friend?	1.486 ± 0.888	3.775 ± 1.268	52

Appendix I: Survey Responses, Spring 2000

Presented below is the complete set of responses for the survey distributed in Spring 2000. The original survey numbering is shown here. Two sets of tables are shown, the first (Table A15) for students in all sections other than the two which had the common teaching assistant, the second (Table A16) for those other two sections.

Table A15: Survey Responses for Sections without the common TA, Spring 2000

Item	Statement	Control	Experimental	New #
	CONFIDENCE IN YOUR ABILITY TO…			
10	Understand Key Concepts of Chemistry	3.645 ± 0.911	3.897 ± 0.795	25
11	Solve Chemistry Problems	3.427 ± 0.944	3.812 ± 0.830	26
12	Understand the Chemistry Underlying Lab Experiments	3.365 ± 0.998	3.709 ± 0.862	27
13	Perform Lab Experiments	3.773 ± 0.928	4.000 ± 0.830	28
14	Visualize Key Concepts of Chemistry	3.486 ± 0.864	3.735 ± 0.875	29
15	Apply your Knowledge of Chemistry to the Real World	3.271 ± 0.936	3.538 ± 0.905	30
16	Understand Other Areas of Science	3.824 ± 0.840	3.949 ± 0.839	31
17	Succeed in Another Chemistry Course	3.583 ± 0.965	3.872 ± 0.836	32
18	Succeed in a Chemistry-Related Discipline	3.435 ± 1.001	3.701 ± 0.958	33
	INTEREST IN..			
19	Studying Chemistry in General	3.008 ± 1.205	3.128 ± 1.126	34
20	Taking More Chemistry	2.917 ± 1.320	3.111 ± 1.230	35

Table A15 continues on the next page

Table A15, continued

Item	Statement	Control	Experimental	New #
21	Pursuing a Chemistry-Related Major	2.654 ± 1.405	2.795 ± 1.349	36
22	Pursuing a Science-Related Field	4.224 ± 1.006	4.308 ± 0.923	37
23	Working with Others to Learn Science	3.795 ± 1.055	3.957 ± 1.003	38
24	Chemistry in Industry	2.665 ± 1.184	2.776 ± 1.173	39
25	Chemistry in the Environment	2.984 ± 1.203	3.129 ± 1.059	41
26	Chemistry in Medicine	3.764 ± 1.254	3.966 ± 1.012	40
27	Science in General	4.075 ± 0.959	4.224 ± 0.905	42
	GENERAL QUESTIONS			
28	When did you take CH 302 (or its equivalent)?	1.302 ± 0.726	1.246 ± 0.711	
29	Did your General Chemistry lecture experience help you in your laboratory course?	3.138 ± 1.134	3.000 ± 1.157	
30	Did you use the General Chemistry textbook to help solve problems in your laboratory course?	3.194 ± 1.230	1.974 ± 1.138	
31	Do you see value in taking laboratory courses?	3.063 ± 1.236	3.888 ± 0.985	
	IMPACT ON LEARNING			
32	Activities: Lab Lecture	3.225 ± 1.088	3.241 ± 1.084	10
33	Activities: Wet Lab	3.510 ± 1.090	4.250 ± 0.790	11
34	Activities: Computer Labs	2.672 ± 1.035	3.526 ± 1.017	
35	Activities: Exams	2.737 ± 0.985	3.733 ± 0.868	12
36	Activities: Quizzes	2.884 ± 1.095	3.543 ± 0.955	13
37	Activities: Homework/Exercises	2.632 ± 1.242	3.362 ± 1.114	14

Table A15 continues on the next page

Table A15, continued

Item	Statement	Control	Experimental	New #
	IMPACT ON CONFIDENCE			
38	Activities: Lab Lecture	3.369 ± 1.076	3.103 ± 0.990	15
39	Activities: Wet Lab	3.386 ± 1.042	3.931 ± 0.831	16
40	Activities: Computer Lab	2.984 ± 1.106	3.621 ± 0.841	
41	Activities: Exams	2.791 ± 1.016	3.836 ± 0.812	17
42	Activities: Quizzes	2.900 ± 1.115	3.397 ± 0.941	18
43	Activities: Homework/Exercises	2.598 ± 1.259	3.431 ± 0.916	19
	IMPACT ON ENTHUSIASM			
44	Activities: Lab Lecture	2.564 ± 1.111	2.578 ± 1.073	20
45	Activities: Wet Lab	2.968 ± 1.245	3.784 ± 0.912	21
46	Activities: Computer Lab	2.434 ± 1.088	3.138 ± 0.977	
47	Activities: Exams	2.293 ± 1.006	3.103 ± 0.838	22
48	Activities: Quizzes	2.270 ± 0.992	2.853 ± 0.877	23
49	Activities: Homework/Exercises	2.036 ± 1.125	2.974 ± 0.849	24
	IMPRESSIONS OF LECTURE			
50	I enjoyed the formal laboratory (1 hour) lectures.	2.546 ± 1.089	2.526 ± 1.233	43
51	The organization of the lectures was important for my learning.	3.052 ± 1.198	3.121 ± 1.166	44
52	The applications of chemistry discussed in this course made certain concepts easier to understand.	3.004 ± 1.176	3.526 ± 0.946	45
53	The applications of chemistry discussed in this course made learning chemistry interesting.	2.825 ± 1.178	3.457 ± 1.033	46

Table A15 continues on the next page

Table A15, continued

Item	Statement	Control	Experimental	New #
	IMPRESSIONS OF LABS			
54	I enjoyed the labs.	2.788 ± 1.246	3.741 ± 0.934	47
55	The organization of the labs was important for my learning.	3.041 ± 1.182	3.914 ± 0.860	
56	I understood the chemistry behind the labs before I did them.	2.612 ± 1.145	3.250 ± 0.903	48
57	Eventually I understood the chemistry behind the labs.	3.385 ± 1.096	4.121 ± 0.804	49
58	The labs helped me understand important concepts in this course.	3.110 ± 1.174	4.078 ± 0.818	50
59	The labs related well to the CH 302 lecture material.	3.140 ± 1.166	3.414 ± 1.047	
60	Enough time was allowed for labs.	3.597 ± 1.241	4.504 ± 0.718	51
	GENERAL QUESTIONS			
61	Average hours each week spent on this course	3.062 ± 0.855	2.702 ± 0.677	
62	Would you recommend this course to a friend?	2.067 ± 1.200	4.150 ± 1.071	52

The same survey data for sections with the common TA is presented in Table A16.

Table A16: Survey Responses for Sections with the common TA, Spring 2000

Item	Statement	Control	Experimental	New #
	CONFIDENCE IN YOUR ABILITY TO…			
10	Understand Key Concepts of Chemistry	3.722 ± 1.074	4.000 ± 0.853	25
11	Solve Chemistry Problems	3.556 ± 1.042	3.917 ± 0.900	26
12	Understand the Chemistry Underlying Lab Experiments	3.333 ± 1.029	4.000 ± 0.853	27
13	Perform Lab Experiments	3.889 ± 0.832	4.167 ± 0.718	28
14	Visualize Key Concepts of Chemistry	3.667 ± 1.029	3.750 ± 0.866	29
15	Apply your Knowledge of Chemistry to the Real World	3.556 ± 0.922	3.750 ± 0.965	30
16	Understand Other Areas of Science	4.056 ± 0.873	4.167 ± 0.718	31
17	Succeed in Another Chemistry Course	3.889 ± 1.023	3.917 ± 0.793	32
18	Succeed in a Chemistry-Related Discipline	3.444 ± 1.149	3.667 ± 0.651	33
	INTEREST IN..			
19	Studying Chemistry in General	3.000 ± 1.283	3.167 ± 1.030	34
20	Taking More Chemistry	2.667 ± 1.188	3.083 ± 1.165	35
21	Pursuing a Chemistry-Related Major	2.278 ± 0.826	2.833 ± 1.267	36
22	Pursuing a Science-Related Field	3.944 ± 1.305	4.500 ± 0.522	37
23	Working with Others to Learn Science	3.833 ± 1.200	4.250 ± 0.754	38
24	Chemistry in Industry	2.444 ± 1.097	1.917 ± 0.900	39
25	Chemistry in the Environment	2.833 ± 1.043	2.500 ± 1.000	41
26	Chemistry in Medicine	3.611 ± 1.290	4.250 ± 0.754	40
27	Science in General	3.778 ± 1.166	4.167 ± 0.937	42

Table A16 continues on the next page

Table A16, continued

Item	Statement	Control	Experimental	New #
	GENERAL QUESTIONS			
28	When did you take CH 302 (or its equivalent)?	1.333 ± 0.594	1.083 ± 0.289	
29	Did your General Chemistry lecture experience help you in your laboratory course?	3.056 ± 1.110	3.500 ± 1.168	
30	Did you use the General Chemistry textbook to help solve problems in your laboratory course?	2.833 ± 1.383	1.417 ± 0.669	
31	Do you see value in taking laboratory courses?	2.722 ± 1.320	3.917 ± 0.515	
	IMPACT ON LEARNING			
32	Activities: Lab Lecture	3.111 ± 1.278	2.917 ± 1.165	10
33	Activities: Wet Lab	2.778 ± 1.215	4.333 ± 0.492	11
34	Activities: Computer Labs	2.444 ± 1.149	2.583 ± 1.240	
35	Activities: Exams	2.500 ± 1.366	3.333 ± 0.492	12
36	Activities: Quizzes	2.667 ± 1.237	3.083 ± 0.900	13
37	Activities: Homework/Exercises	2.222 ± 1.114	2.500 ± 0.905	14
	IMPACT ON CONFIDENCE			
38	Activities: Lab Lecture	3.000 ± 1.085	2.583 ± 1.165	15
39	Activities: Wet Lab	2.706 ± 1.160	4.167 ± 0.718	16
40	Activities: Computer Lab	2.765 ± 1.251	3.167 ± 0.835	
41	Activities: Exams	2.533 ± 1.060	3.667 ± 0.888	17
42	Activities: Quizzes	2.706 ± 1.213	3.333 ± 0.651	18
43	Activities: Homework/Exercises	2.176 ± 1.185	2.833 ± 0.937	19

Table A16 continues on the next page

Table A16, continued

Item	Statement	Control	Experimental	New #
	IMPACT ON ENTHUSIASM			
44	Activities: Lab Lecture	2.882 ± 1.054	2.250 ± 1.055	20
45	Activities: Wet Lab	2.529 ± 1.419	4.083 ± 0.669	21
46	Activities: Computer Lab	2.471 ± 1.231	2.667 ± 1.231	
47	Activities: Exams	2.313 ± 1.250	2.750 ± 0.622	22
48	Activities: Quizzes	2.471 ± 1.231	2.583 ± 0.793	23
49	Activities: Homework/Exercises	2.118 ± 1.111	2.167 ± 0.835	24
	IMPRESSIONS OF LECTURE			
50	I enjoyed the formal laboratory (1 hour) lectures.	2.706 ± 0.985	2.500 ± 1.087	43
51	The organization of the lectures was important for my learning.	3.294 ± 1.312	3.417 ± 0.996	44
52	The applications of chemistry discussed in this course made certain concepts easier to understand.	2.706 ± 1.359	3.833 ± 0.937	45
53	The applications of chemistry discussed in this course made learning chemistry interesting.	2.529 ± 1.419	3.750 ± 0.754	46
	IMPRESSIONS OF LABS			
54	I enjoyed the labs.	2.118 ± 1.219	4.000 ± 0.632	47
55	The organization of the labs was important for my learning.	2.353 ± 1.320	3.818 ± 0.874	
56	I understood the chemistry behind the labs before I did them.	2.235 ± 1.091	2.909 ± 1.044	48
57	Eventually I understood the chemistry behind the labs.	2.882 ± 1.409	4.273 ± 0.647	49
58	The labs helped me understand important concepts in this course.	2.353 ± 1.320	4.182 ± 0.603	50

Table A16 continues on the next page

Table A16, continued

Item	Statement	Control	Experimental	New #
59	The labs related well to the CH 302 lecture material.	2.529 ± 1.179	3.545 ± 1.214	
60	Enough time was allowed for labs.	3.235 ± 1.348	4.091 ± 1.044	51
	GENERAL QUESTIONS			
61	Average hours each week spent on this course	3.313 ± 0.704	2.400 ± 0.516	
62	Would you recommend this course to a friend?	1.667 ± 1.291	3.900 ± 0.876	52

Appendix J: Survey Responses, Fall 2000

Presented below is the complete set of responses for the survey distributed in Fall 2000. The original survey numbering is shown here. The data are broken into two tables, Table A17 which illustrates survey responses only for the experimental and control groups, while Table A18 compares survey responses for the experimental and PENS groups.

Table A19: Survey Responses for Experimental and Control Groups, Fall 2000

Item	**Statement**	**Control**	**Experimental**	**New #**
	CONFIDENCE IN YOUR ABILITY TO…			
10	Understand Key Concepts of Chemistry	3.526 ± 1.033	3.682 ± 0.829	25
11	Solve Chemistry Problems	3.282 ± 1.075	3.422 ± 0.917	26
12	Understand the Chemistry Underlying Lab Experiments	3.205 ± 1.080	3.489 ± 0.920	27
13	Perform Lab Experiments	3.667 ± 0.982	3.867 ± 0.786	28
14	Visualize Key Concepts of Chemistry	3.462 ± 1.097	3.267 ± 1.009	29
15	Apply your Knowledge of Chemistry to the Real World	3.103 ± 1.188	3.111 ± 0.982	30
16	Understand Other Areas of Science	3.718 ± 1.050	3.867 ± 0.726	31
17	Succeed in Another Chemistry Course	3.487 ± 1.097	3.533 ± 0.919	32
18	Succeed in a Chemistry-Related Discipline	3.436 ± 1.165	3.222 ± 0.997	33

Table A17 continues on the next page

Table A17, continued

Item	Statement	Control	Experimental	New #
	INTEREST IN..			
19	Studying Chemistry in General	3.128 ± 1.281	2.689 ± 1.125	34
20	Taking More Chemistry	2.897 ± 1.410	2.511 ± 1.199	35
21	Pursuing a Chemistry-Related Major	2.487 ± 1.393	2.178 ± 1.284	36
22	Pursuing a Science-Related Field	3.872 ± 1.174	4.200 ± 0.968	37
23	Working with Others to Learn Science	3.641 ± 1.158	3.705 ± 1.112	38
24	Chemistry in Industry	2.436 ± 1.273	2.311 ± 1.145	39
25	Chemistry in the Environment	2.872 ± 1.361	2.756 ± 1.190	41
26	Chemistry in Medicine	3.744 ± 1.163	3.978 ± 1.055	40
27	Science in General	4.103 ± 1.046	4.089 ± 0.925	42
	GENERAL QUESTIONS			
28	When did you take CH 302 (or its equivalent)?	2.103 ± 1.353	2.522 ± 1.188	
29	Did your General Chemistry lecture experience help you in your laboratory course?	3.333 ± 1.199	2.739 ± 1.144	
30	Did you use the General Chemistry textbook to help solve problems in your laboratory course?	3.077 ± 1.201	1.630 ± 0.997	
31	Do you see value in taking laboratory courses?	3.231 ± 1.245	3.326 ± 1.117	
	IMPACT ON LEARNING			
32	Activities: Lab Lecture	3.436 ± 1.142	3.152 ± 1.074	10
33	Activities: Wet Lab	3.410 ± 1.141	3.717 ± 0.958	11
34	Activities: Computer Labs	2.846 ± 1.159	3.478 ± 0.960	
35	Activities: Exams	2.811 ± 1.126	3.174 ± 0.902	12

Table A17 continues on the next page

Table A17, continued

Item	Statement	Control	Experimental	New #
36	Activities: Quizzes	3.000 ± 1.162	3.000 ± 0.816	13
37	Activities: Homework/Exercises	3.077 ± 1.285	3.047 ± 1.090	14
	IMPACT ON CONFIDENCE			
38	Activities: Lab Lecture	3.436 ± 1.142	3.326 ± 0.967	15
39	Activities: Wet Lab	3.385 ± 1.091	3.587 ± 0.884	16
40	Activities: Computer Lab	3.077 ± 1.201	3.600 ± 0.889	
41	Activities: Exams	2.865 ± 1.110	3.022 ± 1.043	17
42	Activities: Quizzes	2.974 ± 1.219	3.043 ± 0.815	18
43	Activities: Homework/Exercises	2.923 ± 1.306	2.952 ± 1.035	19
	IMPACT ON ENTHUSIASM			
44	Activities: Lab Lecture	2.921 ± 1.148	2.500 ± 1.027	20
45	Activities: Wet Lab	3.053 ± 1.413	3.196 ± 1.185	21
46	Activities: Computer Lab	2.553 ± 1.288	2.822 ± 1.007	
47	Activities: Exams	2.500 ± 1.254	2.400 ± 1.009	22
48	Activities: Quizzes	2.459 ± 1.238	2.239 ± 0.899	23
49	Activities: Homework/Exercises	2.474 ± 1.289	2.349 ± 1.066	24
	IMPRESSIONS OF LECTURE			
50	I enjoyed the formal laboratory (1 hour) lectures.	2.895 ± 1.034	2.717 ± 1.167	43
51	The organization of the lectures was important for my learning.	3.421 ± 1.130	3.022 ± 1.125	44
52	The applications of chemistry discussed in this course made certain concepts easier to understand.	3.395 ± 1.220	3.304 ± 1.030	45

Table A17 continues on the next page

Table A17, continued

Item	**Statement**	**Control**	**Experimental**	**New #**
53	The applications of chemistry discussed in this course made learning chemistry interesting.	3.184 ± 1.111	3.043 ± 1.032	46
	IMPRESSIONS OF LABS			
54	I enjoyed the labs.	2.973 ± 1.142	3.152 ± 1.229	47
55	The organization of the labs was important for my learning.	3.135 ± 1.032	3.348 ± 0.875	
56	I understood the chemistry behind the labs before I did them.	2.703 ± 1.077	2.891 ± 0.994	48
57	Eventually I understood the chemistry behind the labs.	3.378 ± 1.089	3.674 ± 1.012	49
58	The labs helped me understand important concepts in this course.	3.135 ± 1.110	3.500 ± 0.863	50
59	The labs related well to the CH 302 lecture material.	3.243 ± 1.011	3.136 ± 1.091	
60	Enough time was allowed for labs.	3.351 ± 1.184	3.935 ± 1.181	51
	GENERAL QUESTIONS			
61	Average hours each week spent on this course	3.189 ± 0.811	3.065 ± 0.712	
62	Would you recommend this course to a friend?	2.216 ± 1.134	4.087 ± 1.092	52

Table A18: Survey Responses for Experimental and PENS Groups, Fall 2000

Item	Statement	Experimental	PENS	New #
	CONFIDENCE IN YOUR ABILITY TO…			
10	Understand Key Concepts of Chemistry	3.682 ± 0.829	3.733 ± 0.704	25
11	Solve Chemistry Problems	3.422 ± 0.917	3.467 ± 0.990	26
12	Understand the Chemistry Underlying Lab Experiments	3.489 ± 0.920	3.400 ± 0.828	27
13	Perform Lab Experiments	3.867 ± 0.786	3.933 ± 0.704	28
14	Visualize Key Concepts of Chemistry	3.267 ± 1.009	3.467 ± 0.743	29
15	Apply your Knowledge of Chemistry to the Real World	3.111 ± 0.982	3.600 ± 0.632	30
16	Understand Other Areas of Science	3.867 ± 0.726	4.267 ± 0.704	31
17	Succeed in Another Chemistry Course	3.533 ± 0.919	3.733 ± 0.884	32
18	Succeed in a Chemistry-Related Discipline	3.222 ± 0.997	3.667 ± 0.900	33
	INTEREST IN..			
19	Studying Chemistry in General	2.689 ± 1.125	2.400 ± 1.056	34
20	Taking More Chemistry	2.511 ± 1.199	2.267 ± 1.033	35
21	Pursuing a Chemistry-Related Major	2.178 ± 1.284	1.933 ± 1.163	36
22	Pursuing a Science-Related Field	4.200 ± 0.968	3.867 ± 1.187	37
23	Working with Others to Learn Science	3.705 ± 1.112	3.467 ± 1.302	38
24	Chemistry in Industry	2.311 ± 1.145	1.933 ± 0.884	39
25	Chemistry in the Environment	2.756 ± 1.190	2.400 ± 0.986	41
26	Chemistry in Medicine	3.978 ± 1.055	3.800 ± 1.014	40
27	Science in General	4.089 ± 0.925	3.867 ± 0.915	42

Table A18 continues on the next page

Table A18, continued

Item	Statement	Experimental	PENS	New #
	GENERAL QUESTIONS			
28	When did you take CH 302 (or its equivalent)?	2.522 ± 1.188	2.533 ± 1.187	
29	Did your General Chemistry lecture experience help you in your laboratory course?	2.739 ± 1.144	2.600 ± 1.242	
30	Did you use the General Chemistry textbook to help solve problems in your laboratory course?	1.630 ± 0.997	1.600 ± 1.121	
31	Do you see value in taking laboratory courses?	3.326 ± 1.117	2.933 ± 0.961	
	IMPACT ON LEARNING			
32	Activities: Lab Lecture	3.152 ± 1.074	3.200 ± 1.082	10
33	Activities: Wet Lab	3.717 ± 0.958	3.467 ± 0.743	11
34	Activities: Computer Labs	3.478 ± 0.960	3.133 ± 0.990	
35	Activities: Exams	3.174 ± 0.902	3.267 ± 0.961	12
36	Activities: Quizzes	3.000 ± 0.816	3.267 ± 1.033	13
37	Activities: Homework/Exercises	3.047 ± 1.090	3.267 ± 0.961	14
	IMPACT ON CONFIDENCE			
38	Activities: Lab Lecture	3.326 ± 0.967	3.133 ± 0.915	15
39	Activities: Wet Lab	3.587 ± 0.884	3.133 ± 0.915	16
40	Activities: Computer Lab	3.600 ± 0.889	3.133 ± 0.516	
41	Activities: Exams	3.022 ± 1.043	3.133 ± 0.990	17
42	Activities: Quizzes	3.043 ± 0.815	3.133 ± 1.187	18
43	Activities: Homework/Exercises	2.952 ± 1.035	3.133 ± 0.743	19

Table A18 continues on the next page

Table A18, continued

Item	Statement	Experimental	PENS	New #
	IMPACT ON ENTHUSIASM			
44	Activities: Lab Lecture	2.500 ± 1.027	2.200 ± 1.014	20
45	Activities: Wet Lab	3.196 ± 1.185	2.467 ± 1.187	21
46	Activities: Computer Lab	2.822 ± 1.007	2.400 ± 1.056	
47	Activities: Exams	2.400 ± 1.009	2.133 ± 0.915	22
48	Activities: Quizzes	2.239 ± 0.899	2.200 ± 1.014	23
49	Activities: Homework/Exercises	2.349 ± 1.066	2.200 ± 1.014	24
	IMPRESSIONS OF LECTURE			
50	I enjoyed the formal laboratory (1 hour) lectures.	2.717 ± 1.167	2.733 ± 1.033	43
51	The organization of the lectures was important for my learning.	3.022 ± 1.125	3.067 ± 1.223	44
52	The applications of chemistry discussed in this course made certain concepts easier to understand.	3.304 ± 1.030	3.533 ± 1.060	45
53	The applications of chemistry discussed in this course made learning chemistry interesting.	3.043 ± 1.032	2.933 ± 1.163	46
	IMPRESSIONS OF LABS			
54	I enjoyed the labs.	3.152 ± 1.229	2.400 ± 1.298	47
55	The organization of the labs was important for my learning.	3.348 ± 0.875	3.067 ± 1.100	
56	I understood the chemistry behind the labs before I did them.	2.891 ± 0.994	2.467 ± 0.743	48
57	Eventually I understood the chemistry behind the labs.	3.674 ± 1.012	3.667 ± 1.175	49
58	The labs helped me understand important concepts in this course.	3.500 ± 0.863	3.200 ± 1.014	50

Table A18 continues on the next page

Table A18, continued

Item	Statement	Experimental	PENS	New #
59	The labs related well to the CH 302 lecture material.	3.136 ± 1.091	2.800 ± 0.941	
60	Enough time was allowed for labs.	3.935 ± 1.181	1.933 ± 1.223	51
	GENERAL QUESTIONS			
61	Average hours each week spent on this course	3.065 ± 0.712	3.733 ± 0.594	
62	Would you recommend this course to a friend?	4.087 ± 1.092	2.467 ± 1.302	52

Appendix K: Survey Responses, Spring 2001

Presented below is the complete set of responses for the survey distributed in Spring 2001. The original survey numbering is shown here. As in Fall 2000, the data are broken into two tables, Table A19 which illustrates survey responses only for the experimental and control groups, while Table A20 compares survey responses for the experimental and PENS groups.

Table A19: Survey Responses for Experimental and Control Groups, Spring 2001

Item	Statement	Control	Experimental	New #
	CONFIDENCE IN YOUR ABILITY TO…			
10	Understand Key Concepts of Chemistry	3.592 ± 1.008	3.916 ± 0.791	25
11	Solve Chemistry Problems	3.536 ± 0.933	3.869 ± 0.825	26
12	Understand the Chemistry Underlying Lab Experiments	3.253 ± 1.008	3.551 ± 0.934	27
13	Perform Lab Experiments	3.583 ± 0.987	3.868 ± 0.794	28
14	Visualize Key Concepts of Chemistry	3.385 ± 0.959	3.689 ± 0.760	29
15	Apply your Knowledge of Chemistry to the Real World	3.140 ± 1.030	3.349 ± 0.895	30
16	Understand Other Areas of Science	3.845 ± 0.943	3.981 ± 0.730	31
17	Succeed in Another Chemistry Course	3.619 ± 0.970	3.849 ± 0.848	32
18	Succeed in a Chemistry-Related Discipline	3.355 ± 1.064	3.566 ± 0.873	33

Table A19 continues on the next page

Table A19, continued

Item	Statement	Control	Experimental	New #
	INTEREST IN..			
19	Studying Chemistry in General	2.848 ± 1.144	2.962 ± 1.112	34
20	Taking More Chemistry	2.747 ± 1.231	2.811 ± 1.303	35
21	Pursuing a Chemistry-Related Major	2.430 ± 1.245	2.330 ± 1.293	36
22	Pursuing a Science-Related Field	4.113 ± 1.060	4.283 ± 0.974	37
23	Working with Others to Learn Science	3.709 ± 1.126	3.858 ± 1.055	38
24	Chemistry in Industry	2.634 ± 1.164	2.377 ± 1.082	39
25	Chemistry in the Environment	2.879 ± 1.161	2.934 ± 1.229	41
26	Chemistry in Medicine	3.668 ± 1.201	3.849 ± 1.248	40
27	Science in General	3.958 ± 1.057	4.104 ± 1.179	42
	GENERAL QUESTIONS			
28	When did you take CH 302 (or its equivalent)?	1.398 ± 0.909	1.698 ± 1.123	
29	Did your General Chemistry lecture experience help you in your laboratory course?	3.155 ± 1.234	2.849 ± 1.194	
30	Did you use the General Chemistry textbook to help solve problems in your laboratory course?	3.008 ± 1.276	1.838 ± 1.264	
31	Do you see value in taking laboratory courses?	2.939 ± 1.210	3.371 ± 1.154	
32	How closely do the skills presented in this lab match your academic and/or career goals?	2.439 ± 1.073	2.829 ± 1.033	
33	Would you recommend this course to a friend?	1.875 ± 1.041	3.514 ± 1.338	52

Table A19 continues on the next page

Table A19, continued

Item	Statement	Control	Experimental	New #
	IMPACT ON LEARNING			
34	Activities: Lab Lecture	3.307 ± 1.136	3.086 ± 1.136	10
35	Activities: Wet Lab	3.196 ± 1.144	3.933 ± 1.012	11
36	Activities: Computer Labs	2.533 ± 1.046	3.276 ± 1.131	
37	Activities: Exams	2.536 ± 0.969	3.524 ± 0.962	12
38	Activities: Quizzes	2.709 ± 1.097	3.143 ± 1.113	13
39	Activities: Homework/Exercises	2.602 ± 1.217	3.356 ± 1.042	14
	IMPACT ON CONFIDENCE			
40	Activities: Lab Lecture	3.216 ± 1.124	3.223 ± 1.093	15
41	Activities: Wet Lab	3.015 ± 1.134	3.724 ± 1.131	16
42	Activities: Computer Lab	2.771 ± 1.094	3.505 ± 1.136	
43	Activities: Exams	2.725 ± 0.966	3.629 ± 1.012	17
44	Activities: Quizzes	2.821 ± 1.125	3.257 ± 1.152	18
45	Activities: Homework/Exercises	2.630 ± 1.152	3.337 ± 1.001	19
	IMPACT ON ENTHUSIASM			
46	Activities: Lab Lecture	2.322 ± 1.167	2.538 ± 1.284	20
47	Activities: Wet Lab	2.473 ± 1.276	3.096 ± 1.273	21
48	Activities: Computer Lab	2.176 ± 1.089	2.752 ± 1.277	
49	Activities: Exams	2.090 ± 0.994	2.638 ± 1.210	22
50	Activities: Quizzes	2.089 ± 1.021	2.400 ± 1.190	23
51	Activities: Homework/Exercises	1.899 ± 1.014	2.558 ± 1.069	24

Table A19 continues on the next page

Table A19, continued

Item	Statement	Control	Experimental	New #
	IMPRESSIONS OF LECTURE			
52	I enjoyed the formal laboratory (1 hour) lectures.	2.415 ± 1.096	2.657 ± 1.167	43
53	The organization of the lectures was important for my learning.	3.016 ± 1.218	3.133 ± 1.075	44
54	The applications of chemistry discussed in this course made certain concepts easier to understand.	2.883 ± 1.091	3.533 ± 0.981	45
55	The applications of chemistry discussed in this course made learning chemistry interesting.	2.580 ± 1.116	3.362 ± 1.102	46
	IMPRESSIONS OF LABS			
56	I enjoyed the labs.	2.463 ± 1.234	3.217 ± 1.211	47
57	The organization of the labs was important for my learning.	2.864 ± 1.153	3.575 ± 1.069	
58	I understood the chemistry behind the labs before I did them.	2.629 ± 1.113	2.962 ± 1.162	48
59	Eventually I understood the chemistry behind the labs.	3.222 ± 1.069	4.019 ± 0.926	49
60	The labs helped me understand important concepts in this course.	2.808 ± 1.068	3.724 ± 0.935	50
61	The labs related well to the CH 302 lecture material.	2.941 ± 1.164	2.962 ± 1.097	
62	Enough time was allowed for labs.	3.553 ± 1.141	4.009 ± 1.159	51
	GENERAL QUESTIONS			
63	Average hours each week spent on this course	3.117 ± 0.682	3.257 ± 0.680	
64	What one resource was most important in helping you understand the concepts presented in this course?	2.787 ± 1.169	2.781 ± 1.160	

Table A19 continues on the next page

Table A19, continued

Item	Statement	Control	Experimental	New #
65	What one resource was most important in helping you complete the experiments in this course?	2.871 ± 0.911	2.877 ± 0.923	
66	What one resource was most important in helping you prepare the laboratory reports in this course?	3.140 ± 1.057	3.202 ± 0.907	

Table A20: Survey Responses for Experimental and PENS Groups, Spring 2001

Item	Statement	Experimental	PENS	New #
	CONFIDENCE IN YOUR ABILITY TO…			
10	Understand Key Concepts of Chemistry	3.916 ± 0.791	3.667 ± 1.042	25
11	Solve Chemistry Problems	3.869 ± 0.825	3.811 ± 0.995	26
12	Understand the Chemistry Underlying Lab Experiments	3.551 ± 0.934	2.946 ± 1.053	27
13	Perform Lab Experiments	3.868 ± 0.794	3.703 ± 1.102	28
14	Visualize Key Concepts of Chemistry	3.689 ± 0.760	3.297 ± 1.077	29
15	Apply your Knowledge of Chemistry to the Real World	3.349 ± 0.895	3.000 ± 1.054	30
16	Understand Other Areas of Science	3.981 ± 0.730	3.946 ± 0.970	31
17	Succeed in Another Chemistry Course	3.849 ± 0.848	3.919 ± 1.010	32
18	Succeed in a Chemistry-Related Discipline	3.566 ± 0.873	3.459 ± 1.120	33
	INTEREST IN..			
19	Studying Chemistry in General	2.962 ± 1.112	3.162 ± 1.214	34
20	Taking More Chemistry	2.811 ± 1.303	3.027 ± 1.323	35

Table A20 continues on the next page

Table A20, continued

Item	Statement	Experimental	PENS	New #
21	Pursuing a Chemistry-Related Major	2.330 ± 1.293	2.622 ± 1.587	36
22	Pursuing a Science-Related Field	4.283 ± 0.974	4.324 ± 1.029	37
23	Working with Others to Learn Science	3.858 ± 1.055	3.784 ± 1.205	38
24	Chemistry in Industry	2.377 ± 1.082	2.459 ± 1.304	39
25	Chemistry in the Environment	2.934 ± 1.229	3.027 ± 1.236	41
26	Chemistry in Medicine	3.849 ± 1.248	3.919 ± 1.256	40
27	Science in General	4.104 ± 1.179	4.216 ± 0.976	42
	GENERAL QUESTIONS			
28	When did you take CH 302 (or its equivalent)?	1.698 ± 1.123	1.081 ± 0.493	
29	Did your General Chemistry lecture experience help you in your laboratory course?	2.849 ± 1.194	2.351 ± 1.136	
30	Did you use the General Chemistry textbook to help solve problems in your laboratory course?	1.838 ± 1.264	1.676 ± 1.082	
31	Do you see value in taking laboratory courses?	3.371 ± 1.154	3.081 ± 1.498	
32	How closely do the skills presented in this lab match your academic and/or career goals?	2.829 ± 1.033	2.541 ± 1.325	
33	Would you recommend this course to a friend?	3.514 ± 1.338	2.514 ± 1.387	52
	IMPACT ON LEARNING			
34	Activities: Lab Lecture	3.086 ± 1.136	2.595 ± 1.166	10
35	Activities: Wet Lab	3.933 ± 1.012	3.459 ± 1.464	11
36	Activities: Computer Labs	3.276 ± 1.131	2.811 ± 1.330	
37	Activities: Exams	3.524 ± 0.962	3.189 ± 1.288	12

Table A20 continues on the next page

Table A20, continued

Item	Statement	Experimental	PENS	New #
38	Activities: Quizzes	3.143 ± 1.113	2.919 ± 1.278	13
39	Activities: Homework/Exercises	3.356 ± 1.042	2.811 ± 1.330	14
	IMPACT ON CONFIDENCE			
40	Activities: Lab Lecture	3.223 ± 1.093	2.444 ± 1.229	15
41	Activities: Wet Lab	3.724 ± 1.131	3.139 ± 1.606	16
42	Activities: Computer Lab	3.505 ± 1.136	3.111 ± 1.489	
43	Activities: Exams	3.629 ± 1.012	3.139 ± 1.437	17
44	Activities: Quizzes	3.257 ± 1.152	2.917 ± 1.360	18
45	Activities: Homework/Exercises	3.337 ± 1.001	2.889 ± 1.237	19
	IMPACT ON ENTHUSIASM			
46	Activities: Lab Lecture	2.538 ± 1.284	2.361 ± 1.268	20
47	Activities: Wet Lab	3.096 ± 1.273	2.556 ± 1.463	21
48	Activities: Computer Lab	2.752 ± 1.277	2.417 ± 1.273	
49	Activities: Exams	2.638 ± 1.210	2.278 ± 1.233	22
50	Activities: Quizzes	2.400 ± 1.190	2.333 ± 1.219	23
51	Activities: Homework/Exercises	2.558 ± 1.069	2.361 ± 1.291	24
	IMPRESSIONS OF LECTURE			
52	I enjoyed the formal laboratory (1 hour) lectures.	2.657 ± 1.167	2.405 ± 1.166	43
53	The organization of the lectures was important for my learning.	3.133 ± 1.075	2.946 ± 1.393	44
54	The applications of chemistry discussed in this course made certain concepts easier to understand.	3.533 ± 0.981	2.892 ± 1.173	45

Table A20 continues on the next page

Table A20, continued

Item	Statement	Experimental	PENS	New #
55	The applications of chemistry discussed in this course made learning chemistry interesting.	3.362 ± 1.102	2.811 ± 1.244	46
	IMPRESSIONS OF LABS			
56	I enjoyed the labs.	3.217 ± 1.211	2.784 ± 1.456	47
57	The organization of the labs was important for my learning.	3.575 ± 1.069	3.216 ± 1.336	
58	I understood the chemistry behind the labs before I did them.	2.962 ± 1.162	2.459 ± 1.192	48
59	Eventually I understood the chemistry behind the labs.	4.019 ± 0.926	3.568 ± 1.259	49
60	The labs helped me understand important concepts in this course.	3.724 ± 0.935	3.216 ± 1.336	50
61	The labs related well to the CH 302 lecture material.	2.962 ± 1.097	2.541 ± 1.304	
62	Enough time was allowed for labs.	4.009 ± 1.159	3.351 ± 1.296	51
	GENERAL QUESTIONS			
63	Average hours each week spent on this course	3.257 ± 0.680	3.784 ± 0.787	
64	What one resource was most important in helping you understand the concepts presented in this course?	2.781 ± 1.160	2.622 ± 0.924	
65	What one resource was most important in helping you complete the experiments in this course?	2.877 ± 0.923	2.861 ± 0.867	
66	What one resource was most important in helping you prepare the laboratory reports in this course?	3.202 ± 0.907	3.229 ± 0.808	

References

1. Lockemann, G. and Oesper, R. E. *J. Chem. Educ.* **1953**, *30*, 202.

2. Collins, A.; Brown, J. S.; Newman, S. E. "Cognitive Apprenticeship: Teaching the Crafts of Reading, Writing, and Mathematics" In *Knowing, Learning, and Instruction: Essays in Honor of Robert Glaser*; Resnick, L. B., Ed.; Lawrence Erlbaum Associates, Publishers: Hillsdale, New Jersey, 1989.

3. Ihde, A. J. The Development of Modern Chemistry, Harper and Row Publishers: New York, 1964, 261.

4. Ihde, A. J. The Development of Modern Chemistry, Harper and Row Publishers: New York, 1964, 262.

5. Shenstone, W. A. Justus von Liebig: His Life and Work, Macmillan and Company, New York, 1895.

6. Berry, R. S. Graduate Education in Chemistry: A Personal Perspective of Where It Has Been and Where It Might Go. In *Graduate Education in the Chemical Sciences: Issues for the 21st Century: A Report of a Workshop*; The National Academy of Sciences, Washington, DC, 2000, 27.

7. Lloyd, B. W. *J. Chem. Educ.* **1992**, *69*, 633.

8. Hawkes, S. J. *J. Chem. Educ.* **2004**, *81*, 1257.

9. Thomas, K. W. *J. Biol. Educ.* **1972**, *6*, 314.

10. Schlesinger, H.I. *J. Chem. Educ.* **1935**, *12*, 524.

11. Pickering, M. *J. Chem. Educ.* **1985**, *62*, 874.

12. Abraham, M. R. *et al* *J. Chem. Educ.* **1997**, *74*, 591.

13. Domin, D. S. *J. Chem. Educ.* **1999**, *76*, 543.

14. Tamir, P. *J Res. Sci. Teach.* **1977**, *14*, 311.

15. Raths, L. E.; Wasserman, S.; Jonas, A.; Rothstein, A. *Teaching for Thinking: Theories, Strategies, and Activities for the Classroom;* Teachers College, Columbia University: New York, 1986.

16. Lagowski, J. J. *J. Chem. Educ.* **1990**, *67*, 541.

17. Domin, D. S. *J. Chem. Educ.* **1999**, *76*, 109.

18. Dearden, R. F. In *The Concept of Education;* Peters, R. S., Ed.; Routledge: London, 1967.

19. Pavelich, M. J. and Abraham, M. R. *J. Chem. Educ.* **1979**, *56*, 100.

20. *National Science Education Standards*; National Academy Press, Washington, DC, 1996.

21. Ricci, R. W.; Ditzler, M. A.; Jarret, R.; McMaster, P.; Herrick, R. *J. Chem. Educ.* **1994**, *71*, 404.

22. Kyle, W. J. *J. Res. Sci. Teach.* **1980**, *17*, 123.

23. Rudd, J. A.; Greenbowe, T. J.; Hand, B. M.; Legg, M. J. *J. Chem. Educ.* **2001**, *78*, 1680.

24. Green, W. J.; Elliott, C.; Cummins, R. H. *J. Chem. Educ.* **2004**, *81*, 239.

25. Abraham, M. R.; Pavelich, M. J. Inquiries into Chemistry, 3rd ed.: Waveland Press, Inc.: Prospect Heights, IL, 1999.

26. Stepien, W. J.; Gallagher, S. A.; Workman, D. *J. Educ. Gift.* **1993**, *16*, 338.

27. Cheronis, N. D. *J. Chem. Educ.* **1962**, *39*, 102.

28. Wright, J. C. *J. Chem. Educ.* **1996**, *73*, 827.

29. Cunningham, H. A. *Sci. Educ.* **1946**, *30*, 70.

30. Kruglak, H. *Am. J. Phys.* **1952**, *20*, 136.

31. Brown, S. C. *Am. J. Phys.* **1958**, *26*, 334.

32. Bradley, R. *Sci. Educ.* **1968**, *52*, 58.

33. Kruglak, H. *Am. J. Phys.* **1953**, *21*, 14.

34. Dubravcic, M. F. *J. Chem. Educ.* **1979**, *56*, 237.

35. Ben-Zvi, R.; Hofstein, A.; Samuel, D.; Kempa, R. F. *J. Chem. Educ.* **1976**, *53*, 518.

36. Kruglak, H. *Am. J. Phys.* **1958**, *26*, 31.

37. Eglen, J. R.; Kempa, R. F. *School Sci. Rev.* **1974**, *56*, 261.

38. Stewart, B. Y. *J. Coll. Sci. Teach.* **1988**, *17*, 269.

39. Hill, B. W. *J. Res. Sci. Teach.* **1976**, *13*, 71.

40. Wheatley, J. H. *J. Res. Sci. Teach.* **1975**, *12*, 101.

41. Raghubir, K. P. *J. Res. Sci. Teach.* **1979**, *16*, 13.

42. Hofstein, A.; Lunetta, V. N. *Rev. Educ. Res.* **1982**, *52*, 201.

43. Ben-Zvi, R.; Hofstein, A.; Samuel, D.; Kempa, R. F. *J. Chem. Educ.* **1976**, *53*, 575.

44. Pickering, M. *J. Chem. Educ.* **1993**, *70*, 699.

45. Nakleh, M. B.; Polles, J.; Malina, E. "Learning Chemistry in a Laboratory Environment" In *The Concept of Education*; Gilbert, J. K.; De Jong, O.; Justi, R.; Treagust, D. F.; Van Driel, J. H., Eds.; Kluwer Academic Publishers: Boston, 2002.

46. Lloyd, B. W. *J. Chem. Educ.* **1992**, *69*, 866.

47. See http://www3.uwm.edu/dept/chemexams/materials/labs.cfm, URL valid as of 1/6/2005

48. Gallagher, J. J. *Sci. Educ*. **1987**, *71*, 351.

49. Moore, J.; Kosciuk, S., "New Traditions: Introductory Chemistry End-of-semester Survey", The Learning through Evaluation, Adaptation, and Dissemination Center, University of Wisconsin Madison. URL: http://www.wcer.wisc.edu/nise/cl1/flag/tools/attitude/ntchempo.htm

Vita

Michael Jeffrey Elliott was born in Hopewell, Virginia, the son of Joan Booth Elliott and William R. Elliott, Jr. After completing his work at Hopewell High School, Hopewell, Virginia, in 1979, he entered the University of Virginia. He received his Bachelor of Arts in Chemistry and French in 1983. Returning to the University of Virginia in 1984, he entered the Graduate School, eventually earning the Master of Arts in Teaching in Chemistry in 1988. During the following years, he was employed as Laboratory Instructor and Stockroom Manager at Barry University, Miami Shores, Florida. In August 1997, he entered the Graduate School of The University of Texas.

Permanent address: 610 SE 13th St #104, Dania Beach, Florida 33004

This dissertation was typed by the author.