Learning in Style: Investigation of Factors Impacting Student Success in Chemical Engineering at Individual and Team-Levels with a Focus on Student Learning Styles

DISSEPTION

Presented in Partial Fulfillment of the Requirements for the Degree Doctor of Philosophy in the Graduate School of The Ohio State University

By
Elif Eda Miskioğlu
Graduate Program in Chemical Engineering

The Ohio State University
2015

Dissertation Committee:
David W. Wood, Advisor
James F. Rathman
David L. Tomasko
Copyright by

Elif Eda Miskioglu

2015
Abstract

Our three studies examine the factors of learning styles, student self-efficacy, collective (team) efficacy, attitudes, perceptions, and performance at individual and team levels. Each study addresses a different environment: (i) Individual Level—we are interested in how variability in learning styles engaged by specific exam problems may correlate with student learning styles, self-efficacy, and performance in our introductory chemical engineering course, Process Fundamentals (i.e., mass and energy or material balances); (ii) Team Level—we are interested in understanding how team composition with respect to learning styles (homogeneous vs. heterogeneous teams) may influence these factors in the upper level Unit Operations course; (iii) Combinatorial Level—we are interested in understanding how collective efficacy may influence individual self-efficacy and again if there are any correlations with learning styles and performance in the senior level Process Design and Development course. Some of the most interesting results of these studies have stemmed from the study on individual students, which has shown correlations between learning style preferences and performance in specific instances. Even more interesting, evaluating and characterizing the learning styles that exam problems engage has shown strong variations in problem types by instructor. This presents new questions regarding how these variations may affect student understanding and subsequent performance. Also included are details regarding a course developed in Technical and Professional Communication (for Chemical Engineers) that was offered Spring 2014 and Spring 2015.
Dedication

This document is dedicated to all educators, and the teachers, mentors, supervisors, friends, family, and colleagues who have been a part of my education.
Acknowledgments

I would like to acknowledge my committee members, Dr. David Tomasko and Dr. James Rathman, for their guidance and support throughout my dissertation. I would also like to extend my gratitude to my advisor, Dr. David Wood, for giving me the opportunity to pursue this research area and develop my own course. Thank you to the faculty who allowed me to study their courses.

Of course, thank you to my friends and family (especially my parents, İbrahim and Ayşe Nur Miskioğlu) for their continued love and support, and my colleagues for their constructive input and encouragement.

Lastly, I would like to acknowledge the sources of funding that made the last five years possible: OSU Graduate School First-year Fellowship, Howard Hughes Medical Institute MED-into-GRAD, and the National Science Foundation Graduate Research Fellowship Program (NSF GRFP, grant no. DGE-0822215).
Vita

June 2006 ........................................... Houghton High School

May 2010 ............................................. B.S., Chemical Engineering, Iowa State University, minor: Genetics

April 2011 ........................................... National Science Foundation Graduate Research Fellowship Program Awardee

June 2011-June 2012 ......................... Howard Hughes Medical Institute MED-into-GRAD Fellow

March 2012 ........................................... Graduate Engineering Education Consortium of Students Fellow

Spring 2012 and 2013 ......................... Instructional Assistant, Graduate-level Research Communication

Spring 2014 and 2015 ......................... Instructor, Technical and Professional Communication for Chemical Engineers (undergraduate)

December 2014 ..................................... M.S. Chemical and Biomolecular Engineering, The Ohio State University

October 2014 to Present ...................... PhD Candidate, Department of Chemical and Biomolecular Engineering, The Ohio State University
Publications

American Society for Engineering Education 2015 – Seattle, WA

Miskioglu, EE. Technical and Professional Communication for Chemical Engineers

Miskioglu, EE. Variability in Instruction of Introductory Chemical Engineering Course: Does it affect our students?

Frontiers in Education 2014 – Madrid, Spain

Miskioglu EE and Wood DW. That’s Not My Style: Understanding the Correlation of Learning Style Preferences, Self-Efficacy, and Student Performance in an Introductory Chemical Engineering Course.

Miskioglu EE and Wood DW. Engineering a Discipline-Specific Communication Course in Chemical Engineering.


Frontiers in Education 2013 – Oklahoma City, OK

Miskioglu EE and Wood D. Correlation of Learning Styles with Team Performance and Perception in Chemical and Biomolecular Engineering Unit Operations Course.

Miskioglu EE and Wood D. Learning in Style: Correlation of Learning Styles with Problem Comprehension and Perceptions in Introductory Chemical Engineering Course.
Frontiers in Education 2011 – Rapid City, SD

Miskioglu, EE. Work in Progress—The Age of Apathy: Reigniting Engineering Education.

Frontiers in Education 2010 – Arlington, VA


Fields of Study

Major Field: Chemical Engineering
Table of Contents

Abstract ................................................................................................................................. ii
Dedication .............................................................................................................................. iii
Acknowledgments ................................................................................................................ iv
Vita ........................................................................................................................................ v
Publications ........................................................................................................................ vi
Fields of Study .................................................................................................................... vii
Table of Contents ................................................................................................................ viii
List of Tables ........................................................................................................................ x
List of Figures ........................................................................................................................ xiii
Chapter 1: Preface .............................................................................................................. 1
Chapter 2: Introduction and Background ........................................................................... 4
Chapter 3: Study on the Individual ....................................................................................... 34
Chapter 4: Study on the Team ............................................................................................. 88
Chapter 5: Combinatorial Study .......................................................................................... 99
Chapter 6: Conclusions and Future Work for CBE Course Studies .................................... 126
Chapter 7: Creation of CBE 4194—Technical and Professional Communication for
Chemical Engineers .......................................................................................................... 133
Chapter 8: Afterword ......................................................................................................... 172
References ............................................................................................................................ 177
Appendix A Compilation of Documents Submitted to Institutional Review Board and
Study Materials for CBE 2200, Process Fundamentals ....................................................... 182
Appendix B Compilation of ILS Student Responses for CBE 2200, Process Fundamentals........................................................................................................186
Appendix C Compilation of Final Student Grades for CBE 2200, Process Fundamentals........................................................................................................198
Appendix D Compilation of Concepts and Inherent Biases on Exams by Various Faculty Members Teaching CBE 2200........................................................................................................206
Appendix E Compilation of Concept Inventory Questions and Answers Administered at the End of Spring 2015 CBE 2200........................................................................................................211
Appendix F Compilation of Documents Submitted to Institutional Review Board and Study Materials for CBE 4630, Unit Operations.................................................................231
Appendix G Compilation of Documents Submitted to Institutional Review Board and Study Materials for CBE 4764, Process Design and Development.................................236
Appendix H Compilation of Survey Responses and Team Scores from Combinatorial CBE 4764, Process Design and Development, Study......................................................247
Appendix I Course Syllabus and Schedule for CBE 4194, Technical and Professional Communication for (Chemical) Engineers.................................................................252
Appendix J Assignments Administered for CBE 4194, Technical and Professional Communication for (Chemical) Engineers.................................................................257
Appendix K Activities Used in CBE 4194, Technical and Professional Communication for (Chemical) Engineers.................................................................280
List of Tables

Table 2.1. Description of dimensions and learning styles preferences in the Felder-Silverman model. .................................................................10
Table 2.2. Type of Validity: Internal.........................................................................................................................28
Table 2.3. Type of Validity: External .....................................................................................................................30
Table 2.4. Type of Validity: Construct ................................................................................................................31
Table 2.5. Type of Validity: Content ..................................................................................................................32
Table 2.6. Type of Validity: Criterion-Related .................................................................................................32
Table 3.1. Categorization criteria for evaluating inherent bias on exam problems..........................42
Table 3.2. Participation numbers for each component of study by faculty and term........48
Table 3.3. Data collected from each semester and faculty instructor.................................................48
Table 3.4. Number of problems administered on each exam. .........................................................49
Table 3.5. Percent of students in class, upper quartile of grades, and lower quartile of grades shown by strength of learning style preference in dimensions of interest ..........54
Table 5.1. Items on self-efficacy and perceptions instrument administered in senior design.................................................................................................................................107
Table 5.2. Summary of survey responses for students flagged as “exceptional conditions” on CATME peer evaluations.................................................................118
Table 7.1. Summary of five day CDI process..........................................................................................138
Table 7.2. Summary of course goals and corresponding objectives..................................................140
Table 7.3. Modified and additional course goals and learning objectives to be used in future iterations, and recommended to other instructors.................................................141
Table 7.4. Bloom's Taxonomy of Learning ................................................................. 142
Table 7.5 Description of Spring 2015 lectures ....................................................... 146
Table 7.6. Average of class responses to first day and end-of-term surveys .......... 163
Table 7.7. Average of class responses to first day and end-of-term surveys .......... 165
Table 7.8 Comparison of self-efficacy responses in 2014 and 2015 ...................... 167
Table D.1. Compilation of concepts on CBE 2200 examinations administered by various faculty ........................................................................................................... 210
List of Figures

Figure 2.1. Summary of learning styles and associated teaching styles.................11
Figure 2.2. Sample of output received upon completion of ILS................................12
Figure 3.1. Student learning styles profiles in active/reflective dimension across four
semesters ..................................................................................................................50
Figure 3.2. Student learning styles profiles in sensing/intuitive dimension across four
semesters ..................................................................................................................50
Figure 3.3. Student learning styles profiles in visual/verbal dimension across four
semesters ..................................................................................................................51
Figure 3.4. Student learning styles profiles in sequential/global dimension across four
semesters ..................................................................................................................51
Figure 3.6. Comparison of the percent of students in the upper quartile of final grade,
lower quartile of final grade, and class totals with respect to sequential/global dimension
for Spring 2013 .......................................................................................................55
Figure 3.7. Comparison of the percent of students in the upper quartile of final grade,
lower quartile of final grade, and class totals with respect to sequential/global dimension
for Spring 2014 .......................................................................................................56
Figure 3.8. Comparison of the percent of students in the upper quartile of final grade,
lower quartile of final grade, and class totals with respect to sequential/global dimension
for Spring 2014, Faculty B .....................................................................................56
Figure 3.9. Faculty D’s unadjusted and adjusted (scaled) grades in Spring 2014
semester .................................................................................................................72
Figure 3.10. Occurrence of inherent bias in presentation on exam problems written by different faculty........................................................................................................73

Figure 3.11. Occurrence of inherent bias in solution on exam problems written by different faculty........................................................................................................73

Figure 3.12. Scores in Faculty D’s section of CBE 2200 on concept inventory (Spring 2015). ..................................................................................................................................................................................77

Figure 3.13. Scores in Faculty F’s section of CBE 2200 on concept inventory (Spring 2015). ..................................................................................................................................................................................77

Figure 3.14. Comparison of student performance on each concept inventory question between Faculty D and F’s section. ........................................................................................................................................................................78

Figure 3.15. Student answers for question 13, the question with statistically significant difference in scores between Faculty D and F. ........................................................................................................................................................................80

Figure 4.1. Timeline of study associated course activities in Maymester........................92

Figure 4.2. Timeline of study related course activities in regular semester....................93

Figure 4.3. Team categorization with respect to learning styles.. ................................94

Figure 4.4. Index of Learning Styles profile for Maymester 2013 unit operations class..95

Figure 5.1. Timeline for study-related events in CBE 4764........................................105

Figure 5.2. Class ILS profile for Spring 2015 senior design.........................................106

Figure 5.3. Responses to Item 14, “I have been able to recall the theory I learned in previous courses and apply it to the design,” for survey 1. ........................................113

Figure 5.4. Responses to Item 15, “I have had difficulty recalling the appropriate theory from previous courses that is needed to proceed with the design,” for survey 1. ........113

Figure 5.5. Student responses for Item 16, “I intend to pursue a career that deviates from chemical engineering,” on survey 1. .................................................................................................................115
Figure 5.6. Student responses to Item 16, “I intend to pursue a career that deviates from chemical engineering,” on survey 3.

Figure B.1. Number of students displaying the strength of each learning style dimension as determined by the ILS from the sum of two separate sections taught by Faculty A and B in Spring 2013 CBE 2200.

Figure B.2. Percentage of students displaying the strength of each learning style dimension as determined by the ILS from the compilation of two separate sections taught by Faculty A and B in Spring 2013 CBE 2200.

Figure B.3. Number of students displaying the strength of each learning style dimension as determined by the ILS from the sum of two separate sections taught by Faculty B and D in Spring 2014 CBE 2200.

Figure B.4. Percentage of students displaying the strength of each learning style dimension as determined by the ILS from the compilation of two separate sections taught by Faculty B and D in Spring 2014 CBE 2200.

Figure B.5. Number of students displaying the strength of each learning style dimension as determined by the ILS from the sum of two separate sections taught by Faculty C and E in Fall 2014 CBE 2200.

Figure B.6. Percentage of students displaying the strength of each learning style dimension as determined by the ILS from the compilation of two separate sections taught by Faculty C and E in Fall 2014 CBE 2200.

Figure B.7. Number of students displaying the strength of each learning style dimension as determined by the ILS from the sum of two separate sections taught by Faculty D and F in Spring 2015 CBE 2200.
Figure B.8. Percentage of students displaying the strength of each learning style
dimension as determined by the ILS from the compilation of two separate sections
taught by Faculty D and F in Spring 2015 CBE 2200. ......................................................189

Figure B.9. Number of students displaying the strength of each learning style dimension
as determined by the ILS from the section taught by Faculty A in Spring 2013 CBE 2200.
........................................................................................................................................190

Figure B.10. Percentage of students displaying the strength of each learning style
dimension as determined by the ILS from the section taught by Faculty A in Spring 2013
CBE 2200. ............................................................................................................................190

Figure B.11. Number of students displaying the strength of each learning style
dimension as determined by the ILS from the section taught by Faculty B in Spring 2013
CBE 2200. ............................................................................................................................191

Figure B.12. Number of students displaying the strength of each learning style
dimension as determined by the ILS from the section taught by Faculty B in Spring 2014
CBE 2200. ............................................................................................................................191

Figure B.13. Percentage of students displaying the strength of each learning style
dimension as determined by the ILS from the section taught by Faculty B in Spring 2013
CBE 2200. ............................................................................................................................192

Figure B.14. Percentage of students displaying the strength of each learning style
dimension as determined by the ILS from the section taught by Faculty B in Spring 2014
CBE 2200. ............................................................................................................................192

Figure B.15. Number of students displaying the strength of each learning style
dimension as determined by the ILS from the section taught by Faculty C in Fall 2014
CBE 2200. ............................................................................................................................193
Figure B.16. Percentage of students displaying the strength of each learning style dimension as determined by the ILS from the section taught by Faculty C in Fall 2014 CBE 2200. .................................................................................................................. 193

Figure B.17. Number of students displaying the strength of each learning style dimension as determined by the ILS from the section taught by Faculty D in Spring 2014 CBE 2200. .................................................................................................................. 194

Figure B.18. Number of students displaying the strength of each learning style dimension as determined by the ILS from the section taught by Faculty D in Spring 2015 CBE 2200. .................................................................................................................. 194

Figure B.19. Percentage of students displaying the strength of each learning style dimension as determined by the ILS from the section taught by Faculty D in Spring 2014 CBE 2200. .................................................................................................................. 195

Figure B.20. Percentage of students displaying the strength of each learning style dimension as determined by the ILS from the section taught by Faculty D in Spring 2015 CBE 2200. .................................................................................................................. 195

Figure B.21. Number of students displaying the strength of each learning style dimension as determined by the ILS from the section taught by Faculty E in Fall 2014 CBE 2200. .................................................................................................................. 196

Figure B.22. Percentage of students displaying the strength of each learning style dimension as determined by the ILS from the section taught by Faculty E in Fall 2014 CBE 2200. .................................................................................................................. 196

Figure B.23. Number of students displaying the strength of each learning style dimension as determined by the ILS from the section taught by Faculty F in Spring 2015 CBE 2200. .................................................................................................................. 197
Figure B.24. Percentage of students displaying the strength of each learning style
dimension as determined by the ILS from the section taught by Faculty F in Spring 2015
CBE 2200. ........................................................................................................... 197

Figure C.1. Number of students whose final grade fell within each range from the section
taught by Faculty A in Spring 2013 CBE 2200. ....................................................... 198
Figure C.2. Number of students whose final grade fell within each range from the section
taught by Faculty B in Spring 2013 CBE 2200. ....................................................... 199
Figure C.3. Number of students whose final grade fell within each range from the section
taught by Faculty B in Spring 2014 CBE 2200. ....................................................... 199
Figure C.4. Number of students whose final grade fell within each range from the section
taught by Faculty C in Fall 2013 CBE 2200. .......................................................... 200
Figure C.5. Number of students whose final grade fell within each range from the section
taught by Faculty C in Fall 2014 CBE 2200. .......................................................... 200
Figure C.6. Number of students whose final grade fell within each range from the section
taught by Faculty D in Spring 2014 CBE 2200 (histogram displays grades that are
unadjusted). ........................................................................................................... 201
Figure C.7. Number of students whose final grade fell within each range from the section
taught by Faculty D in Spring 2014 CBE 2200 (histogram displays grades after they
were adjusted by the faculty member). ................................................................. 201
Figure C.8. This is the same as Figure C.7, with the x-axis now displaying a different
range. ...................................................................................................................... 202
Figure C.9. Number of students whose final grade fell within each range from the section
taught by Faculty D in Spring 2015 CBE 2200 (histogram displays grades that are
unadjusted). ........................................................................................................... 203
Figure C.10. Number of students whose final grade fell within each range from the section taught by Faculty D in Spring 2015 CBE 2200 (histogram displays grades after they were adjusted by the faculty member). ................................................................. 203

Figure C.11. This is the same as Figure C.10, with the x-axis now displaying a different range. ........................................................................................................................................... 204

Figure C.12. Number of students whose final grade fell within each range from the section taught by Faculty E in Fall 2014 CBE 2200. .................................................................................. 204

Figure C.13. Number of students whose final grade fell within each range from the section taught by Faculty F in Spring 2015 CBE 2200. .................................................................................. 205

Figure D.1. Inherent biases observed on exam problems administered by Faculty B during Spring 2014 CBE 2200. ........................................................................................................ 206

Figure D.2. Inherent biases observed on exam problems administered by Faculty C during Fall 2014 CBE 2200. ........................................................................................................ 207

Figure D.3. Inherent biases observed on exam problems administered by Faculty D during Spring 2014 CBE 2200. ........................................................................................................ 207

Figure D.4. Inherent biases observed on exam problems administered by Faculty D during Spring 2015 CBE 2200. ........................................................................................................ 208

Figure D.5. Inherent biases observed on exam problems administered by Faculty E during Fall 2014 CBE 2200. ........................................................................................................ 208

Figure D.6. Inherent biases observed on exam problems administered by Faculty F during Spring 2015 CBE 2200. ........................................................................................................ 209

Figure E.1. Percent of student respondents that selected each possible answer for Question #1 on the concept inventory administered in the sections taught by Faculty D
and F at the end of Spring 2015 CBE 2200. The bottom panel shows each of the possible answers with the correct answer shaded gray.

Figure E.2. Percent of student respondents that selected each possible answer for Question #2 on the concept inventory administered in the sections taught by Faculty D and F at the end of Spring 2015 CBE 2200. The bottom panel shows each of the possible answers with the correct answer shaded gray.

Figure E.3. Percent of student respondents that selected each possible answer for Question #3 on the concept inventory administered in the sections taught by Faculty D and F at the end of Spring 2015 CBE 2200. The bottom panel shows each of the possible answers with the correct answer shaded gray.

Figure E.4. Percent of student respondents that selected each possible answer for Question #4 on the concept inventory administered in the sections taught by Faculty D and F at the end of Spring 2015 CBE 2200. The bottom panel shows each of the possible answers with the correct answer shaded gray.

Figure E.5. Percent of student respondents that selected each possible answer for Question #5 on the concept inventory administered in the sections taught by Faculty D and F at the end of Spring 2015 CBE 2200. The bottom panel shows each of the possible answers with the correct answer shaded gray.

Figure E.6. Percent of student respondents that selected each possible answer for Question #6 on the concept inventory administered in the sections taught by Faculty D and F at the end of Spring 2015 CBE 2200. The bottom panel shows each of the possible answers with the correct answer shaded gray.

Figure E.7. Percent of student respondents that selected each possible answer for Question #7 on the concept inventory administered in the sections taught by Faculty D
and F at the end of Spring 2015 CBE 2200. The bottom panel shows each of the possible answers with the correct answer shaded gray.

Figure E.8. Percent of student respondents that selected each possible answer for Question #8 on the concept inventory administered in the sections taught by Faculty D and F at the end of Spring 2015 CBE 2200. The bottom panel shows each of the possible answers with the correct answer shaded gray.

Figure E.9. Percent of student respondents that selected each possible answer for Question #9 on the concept inventory administered in the sections taught by Faculty D and F at the end of Spring 2015 CBE 2200. The bottom panel shows each of the possible answers with the correct answer shaded gray.

Figure E.10. Percent of student respondents that selected each possible answer for Question #10 on the concept inventory administered in the sections taught by Faculty D and F at the end of Spring 2015 CBE 2200. The bottom panel shows each of the possible answers with the correct answer shaded gray.

Figure E.11. Percent of student respondents that selected each possible answer for Question #11 on the concept inventory administered in the sections taught by Faculty D and F at the end of Spring 2015 CBE 2200. The bottom panel shows each of the possible answers with the correct answer shaded gray.

Figure E.12. Percent of student respondents that selected each possible answer for Question #12 on the concept inventory administered in the sections taught by Faculty D and F at the end of Spring 2015 CBE 2200. The bottom panel shows each of the possible answers with the correct answer shaded gray.

Figure E.13. Percent of student respondents that selected each possible answer for Question #13 on the concept inventory administered in the sections taught by Faculty D
and F at the end of Spring 2015 CBE 2200. The bottom panel shows each of the possible answers with the correct answer shaded gray.

Figure E.14. Percent of student respondents that selected each possible answer for Question #14 on the concept inventory administered in the sections taught by Faculty D and F at the end of Spring 2015 CBE 2200. The bottom panel shows each of the possible answers with the correct answer shaded gray.

Figure E.15. Percent of student respondents that selected each possible answer for Question #15 on the concept inventory administered in the sections taught by Faculty D and F at the end of Spring 2015 CBE 2200. The bottom panel shows each of the possible answers with the correct answer shaded gray.

Figure E.16. Percent of student respondents that selected each possible answer for Question #16 on the concept inventory administered in the sections taught by Faculty D and F at the end of Spring 2015 CBE 2200. The bottom panel shows each of the possible answers with the correct answer shaded gray.

Figure E.17. Percent of student respondents that selected each possible answer for Question #17 on the concept inventory administered in the sections taught by Faculty D and F at the end of Spring 2015 CBE 2200. The bottom panel shows each of the possible answers with the correct answer shaded gray.

Figure E.18. Percent of student respondents that selected each possible answer for Question #18 on the concept inventory administered in the sections taught by Faculty D and F at the end of Spring 2015 CBE 2200. The bottom panel shows each of the possible answers with the correct answer shaded gray.

Figure E.19. Percent of student respondents that selected each possible answer for Question #19 on the concept inventory administered in the sections taught by Faculty D
and F at the end of Spring 2015 CBE 2200. The bottom panel shows each of the possible answers with the correct answer shaded gray.

Figure E.20. Percent of student respondents that selected each possible answer for Question #20 on the concept inventory administered in the sections taught by Faculty D and F at the end of Spring 2015 CBE 2200. The bottom panel shows each of the possible answers with the correct answer shaded gray.

Figure H.1. Responses for Question 10 found on the general perceptions survey administered throughout the Spring 2015 term.

Figure H.2. Responses for Question 11 found on the general perceptions survey administered early in the Spring 2015 term.

Figure H.3. Responses for Question 12 found on the general perceptions survey administered early in the Spring 2015 term.

Figure H.4. Responses for Question 13 found on the general perceptions survey administered early and late in the Spring 2015 term.

Figure H.5. (left panel) Team scores for Final Report in ascending order. (right panel) Teams scores in order of descending standard deviation. Teams with reported dynamic problems are highlighted in gray.

Figure H.6. (left panel) Team scores for Final Presentation in ascending order. (right panel) Teams scores in order of descending standard deviation. Teams with reported dynamic problems are highlighted in gray.

Figure H.7. (left panel) Team scores for Project 3 (team-based) in ascending order. (right panel) Teams scores in order of descending standard deviation. Teams with reported dynamic problems are highlighted in gray.
Figure H.8. (left panel) Team scores for Final Grade in ascending order. (right panel) Teams scores in order of descending standard deviation. Teams with reported dynamic problems are highlighted in gray.

Figure H.9. Map of change in responses between Surveys 1 and 2 (bottom), and Surveys 2 and 3 (top). Responses to left of bolded vertical line are from students on teams reporting dynamics problems. Gray cells represent items where a decrease in self-efficacy, a negative change in perception, or an increase in anxiety was seen, whereas a white cell indicates either no change or a positive change.
Chapter 1 : Preface

“One’s philosophy is not best expressed in words; it is expressed in the choices
one makes…”

—Eleanor Roosevelt

Getting Started: Discovering My Research Passions

My B.S. in chemical engineering with a genetics minor initially drew me to pursue
a Ph.D. in the lab of Dr. David Wood at The Ohio State University, where I began
developing bacterial biosensors for identification of potential insecticides against disease
hosts. I became a Howard Hughes Medical Institute (HHMI) MED-into-GRAD fellow,
which allowed me to further experience the applications of my research in infectious
disease through clinical shadowing and medical school coursework. In my
undergraduate career I had discovered a passion for education through my work
developing K-12 Science, Technology, Engineering, and Mathematics (STEM) programs
in an organization known as Minds of Tomorrow. In graduate school, I continued
following my passion by leading K-12 STEM outreach initiatives, my work with the
University Center for Advancement in Teaching (UCAT), being an instructional assistant
for a graduate level technical research communication course, and
creating/designing/teaching an undergraduate level technical communication course.
Following this variety of experiences in the fields of chemical engineering, genetics,
medicine, and education, my career path has led me into chemical engineering education research.

My interest in education kept me engaged in my own pedagogical research as a hobby while studying bacterial biosensors in Dr. Wood’s research group. My initial meta-analysis work-in-progress regarding the impact of technology on teaching methods and student learning, motivated by my observations of process modeling software misuse in my undergraduate years, received attention at the Frontiers in Education 2011 conference. About six months after this conference, my advisor also took notice of my interest in pedagogy and approached me about the educational component of his CAREER grant that he had not fulfilled, which involved studying chemical engineering student learning styles and the effects on team dynamics and success.

I was excited by the opportunity to pursue educational work with the support of my chemical engineering advisor, who up until my research had not conducted any educational research. His original prompt of learning styles and teamwork grew into three separate projects aiming to understand our undergraduate chemical engineering student population and the nature of the courses we offer. Because this work is so different from my advisor’s primary area of research, I was given full liberty in and responsibility for developing the projects from initial hypotheses through the research plan, study execution, protocol writing and amendments, unexpected outcomes, study improvements, and data analysis.

**With Opportunity, Comes Choice: Deciding My Research Area**

As my plan for the education research projects became more thoroughly developed, I was presented with a choice between continuing my laboratory work in
biosensor development or the pedagogical research. Being an independently funded student through the National Science Foundation Graduate Research Fellowship Program (NSF GRFP), I had the flexibility of choosing my own research path not afforded to many graduate students, and the desire for that flexibility is what had prompted me to apply for the GRFP originally. While I believe in the value of and still hold a deep interest in my previous work in genetic and protein engineering, I saw an opportunity to pursue work that not only aligned with my passions but also addressed a need within, and had the potential to make a direct impact on, my home department. After several terms of balancing both research areas, I chose to focus full-time on pedagogical research.
Chapter 2: Introduction and Background

Introduction

From an early age, children are informally categorized by their approach to learning. Terms like “tinkerer” and “daydreamer,” and descriptions like “he jumps right in without heeding my directions” or “he follows what I say, step by step” are commonly used to describe children by those working with them. In educational theory, these descriptors refer to learning styles—a method of identifying an individual’s learning process preferences. There is little disagreement that these preferences exist; however, there is disagreement regarding the value of learning styles theories as an educational tool, both for developing greater student self-awareness and better curricula, and ultimately for providing our students with necessary tools as they embark on their careers.1-5

The factors that influence (or may influence) student success are seemingly endless. Race,6 gender,6 high school GPA,7 motivation,8 stress,9 commitment to discipline,10 perceived difficulty of subject,11 and even the location a student chooses to sit in the classroom12 may have an effect on student course outcomes. As educators, we are interested in better understanding the factors for student success within our discipline and department, and ensuring we provide all of our students with the necessary means to achieve success.
Engineers (chemical or otherwise) are often described as problem solvers. A key component of problem solving is the ability to successfully retrieve and process data in a variety of ways. We believe that understanding undergraduate student learning styles in our department, Chemical and Biomolecular Engineering (CBE) at The Ohio State University (OSU), will provide insight into our student population and their needs, and opportunities for developing a more robust program. Our curriculum should develop versatile problem solvers\textsuperscript{13} (and support innovative thinking\textsuperscript{14}) by exposing students to tasks that engage a variety of learning styles.

Unique disciplinary demands often result in favoritism towards or development of specific learning styles.\textsuperscript{15} However, because of the broad applicability of engineering, we find it especially important to ensure that our students are comfortable with all learning styles. We believe that learning styles may impact student success, perceptions, and self-efficacy (self-belief in capability), and that this correlation will best be observed at the beginning of their program (in the first discipline-specific course). Furthermore, because engineering is a highly team-oriented field, we also consider it important to understand how learning styles may influence team dynamics of senior students. These students are of additional interest as they will soon graduate and enter the professional world as representatives of chemical engineering at Ohio State.

Thus, we have conducted three studies of our undergraduate students: one at the individual level, one at the team level, and one incorporating both individual and team components. For the individual level study, we are interested in exploring the correlation between learning styles, self-efficacy, and student performance in the context of an introductory chemical engineering course (CBE 2200, Process Fundamentals). At the team level, we are interested in exploring the correlation between learning styles,
collective efficacy (team counterpart to self-efficacy), and team performance in the context of a upper-level team-based laboratory course (CBE 4630, Unit Operations). For the combinatorial study, we are interested in understanding the relationship between learning styles, self-efficacy, team dynamics, and performance in the context of a senior design course that involves both individual and team projects (CBE 4764, Process Design and Development). We believe these three studies help identify our student populations with respect to learning styles, both as they enter and leave our program, and evaluate the potential need for incorporating different teaching techniques to develop more versatile problem solvers and team members.

To our knowledge there has not been an integrated study on the correlation between learning style preferences, self-efficacy, and performance with chemical engineering undergraduates. Since we are trying to understand student learning and problem solving processes, a traditional chemical engineering background is required in order to analyze the tasks students are performing and identify toward what learning styles these tasks may be biased. Additionally, as our department does not traditionally conduct any substantial educational research, we also believe this is a unique situation where education can be studied in a traditionally research-oriented department. With the increasing support for scientific research in education and the urgency in developing higher performing engineers, we hope that this work marks the beginning of continued engagement in education research by our department.

**Background**

Every discipline has unique demands. Where some may require a great degree of collaboration, others may involve more solitary work. Some may rely on words, while others rely on visuals. Generally, these unique demands result in disciplines that
naturally attract individuals with certain characteristics that are favorable for work in that field. One way to categorize the characteristics of individuals is learning styles, which describe individual preferences for gathering, processing, and understanding information.\textsuperscript{19} Currently, there are at least 71 reported learning style schemes,\textsuperscript{2,3} some with subsequent instruments for determining an individual’s learning style.\textsuperscript{1,2}

While the study of learning styles offers a potential tool for better understanding student populations and developing more robust curricula, researchers disagree amongst themselves about how learning styles should be used, if at all. Some argue that research to date offers little evidence that learning styles have a significant impact on educational outcomes,\textsuperscript{1,2} while others acknowledge the benefits that may be gained from learning styles but remain aware of the lack of consensus among researchers.\textsuperscript{3,4} Critics and supporters alike agree that it is important to realize the limitations of the learning style models and ensure they are used appropriately.\textsuperscript{1,3,4,20}

As educational researchers in academia continue to promote their preferred learning style model(s), mainstream educational resources (outside of academia) have also developed their own. Browsing the internet reveals many online sources for curious individuals to identify their personal learning style. Among these are “The Seven Learning Styles” of Learning Styles Online\textsuperscript{21} and the learning styles model promoted by Edutopia.\textsuperscript{22} The availability of these mainstream resources signifies the growing interest in learning styles as an educational, personal, and professional development tool.

One of the more common learning styles models for academic educational research is the Kolb model. Based on how they perceive and process information, learners are divided into four categories: accommodators, divergers, convergers, and assimilators.\textsuperscript{19,23} The associated Kolb Learning Styles Inventory is used to identify
individual learning styles, however, it is not designed to be discipline-specific but rather for broad use in both STEM and non-STEM fields.\textsuperscript{24}

The Myers-Briggs Personality Type Indicator (MBTI)\textsuperscript{25} is also often used in education work on learning styles\textsuperscript{3,4,26} despite being intended to identify personality types. The MBTI consists of four dimensions of personality with two opposing preferences in each dimension. These are: extroversion/introversion, sensing/intuitive, thinking/feeling, and judging/perceiving. An individual “personality type” is composed of a dominant preference from each dimension. This provides 16 possible ($2^4$) personality types, though they are often considered one dimension at a time in research.

Among the 71 recognized models is another popular one, the Felder-Silverman model, which was specifically developed for use in engineering education.\textsuperscript{27} Felder, a chemical engineer, and Silverman, a psychologist, present a multi-dimensional model (a parallel structure to the MBTI) for learning styles that offers greater distinction between individual preferences. The Felder-Silverman model provides extensive differentiation among learning styles (described in detail in the next section). Despite being intended for engineering, the Felder-Silverman model and the associated Felder-Soloman Index of Learning Styles (ILS) have also been utilized in numerous scientific fields ranging from engineering and computer sciences to internal medicine\textsuperscript{20,28,29} and has been recommended for its validity and reliability.\textsuperscript{20,30,31} For these reasons, we are using the Felder-Silverman model for the proposed studies.

\textbf{Felder-Silverman Model of Learning Styles}

Felder and Silverman published their model learning and teaching styles in 1988.\textsuperscript{27} For our study, we were initially only interested in learning styles. The Felder-Silverman model identifies four dimensions of learning styles: active/reflective,
sensing/intuitive, visual/verbal, and sequential/global. These dimensions can be summarized as follows:

*Active vs. Reflective*

As the words suggest, active learners prefer actively engaging the material (“active experimentation”) and reflective learners prefer to think about the material (“reflective observation”) when presented with a new topic. Active learners are generally thought to favor working in groups, while reflective learners would rather work individually.

*Sensing vs. Intuitive*

This dimension directly correlates with the MBTI\textsuperscript{25} Sensing vs. Intuitive dimension of personality types. Learners with a preference towards sensing favor facts and generally like concrete, numerical, and practical problems over theoretical concepts. Intuitors, on the other hand, prefer to consider the possible outcomes or results and more abstract relationships rather than concrete facts.

*Visual vs. Verbal (Auditory)*

This dimension describes how students prefer to receive their information. Visual learners naturally gravitate toward diagrams, graphs, and cartoons, whereas verbal/auditory learners prefer words (written or oral).

*Sequential vs. Global*

Sequential/global is a dimension that describes how students view material in the context of the larger picture. Sequential learners prefer calculated steps and are able to focus on and follow details without needing to grasp the big picture. Global learners, on the other hand, tend to learn in a less stepwise fashion and need to comprehend the big picture before they can focus on the details and see where those details fit.
Table 2.1. Description of dimensions and learning styles preferences in the Felder-Silverman model.

| Learning Dimension | Preference | Description (preference for…)
<table>
<thead>
<tr>
<th></th>
<th></th>
<th></th>
</tr>
</thead>
<tbody>
<tr>
<td>Processing</td>
<td>Active</td>
<td>Trying things out to learn new material</td>
</tr>
<tr>
<td></td>
<td>Reflective</td>
<td>Thinking about new material before trying something</td>
</tr>
<tr>
<td>Perceiving</td>
<td>Sensing</td>
<td>Concrete, numerical, factual information</td>
</tr>
<tr>
<td></td>
<td>Intuitive</td>
<td>Abstract, conceptual, theoretical information</td>
</tr>
<tr>
<td>Receiving</td>
<td>Visual</td>
<td>Graphs, diagrams, pictures, and other visuals</td>
</tr>
<tr>
<td></td>
<td>Verbal</td>
<td>Words, spoken or written</td>
</tr>
<tr>
<td>Understanding</td>
<td>Sequential</td>
<td>Linear thought process</td>
</tr>
<tr>
<td></td>
<td>Global</td>
<td>Non-linear, may jump around and learn in “fits and starts”</td>
</tr>
</tbody>
</table>

**Teaching Styles**

Although studying the teaching styles of department faculty was not an original objective of our studies, results from Spring 2014 exposed significant differences in raw student grades (i.e., grades before any scale was imposed) between sections of the same course taught by different instructors and highlighted strong variation in the types of exam questions developed. These observations led to a greater interest in exploring teaching styles.

To accompany their model of learning styles, Felder and Silverman also developed a parallel model of teaching styles summarized in Figure 2.1. Felder-Silverman’s teaching styles are meant to offer a means for instructors to categorize their techniques, as well as suggestions on how to address each learning style. Again, learning styles are preferences not absolutes, and we do not believe that students should be taught to their particular learning style. Rather, we argue that challenging
students to engage in as many learning styles as possible, by exposing them to a variety of teaching styles, is ideal in developing the most versatile problem solvers.

Index of Learning Styles

The ILS is a 44-question survey designed to identify student learning preferences in the four dimensions of the Felder-Silverman model. Each dimension is represented by 11 dichotomous forced-choice questions. Answers are scored on a scale from -11 to +11 within each dimension, where positive and negative integers correspond to the opposing preferences. A score with an absolute value between 1 and 3 is considered “balanced,” 5 to 7 a “moderate” preference, and 9 to 11 a “strong” preference. The model does not differentiate between balanced on one end of the spectrum (e.g., a score of 3 on the active side) and balanced on the other (e.g., a score of 3 on the reflective end of the scale). These preferences are considered equivalent, and balanced learners are thought to be able to utilize both preferences within a dimension. Assignment of the positive vs. negative scale within each dimension is arbitrary; active, sensing, visual, and sequential are conventionally considered positive. ILS results are
outputted in the form of a scale running the spectrum of strong preference A to strong preference B within a dimension, where “x marks the spot” for the reported preference. Figure 2.2 shows an example of output generated when the ILS is taken. The ILS is publicly available, hosted on North Carolina State University’s website.\(^{32}\)

<table>
<thead>
<tr>
<th>Results for: Example Learner</th>
<th></th>
</tr>
</thead>
<tbody>
<tr>
<td>x</td>
<td>Reflective</td>
</tr>
<tr>
<td>Active</td>
<td>x</td>
</tr>
<tr>
<td>11 9 7 5 3</td>
<td>1 1 3 5 7 9 11</td>
</tr>
</tbody>
</table>

| Sensing     |          |
| x          | Intuitive |
| 11 9 7 5 3 | 1 1 3 5 7 9 11 |

| Visual      |          |
| x          | Verbal   |
| 11 9 7 5 3 | 1 1 3 5 7 9 11 |

| Sequential  |          |
| x          | Global   |
| 11 9 7 5 3 | 1 1 3 5 7 9 11 |

Figure 2.2. Sample of output received upon completion of ILS. Example Learner shows a balanced active / reflective preference (indicated by score of 1 for active), a moderate intuitive preference (score of 7), a balanced visual/verbal preference (score of 3 for verbal), and a moderate global preference (score of 7).

ILS reliability and validity studies have shown strong student agreement with results.\(^{20,31,33}\) This is measured by comparing students’ self-reported learning style preferences with ILS results as well as ensuring consistency of ILS results from repeated assessment over a short (several month) period.\(^{20}\) A recent study compared three
learning styles instruments for reliability and validity, and recommends the Felder-Soloman ILS for assessing learning style preferences.30

The dominant learning style preferences of undergraduate engineering student populations as determined by the ILS are reported as active, sensing, visual, and sequential.20 This is reported by a study compiling data from ten institutions over multiple years.20 Faculty learning styles preferences, on the other hand, tend towards reflective, intuitive, visual, and global.20 While for our studies we are not interested in assessing faculty learning styles (and their potential association with the faculty’s preferred teaching styles), or how a potential mismatch might affect student learning, learning style preferences are considered fluid traits that can be influenced by educational experience.20 For this reason, it is thought that learning style preferences become more uniform among the students (and more similar to faculty teaching styles) as they progress through their undergraduate careers. This should be considered when evaluating a study population, as it suggests that students with fewer shared educational experiences (i.e., freshman and sophomores in a program) will have a greater variety of learning styles preferences among the population than those with more shared education experiences (i.e., juniors and seniors in a program).

Learning Styles and Student Performance

Learning styles are emphasized as being student preferences for how they receive, perceive, process, and understand information.27 They are not intended to suggest suitable career paths nor predict performance.20 Rather, learning style preferences are a tool to better understand the student population’s educational needs, and for providing guidance in developing personally beneficial study habits.34 This line of thought has not, however, prevented a few researchers from exploring whether or not
student performance can be dependent on matching question type to learning style. In a study by Cook et al., 89 medical residents and students were administered a web-based learning module. Some were presented with questions that matched their learning style, while others were presented questions intentionally designed to be a mismatch.

No statistical significance was found in student performance regardless of whether their questions matched or mismatched their learning style, but small sample size and the inherently high inclination of the sample population to succeed regardless of circumstances may have been contributing factors to this lack of correlation. Since preferences can be influenced by education, the students’ advanced point in their educations may have also played a contributing role. In a different investigation using the Kolb Learning Style Instrument, Kaminski et al. reported significantly higher grades among students of the more dominant (higher frequency) learning style preference in the population compared to students of non-dominant style preferences. Further work is needed to better understand the potential correlation between learning styles and individual student performance.

Learning Styles and Teamwork

While individual performance is important for undergraduate success, strong team skills are also a critical component of professional development since engineering is a highly team-oriented field. Teamwork is emphasized in high-level engineering courses to help further prepare students for the career their degree entails. In the educational setting, careful team selection by instructors is recommended, with teams of 3-to-5 considered the ideal size. When left to themselves, students tend to form groups that are homogenous with respect to several indicators, including personality and learning style. While homogeneous groups may occasionally be preferred for specific
tasks, heterogeneous groups have demonstrated better performance over a broader range of tasks. Qualitative data from interviews and quantitative data from Likert-type scale (measuring degree of agreement) surveys suggest that students also grasp the value of a heterogeneous group and that, despite some difficulties (such as communication) because of clashing styles, students are able to recognize the benefits of such diversity.

Student Perceptions of Capability

Self-Efficacy

Self-efficacy refers to an individual’s judgment of their own ability or competence. Higher self-efficacy indicates a greater belief in personal ability; however, perception varies as a result of a number of factors, including the nature of the specific task at hand and the immediate physiological state of the individual. Self-efficacy is not to be confused with metacognition, which is the term used for an individual’s knowledge about what they know. High metacognition indicates an accurate judgment of one’s own knowledge, while low metacognition indicates an inaccurate judgment of the extent of one’s own knowledge. Self-efficacy is a belief in ability and limitations (“I think I can” or “I think I know”), whereas metacognition is an accurate knowledge of ability and limitations (“I know I can” or “I know I know”). Both metacognition and self-efficacy are important in student cognitive development, and while our focus is on self-efficacy, metacognition is also evaluated (as a natural consequence) to some extent through our studies.

Modern self-efficacy work is still based on theory developed by Bandura. Bandura describes four factors that contribute to self-efficacy: mastery experiences, vicarious experiences, verbal/social persuasions, and physiological states. In short,
these factors represent how things such as experience, support, and mood can influence self-efficacy. Self-efficacy determines an individual’s resilience and persistence when faced with new challenges.\textsuperscript{42,43} Individuals with low self-efficacy are more likely to give up when presented with new difficulties or after experiencing failure.\textsuperscript{42-44} In the engineering world, high self-efficacy has been linked to greater critical thinking skills in first-year mechanical engineering students in the context of a multidisciplinary design course.\textsuperscript{45} Self-efficacy is an important contributor to cognitive development; fostering high self-efficacy among students should be a concern for educators across all disciplines, including engineering.\textsuperscript{46}

**Collective Efficacy**

Collective efficacy refers to a group or team’s belief in its combined capabilities.\textsuperscript{39} Whereas self-efficacy refers to the individual belief in personal ability, collective efficacy refers to the individual or team’s belief in the team’s ability when working together.\textsuperscript{39} Collective efficacy has demonstrated positive correlation with team cohesion among undergraduate engineering students in the context of an introductory design-based course.\textsuperscript{47} It has also shown positive correlations with self-evaluations of team performance and instructor evaluations of student performance.\textsuperscript{47} It is interesting to note that in a study by Lent et al., instructor evaluation of team performance was not through quantitative grades but rather by a survey to the team on team performance (performed on a three point scale).\textsuperscript{47} Investigating collective efficacy responses with a more quantitative representation of performance (i.e., grades), as well as team composition with respect to learning styles, will provide a foundation for ensuring the development of engineering students who are successful team members.
Instruments for Measuring Self and Collective Efficacy

Self-efficacy and collective efficacy instruments have been developed and used by previous engineering researchers.47,48 These instruments, developed following guidelines established by Bandura,49 have focused more on evaluating general student confidence as opposed to specific task-related confidence. For example, a collective efficacy item from Lent et al. states, “[Group members] communicate well with one another despite differences in cultural background.”47 A self-efficacy instrument developed by Carberry et al. asks students to rate confidence in their ability on items such as “conduct engineering design” and “identify a design need.”48 Instruments must consider three forms of validity—content, criterion-related, and construct—to ensure that they appropriately measure the intended subject (referred to in the literature as “domain”).50 Self-efficacy and collective efficacy instruments provide a means for quantitative evaluation of these traits.

Proposed Work and Objectives

To our knowledge there has not been an integrated study on the correlation between learning style preferences, self-efficacy, and performance with chemical engineering undergraduates. Despite Felder’s (of the Felder-Silverman model) association with chemical engineering, learning styles have received limited direct attention in this field.14,51,52

Summary of Work

We are interested in correlations between learning style preferences and self/collective efficacy, perceptions (a broad term for student attitudes, reactions, etc.), and performance at the individual and team levels in traditional chemical engineering
classroom settings. For investigation at the individual level, we have studied a traditional lecture-based introductory chemical engineering course (CBE 2200, Process Fundamentals). This classroom setting is representative of how most courses are taught in our department, as well as extensively throughout engineering education. This offers a distinctly different educational scenario from the design-based engineering courses considered in the literature.\textsuperscript{45,47,48} For the investigation at the team-level, our sample population consists of students in the upper-level laboratory course in our program (CBE 4630, Unit Operations). This course includes the best representation of real-world chemical engineering processes and the teamwork that is characteristic of the field. In our third study, we strive to bring these two studies together in a combinatorial study at the individual and team levels in a senior-design course (CBE 4764, Process Design and Development), also highly representative of real-world chemical engineering teams.

We have developed our own instruments to evaluate student attitudes/perceptions along with self-efficacy and collective efficacy. These instruments (referred to as surveys in subsequent sections pertaining to our studies) are a combination of the general confidence items seen in previous work as well as items related to very specific individual tasks. At the individual level we aim to understand self-efficacy on tasks that demonstrate bias with respect to each of the Felder-Silverman learning style dimensions, as well as student approaches and perceptions of these tasks. At the team level, we aim to understand student evaluations of collective efficacy on laboratory assignments, whether a correlation with learning styles exists, and track what changes may occur in collective efficacy as the teams continue to work together on subsequent tasks. In the combinatorial study, we use an abbreviated version of the Carberry et al. instrument for engineering design self-efficacy, as well as team...
evaluations, to better understand correlations between team dynamics and changes in self-efficacy. The designed instruments are to aid in our understanding of the student population. At this stage of the research, demonstrating the validity and reliability of the instruments is not a focus of this work.

We analyze data that comes in the form of ILS results, student grades, and survey responses for correlations between these factors of interest. Furthermore, at the individual level we have examined how variability in course instructor/teaching style may influence student performance and class experience.

Objectives of Research

We believe studies performed by other research groups have several drawbacks. Many studies with learning styles focus on models that are simpler than the Felder-Silverman model, and may not capture the intricacies of learning styles. We believe that the Felder-Silverman model will provide a more robust analysis and better identification of specific learning style preferences that may contribute to self-efficacy and/or performance. Furthermore, previous work relies on end-of-term surveys for self-efficacy, gathering only data at one time point for the students. By gathering data throughout the course, we hope to gain a more complete understanding of the relationship between self-efficacy and performance.

We strive to better understand the relationship between learning styles, self/collective efficacy, perceptions, and performance in individual and group tasks among undergraduate students enrolled in CBE at OSU. As with any engineering program, we aim to provide students with the knowledge, tools, and skills that will mold them into successful professional engineers. Findings from our work will allow us to better understand students, both at the individual and team level, and the integration of the two.
With these understandings we can more critically examine our existing curriculum and support the improvement of our program in a fashion that is most beneficial to student learning and student development as chemical engineers.

**Studying the Individual**

This work strives to establish if the existence of differences in learning styles can be observed, identified, and quantified through analysis of student performance on tasks inherently biased toward specific styles, and whether these learning style preferences correlate with individual student performance and perception/self-efficacy in the context of an introductory chemical engineering course (CBE 2200, Process Fundamentals). When discussing perceptions, we refer to student attitudes towards problems or course material as well as preferences and problem-solving approaches. Our hypothesis is that assignment biases for specific learning styles dimensions (which naturally occur in coursework) will result in a significant difference in student performance and self-efficacy, and students whose learning style matches the assignment with respect to that dimension will demonstrate better performance and greater self-efficacy.

Additionally, we are interested in the effects of variability in teaching and evaluation styles on student performance. Specifically, we seek to understand whether variations in exam problem types, with respect to inherent learning style biases and conceptual content, may correlate to the differences in student performance observed between sections taught by different instructors. Our hypothesis is that there will be variation in student performance, and that students will perform best in classes with highly sequential and sensing problems, and fewer concepts covered on each exam.
**Studying the Team**

We are looking for correlations between diversity of learning styles within a team, individual evaluation of collective efficacy and team dynamics from surveys and peer evaluations, and group performance through the analysis of groups performing chemical engineering unit operation laboratory tasks (in the class CBE 4630, Unit Operations Laboratory). Our hypothesis is that teams composed of students of differing learning styles (i.e., heterogeneous teams) will initially have more difficulty working together, as reflected in survey results, but will ultimately perform better than more homogenous teams.

**Combinatorial Study of the Individual and Team**

The combinatorial study of the individual and the team will focus on some of the aspects of the separate aforementioned studies, but with an added component of comparing the students in both individual and team settings. We are interested in not only student self-efficacy on their individual projects, but also if (and how) their self-efficacy is influenced by their team experiences in the context of senior design (CBE 4764, Process Design and Development). We hypothesize that positive team experiences (reflected by positive reports on team dynamics) will result in higher self-efficacy, and negative team experiences will result in lower self-efficacy. We further hypothesize that students of heterogeneous team composition with respect to learning styles will report lower team dynamics and performance earlier on, but demonstrate higher performance and report higher self-efficacy at the end of the term.
Research Plan

The three studies are designed to test the presented hypotheses, and each is customized for the hypothesis in question and the course structure. In each case, the data collected include student learning style preferences (i.e., ILS results), student grades, and survey results.

All studies are correlational, using surveys as a means of data acquisition. The studies contain both qualitative and quantitative components, since we are examining student performance as reflected by grades and student feedback through surveys. Survey questions include those on a Likert scale, multiple choice questions, and open response questions. We chose a five-point Likert scale, as opposed to the 100 point scale used by Carberry et al., to avoid overwhelming students with a large response scale. To ensure the validity of all survey responses analyzed, the survey includes repeated questions restated for both affirmative and negative responses. Thus, a student who answers affirmative or negative to both conflicting questions (i.e., “I am confident in my solution” and “I am uncertain of my solution”) is likely guilty of completing the survey without paying proper attention to the questions. These responses are omitted from the data used in analysis.

As the study coordinator, my contact with the participating classes was limited to introducing the study, collecting consent forms, informing students when a survey was available, and answering potential participant questions regarding the study. I had no involvement in grading or teaching. This avoids any bias that may otherwise arise from administering assignments, assistance, or grading with knowledge of learning styles. Furthermore, the course graders and instructors have no knowledge of which students have consented to participate and which have declined.
Introduction to Design and Methods

While detailed procedures for each study are provided within the respective chapter, overarching design considerations are addressed here.

Study Design and Threats to Validity

There are three key components to experimental design: randomization, replication, and blocking. Randomization allows the minimization of uncontrollable and unknown nuisance variables, replication provides an estimate of the random error of the experiments, and blocking minimizes the effects of controllable nuisance variables. By nature and for ethical reasons, behavioral studies with human subjects do not allow for the same degree of control as conventional chemical engineering experiments. This makes them a unique experimental design challenge.

It is also important to note that the research described in this dissertation is observational in nature, rather than experimental. That is, no interventions are introduced to the courses in question, rather they are evaluated in their natural state in an effort to better understand the current status of these courses. Recommendations for future studies and suggestions for potential interventions that may lead to educational gains based on literature and our studies’ results are provided in Chapter 6.

Because we are not introducing an intervention, randomization in this work is not conducted in the traditional experimental sense. Rather, our primary concern is proper selection of our population and having a representative sample from that population. The sample population for each study is dictated by the course of interest (i.e., the sample population is the body of students enrolled in that course). The participant population is the subset of the sample population that provides consent for study participation and complies with study procedures (completes surveys and ILS). Because we are
dependent on student willingness to participate, we must then check that the participant population has similar relative characteristics to the greater population and may be considered a representative sample if we are to draw conclusions for the greater population. That is, the participant population has similar ILS results and comparable spread of performance as the sample population.

Exact replication, in the sense of repetition of identical experiments, cannot be achieved. In the individual level study, each experiment (set of surveys and grades associated with a specific problem) is dictated by the exam problems, which are unique problems. In team studies, each survey is associated with a separate lab or design project, again providing a unique and non-replicable experiment.

In the case of the individual level, the study has been repeated in different sections of the course and during different semesters. This provides an opportunity to observe whether conclusions and inferences made from one section or semester of study appear again. However, there are numerous nuisance factors that must be acknowledged and taken into account when making any observation across sections or semesters (a threat to external validity).

The last component of traditional experimental design, blocking, aids in control of these nuisance factors. There are three types of nuisance factors—controllable, uncontrollable, and noise. Controllable nuisance factors for each specific study are:

Individual Level:

- Different instructors for spring and fall terms, with two instructors (different sections) per term
- Different semesters (students in the spring semester often represent a different population from the fall semester)
• Differences in problem level of difficulty

Team-level:
• Different team experimental tracks (classical, environmental, biological)
• Differences in experiments
• Differences in experience with T.A. supervising experiment

Combinatorial Level:
• Different instructors in spring and fall terms
• Different experiences with teaching assistants (TAs) in meetings

The strategy for dealing with these nuisance factors is blocking. Data from different sections of the same course are analyzed separately. Furthermore, each set of surveys associated with a specific problem in CBE 2200 (individual) are analyzed separately (blocked). For CBE 4630 (team), each set of experimental tracks, experiments (and associated TAs) are analyzed separately, and for CBE 4764 (combinatorial) the different terms and TAs are considered. In short, we block by all controllable nuisance variables and evaluate if there are any significant differences that may exist because of that nuisance variable.

Randomization minimizes uncontrollable nuisance factors and noise. Because true randomization cannot be achieved in our study, we rely on a sufficiently large and representative participant population to minimize these factors (as described in section on randomization above). Uncontrollable nuisance factors include student mood (e.g., happy, sad), physical state (e.g., tired, hungry, ill), and mental/emotional state (e.g., life events, stress). With a sufficiently large sample population, these factors should not influence our overall findings. This is also the case for other nuisance factors we may be
unaware of (noise). A large and representative study sample is our best defense against these.

Our main concern in study design is minimizing threats to validity.53,56-58 Validity refers to the extent to which meaningful inferences can be made from the data gathered. There are several types of validity in educational methods, the most widely applicable being internal and external validity.

Internal validity refers to the extent to which inferences made from the data are supported by the data. Threats to internal validity in educational research include:\53

- **History**—participants may have varying histories/backgrounds that influence their attitudes toward the study topic
- **Maturation**—participants may mature during study period, thus their attitudes may change during the course of the study
- **Selection**—selected participants may have a predisposition toward a specific characteristic (e.g., high achieving students)
- **Treatment/Non-Treatment Group Interactions**—communication between experimental (treatment) and control (non-treatment) groups may result in altered perspective from information gained or resentment from the control group for being excluded from a beneficial intervention (note: because we do not have an intervention, this threat is not applicable to our current study)
- **Attrition**—participants may drop out of study for a variety of reasons (personal, loss of interest, etc.)
- **Sample Size**—sample size may be too small for meaningful results
• Testing Effects—participants may be inclined to give answers they believe are more correct, participants may develop familiarity with test that alters responses with repeated administration

These threats can largely be minimized by proper selection and definition of the sample population. In our case, the sample population includes students enrolled in the course of interest. To garner a sufficient sample size, we personally introduce the study to the students and explain the motivation, the risks (which are minimal to none) of participating, time involved, and potential benefits. We follow up through e-mail reminders when surveys are available, and solicit the support of the instructor in also providing reminders to students and encouraging them to consider and/or continue participation. This works to minimize the threat of attrition. Because our study populations are at the same relative point in their chemical engineering curriculum, we minimize the threat of history effects with respect to our factors of interest. Furthermore, the students are expected to mature at the same (or similar) rate during the progression of the course (relative to these factors), minimizing the threat of maturation. Testing effects are minimized by the low-risk associated with the survey responses. Students are not evaluated on survey responses, and data is de-identified before analysis so students are no longer linked to their responses. This low-risk scenario encourages more honest responses. We alter and reorder questions, as well as include questions measuring the same construct but presented in both a positive and a negative manner, to check for mindful responses. If a participant responds to a positively phrased item with agreement, but then also agrees with the equivalent negatively phrased item, the response is omitted.
External validity refers to the extent which inferences from a set of data can be further generalized. Threats to external validity include generalization beyond the sample population, setting, and time. Because of the highly dynamic nature of education and the research subjects, these generalizations cannot be made. To minimize threats to external validity, any generalization must take care not to overstep the bounds of the study. That is, generalizations should only be made for similar populations and settings (students at the same point in their curriculum, also at a Research I university, etc.), and acknowledgement should be made that these inferences are only truly valid for the time period over which the supporting data was gathered. Internal and external threats to validity, and how they are minimized in this study, are outlined in Tables 2.2 and 2.3.

Table 2.2. Type of Validity: Internal

<table>
<thead>
<tr>
<th>Threat</th>
<th>Description</th>
<th>How We Reduce Threat</th>
</tr>
</thead>
<tbody>
<tr>
<td>History</td>
<td>Participant history may affect responses/results</td>
<td>The context of our study is within the chemical engineering curriculum, for each study, our population consists of students at the same (or very similar) point in the curriculum, and thus share a similar history relative to the context.</td>
</tr>
<tr>
<td>Maturation</td>
<td>Participants may mature during study, affecting results</td>
<td>Selected participants are expected to mature at the same rate during the course with respect to factors that may influence study outcomes.</td>
</tr>
<tr>
<td>Selection</td>
<td>Participants may be selected with predisposition to certain outcomes</td>
<td>The only criteria for participant selection is belonging to the study population (enrollment in course of interest). The characteristics of the participant pool (final grade distribution) and of the greater population (total students enrolled) to ensure that it is representative.</td>
</tr>
</tbody>
</table>

(continued)
| Treatment/ Non-Treatment Group Interactions | Information can be disseminated between “treated” and “non-treated” groups that influence results. The non-treated group may experience resentment for being excluded from potential gains. | This is not a concern for our current study as we are not administering a treatment or intervention. |
| Attrition | Participants drop out of study for unknown reasons | Seek large enough sample that participation loss effect will be minimal. Minimize factors under our control that may influence student participation (e.g., students may be bored with study and drop out, so we can work to keep the study engaging) |
| Sufficient Sample Size | Sample size may be too small or not representative of population | Personally introduce study to population so they are aware of study design and delivery, what is requested of them, and any risks potentially associated. This also allows any concerns to be acknowledged and any confusion to be cleared up. Also, the support of the instructor in reminding students about a survey’s availability increases likelihood of participant completion. |
| Testing Effects | Repetition of similar tests may result in biased answers developing. Respondents may remember a previous test and modify their response based on what they believe is a more correct or favorable answer. | Our instrument does not include items with a “right” or “wrong” answer. Furthermore, students are clearly told and continually reminded that the purpose of the instrument is to understand their perceptions and approaches so that we may better develop curriculum, not evaluate them. Results are de-identified for analysis, so the student is not associated with their responses. This creates a low-risk, high-reward (in the grand scheme) outcome for them. |
Instrument Design

With respect to an instrument (e.g., survey), there are three important types of validity: construct, content, and criterion-related. Construct validity refers to whether an instrument measures what it intends to. That is, for example, whether a self-efficacy
instrument truly measures self-efficacy, or rather measures metacognition instead. Content validity refers to whether an instrument fairly and accurately covers the breadth of the construct it intends to measure. Lastly, criterion-related validity refers to whether an instrument's results can be related to another (related) external criterion. For example, in developing self-efficacy instruments it is often expected that students with greater levels of experience in the construct of interest will report high self-efficacy, thus experience is commonly the external criterion used to evaluate criterion-related validity in such an instrument.

The validity of an instrument can be established first through minimizing the internal and external threats to validity for the study, ensuring the scope of work is properly defined and the appropriate population is selected, and then demonstrating that the instrument measures what is intended (construct validity), that it covers the intended domain (content validity), and demonstrates correlation between instrument results and identified external criterion (criterion-related validity). Establishing instrument validity is important before widespread application of the instrument; however, doing so in our study is beyond the scope of this work. Future work incorporating validity studies on the designed instrument are mentioned in Chapter 6. Tables 2.4-2.6 summarize threats to instrument validity and how the threat may be reduced.

Table 2.4. Type of Validity: Construct

<table>
<thead>
<tr>
<th>Threat</th>
<th>Description</th>
<th>How to Reduce Threat</th>
</tr>
</thead>
<tbody>
<tr>
<td>Ambiguity</td>
<td>Construct is unclear</td>
<td>Properly define construct(s) of interest from literature review and study objectives.</td>
</tr>
<tr>
<td>Inappropriate Items</td>
<td>Items/instrument do not measure what they intend to</td>
<td>Develop instrument from knowledge gained in literature review, with focus on construct definition and study objectives.</td>
</tr>
</tbody>
</table>
Table 2.5. Type of Validity: Content

<table>
<thead>
<tr>
<th>Threat</th>
<th>Description</th>
<th>How to Reduce Threat</th>
</tr>
</thead>
<tbody>
<tr>
<td>Ambiguity</td>
<td>Construct and appropriate breadth for study are unclear</td>
<td>Fully define construct and scope of interest. If there is a case where a component that is traditionally accepted in the construct of interest (as observed in literature) are omitted, provide sufficient justification for decision.</td>
</tr>
<tr>
<td>Incompleteness</td>
<td>Instrument does not cover breadth of construct</td>
<td>Use construct definition to ensure that all components of construct are covered in instrument. Provide supporting evidence from literature and connection to components of instrument.</td>
</tr>
</tbody>
</table>

Table 2.6. Type of Validity: Criterion-Related

<table>
<thead>
<tr>
<th>Threat</th>
<th>Description</th>
<th>How to Reduce Threat</th>
</tr>
</thead>
<tbody>
<tr>
<td>Inappropriate Criterion</td>
<td>External criterion chosen does not have correlation with instrument construct.</td>
<td>Choose external criterion based on theoretical framework from literature.</td>
</tr>
</tbody>
</table>

Another important attribute that must be considered with instrument design is its reliability. Reliability refers to the degree to which an instrument produces consistent (reproducible) results. For quantitative work, there are three main forms of reliability: stability, equivalence, and internal consistency. Stability measures the consistency of responses to an instrument over time and similar populations. Equivalence measures a new instrument against an instrument that has been previously shown reliable, and evaluates whether they are the same. Internal consistency is similar to construct validity and measures whether items on the same instrument intended to serve the same
construct actually do. Again, as the aim of this work is not development of the instrument, reliability is not addressed here but left for future work.

Reliability in qualitative work includes observational stability (whether observations are influenced by time and location), parallel forms (whether observations are independent of other occurrences at the time) and inter-rater ability (whether observations are independent of observer, i.e., different observers with same theoretical knowledge would provide same interpretation).

A well designed experimental plan is essential to any study. While on the surface experimental design and research plans may appear highly variable between disciplines, all research has the same ultimate objective: to answer questions. In the process of seeking answers, we must ensure that our methods are valid and reliable, and that we are minimizing factors that may jeopardize our ability to make sound conclusions. While technical research and engineering education research may appear different, both rely on rigorous experimental design and data analysis.
Chapter 3 : Study on the Individual

CBE 2200: Process Fundamentals, which is commonly referred to as Material (or Mass and Energy) Balances, is the first core course in OSU’s chemical engineering program, and represents the beginning of undergraduate students’ careers as chemical engineers. Comprised mostly of sophomores, at this point students still retain the influences of diverse high school backgrounds and varied general education selections. Students are required to complete certain general (mathematics, science, English, etc.) pre-requisites before they are eligible to apply for the chemical engineering major. We are interested in how variability in learning styles engaged by specific exam problems (inherent bias) may correlate with student learning styles, self-efficacy, and performance in this introductory chemical engineering course. It has been suggested that learning styles are malleable and over time students adjust their preferences to their curriculum.20 To minimize this effect, we have been studying students as they begin their CBE curriculum.

CBE 2200 is a lecture-based course with assessment conducted through homework, quizzes, and exams. In some sections, homework problems are assigned as “individual” or “group problems,” to be completed accordingly (groups are typically randomly assigned). In the early phases of our study we examined correlations between
student learning style and student performance on and perception of homework problems, however, we found that these were not a reliable source of data. The homework problems for the course are from the widely-used Felder-Rousseau textbook, and during this portion of the study we learned that solutions are freely available online. For this reason, there is a high degree of solution-assisted problem solving that occurs on the homework. Thus, we revised our protocol to investigate student learning styles, performance, self-efficacy, and perceptions (attitudes, problem solving approaches) on exam problems written by the instructors. While homework was originally appealing for the wide pool of problems available throughout the term, exams eliminate the ability of the student to use solutions, providing more reliable data regarding student performance and preference. Also, students became disengaged in the study when surveys were included with weekly homework assignments (surveys were too frequent). Thus, our study of this course focuses on exam problems only, which we believe are a more reliable source of data and have proven to have better sustained student survey participation. It is important to acknowledge that exams can be a high-stress situation as they emphasize a single performance, and self-efficacy is known to be affected by a number of factors, including anxiety. For this reason, we believe that we will see an overall lower self-efficacy among students on exam problems than we may on homework, but that this trend will remain consistent across the problems of interest and will not affect final conclusions.

As the study progressed, our investigation of correlations between student performance and inherent learning style biases on exam problems generated new questions. We noticed variation in overall class performance (average final grades) between certain faculty, as well as differences in the types of exam questions given by
faculty when categorized for inherent bias (categorization and inherent bias are explained in more detail in the section “Evaluating Inherent Bias” found later in this chapter). Thus, in addition to potential correlations between student learning style, self-efficacy, and performance, we became more interested in examining the inherent biases of exam problems, student problem solving strategies, and how the teaching/evaluation styles employed by various faculty affect student performance. To offer a stronger basis for comparison between sections, we administered a material balances concept inventory in our last semester (Spring 2015) of study.

**Aims and Hypotheses**

Originally, our aim was to determine whether differences in learning styles can be observed, identified, and quantified through evaluation of student performance, self-efficacy, problem solving strategies, and attitudes on inherently biased tasks (i.e., a problem that exploits specific learning styles in presentation or solution).

After several semesters of study, we revised our aim to also consider faculty-driven differences between sections of CBE 2200, specifically through further categorization of exam problems developed by different faculty. As with the original, our aim is still to determine the correlation(s) between student performance, self-efficacy, problem-solving strategies, attitudes on biased tasks, and learning style preferences. However, we also compare student performance in different sections of the course taught by various faculty, and strive to identify differences in teaching and evaluation style that may account for those differences.

Our main hypothesis was that differences in performance based on learning style will be observed, as seen in other studies. We also believe that student self-efficacy and perceptions will correlate with learning style. In these cases, we believe that
a match between learning style exploited in the problem and student learning style will result in higher performance, higher self-efficacy, and more positive perceptions. Lastly, based on initial observations from early semesters of the study, we developed the hypothesis that student performance will vary by faculty, and the types of exam problems given by the faculty. We believe that students in sections with highly sequential and sensing problems on exams, as well as fewer overall concepts covered on each exam, will demonstrate higher performance.

**Study Procedures (Methods)**

This study aims to investigate the sample population’s performance and self-efficacy with respect to learning styles without otherwise influencing the course content or design. The sample population consists of students enrolled in CBE 200, Chemical and Biomolecular Engineering Process Fundamentals. The students are from five semesters between 2013 and 2015, which includes nine sections with six different faculty instructors denoted as Faculty A through F. In summary, the study consists of the following (items marked with “update” were added in the final semester of study, Spring 2015):

1) Introduction of study and collection of informed consent.
2) Administration of the ILS questionnaire in the first two weeks of the term.
3) Compilation of ILS data to identify course make-up with respect to learning styles.
4) Inspection of exam problems for problems demonstrating strong inherent bias
5) Self-efficacy surveys correlated with specific exam problems made available at appropriate time throughout term.
6) Collection of student performance data (grades) on specific problems (corresponding to problems included in surveys) and overall course grade.

7) Analysis of data for a correlation between student performance and learning style preference, student performance and self-efficacy, and/or self-efficacy and learning style.

8) Update: Administration of a standard concept inventory to better compare different sections taught by different instructors.

9) Evaluation of concepts covered on each exam administered by each faculty.

10) Categorization of exam problem presentation and solution with respect to learning style (for all available exams).

11) Analysis of data for a correlation between student performance, instructor, types of exam problems, and exam content.

Data collected are the ILS results, surveys administered with exams, and student grades on the individual problems addressed in the surveys as well as overall homework, exam, and course grades, and concept inventory score (Spring 2015 only).

All information is de-identified before analysis and saved in a de-identified form.

Internal Review Board Approval

In Spring 2013 and Fall 2013, this study was run under internal review board (IRB) exemption, which means that the IRB does not oversee the study unless a change in protocol is made (no continuing review or study completion paperwork). As we transitioned from using homework problems to exams, we submitted for full IRB approval.
All supplementary documents submitted to the IRB are included in Appendix A: the consent form, recruitment script, and master survey. Each document is the latest approved version. The informed consent document required the most revision by the IRB, as it appeared that each set of reviewers had differing opinions. The current IRB approval is valid through December 2015 and will be up for continuing review in October 2015.

Measurement / Instrumentation

The variable of interest is difference in learning styles, with each of the four dimensions considered separately. Learning styles are assessed using the previously mentioned ILS questionnaire. Each learning style dimension is investigated through inherent problem biases and follow-up surveys. These problems are part of the regular course material (exams) and are administered throughout the semester. Because of the cumulative nature of the course, generally exams increase in difficulty as the semester progresses and more material is covered, and cumulative knowledge is required to complete the exams. This allows for repetition of the study with different difficulties of problems, since learning styles could be more significant as learning and problem-solving demands become more complex. Student performance (grades) on these exams and in the overall course are the quantitative measurements obtained from the study. The corresponding surveys provide more qualitative data evaluating the student’s response to the given task, ranked on a Likert-type scale of five levels from Strongly Disagree to Strongly Agree (Strongly Disagree, Disagree, Neutral, Agree, Strongly Agree). Surveys also may include True/False questions, multiple choice regarding problem approach, or short answer. Each survey is customized to the exam, and covers exam-specific as well as general self-efficacy, perception, and problem-solving
questions. Repeated questions with reversed wording (positive voice changed to negative) are utilized to catch any students who may not be answering mindfully. The latest IRB approved survey example is in Appendix A.

Surveys were administered with each exam. Survey questions reference specific exam problems, problem types, problem solving strategies, and course concepts. In sum, we asked about no more than eight different problems throughout the semester, where ideally one problem representative of each preference (four dimensions with two opposing preferences) would be considered. This was, however, dictated by the questions the faculty wrote during the course. We had no influence on the selection of questions or course content in any fashion. Surveys originally came in two parts: (i) part one being available for 48 hours immediately following the exam or until the exam is returned (whichever is sooner), and (ii) part two being available for 48 hours following the return of the exams. These surveys assess the students’ immediate perception of a specific problem and their performance, as well as their reaction to their actual performance. Beginning in Spring 2014, we revised the surveys to incorporate a larger variety of questions as well as greater customization for each survey to the corresponding problem(s). However, in later semesters (Fall 2014 and Spring 2015), the second survey was dropped as it did not show to be a valuable source of data in the semesters it was administered.

In Spring 2015, we added an additional instrument, the standard material balances concept inventory developed by Ngoathai et al. This concept inventory consists of 20 multiple choice questions covering general concepts of a material balances course: unit conversions, mass balances, energy transfer, etc. It is administered at the end of term (final week of classes) to both sections online. A time-
limit of two hours was imposed so as to give students plenty of time (estimated time of completion was 30 to 60 minutes) but also ensure that they completed the inventory in one sitting. Due to time constraints in the first semester of implementation, it was administered online through the Carmen site, but in future semesters we recommend administering it in-class as it is well suited for a 50-minute class session.

Evaluating Inherent Bias

We use the term inherent bias to describe the presentation and solution styles exploited by a specific task (problem). Thus, it is identified by the problem presentation or problem solving methodology used in the proper solution. For each dimension, the criteria used to identify the inherent bias of a problem are described in Table 3.1. These criteria were developed to minimize subjectivity in categorizing problem types. Problem type categorization was verified by multiple CBE graduate students (specifically with a bachelor’s degree in chemical engineering). Each graduate student categorized problems independently, followed by comparison of categorization and discussion of any differences. The most common cause of disagreement was from lack of experience with the criteria, and failure on the part of the investigator to emphasize that not every problem can be categorized for every dimension. The focus is on identifying if any learning styles are strongly exploited through problem presentation or solution, so in some cases there might be no inherent biases present. Additionally, evaluating the active/reflective dimension is difficult without further involvement in the specific course, so while we have developed the listed criteria for this dimension we do not use it in our categorization. We do recommend it to other researchers, however, who are able to provide that assessment.
Table 3.1. Categorization criteria for evaluating inherent bias on exam problems.

<table>
<thead>
<tr>
<th>Dimension Preference</th>
<th>Criteria</th>
</tr>
</thead>
<tbody>
<tr>
<td>Active</td>
<td>- Problem presentation or solution is highly representative of a problem the students have previously solved (similar to previous problem)</td>
</tr>
<tr>
<td>Reflective</td>
<td>- Problem presentation or solution is representative of ideas covered but not practiced in class (e.g., a law or theorem that was presented but no homework regarding it was assigned)</td>
</tr>
<tr>
<td>Sensing</td>
<td>- Problem presentation strongly focuses on providing numbers and implies that the solution will require numerical calculations (e.g., “plug-and-chug”) - Problem solution focuses on numerical solution</td>
</tr>
<tr>
<td>Intuitive</td>
<td>- Problem presentation focuses on concepts and theories (e.g. introduces a new formula, concept, or theory in the problem statement or directly refers to application of a theory) - Problem solution requires conceptual and theoretical understanding rather than numerical</td>
</tr>
<tr>
<td>Visual</td>
<td>- Problem presentation uses visuals (e.g. table, image, graph, chart, but not a straight data table), with few/no text descriptions - Problem solution requires interpreting visually presented data (e.g., graphs, charts) - Problem solution requires creating visual depiction (e.g., process diagram)</td>
</tr>
<tr>
<td>Verbal</td>
<td>- Problem presentation uses words without using any of the visuals described above - Problem solution requires extensive written explanation (rare, often paired with intuitive)</td>
</tr>
<tr>
<td>Sequential</td>
<td>- Problem presentation suggests one part of the problem leads into the next in a step-by-step (i.e. sequential) fashion - Problem solution follows a distinct sequence of steps/calculations</td>
</tr>
<tr>
<td>Global</td>
<td>- Problem is presented directly, where information is provided and the final question is asked without any indication or hints of possible steps needed to get to the solution - Problem solution does not follow a distinct sequence of steps/calculations, but rather tests overall understanding of how to obtain the final answer</td>
</tr>
</tbody>
</table>
For proper comparison of the influence of specific dimensions on student performance (e.g., whether active/reflective students show greater differences than sequential/global), items identified with inherent bias for different dimensions should have similar relative properties such as levels of difficulty, discrimination ability, and resistance to guessing.

The use of homework problems was eliminated after two semesters of study (in favor of focusing on exams) to better ensure that the selected problems have similar relative properties. Homework problems have wide variability, and are further compromised by the potential availability of the textbook solution manual. Exam problems have less variability, and maintain a degree of similar relative properties. That is, the properties of the problems (relative to student knowledge and progress) contained in a single exam are similar from exam to exam within the same course/instructor. Thus, although Exam 3 is inherently expected to be more difficult than Exam 1, both exams are representative of the same relative difficulty with respect to course progression. Relative to the tools the students have for solving the problems, these exams are designed to be comparable. Midterm exams are meant to evaluate student knowledge and understanding of the material covered to that point in a holistic fashion, with each exam building from the material covered on the previous. It is important to note that no surveys were administered with the cumulative final exam was because questions have greater variability in difficulty, as more simple questions from early in the term may be present. Thus, focus on midterm exam problems increases tendency for the pool of questions to have similar relative properties.

As a post-assessment check for level of difficulty, the average performance of students on the selected question is compared with the overall exam performance and
performance on other questions in the exam. Any question that suggests an overall greater or lesser difficulty (as evidenced by lower or higher performance from the population on average) are noted for discussion.

Furthermore, time limitations in taking the exam, which may influence performance, must also be considered. If an exam is inadvertently too long for the allotted time, most students may not complete the last problem(s). This scenario arose in one instance in the Spring 2014 study, where the problem-of-interest was the last problem on an exam, but most students did not have time to complete it. Surveys were adjusted to account for the possibility of students not having enough time, and evaluated their confidence in their ability to complete the question had there been sufficient time. This type of flexibility is crucial to educational studies.

With regards to discrimination ability, from the participant perspective we expect an individual’s discrimination ability regarding problem type to vary from dimension to dimension but to be fairly consistent for each dimension throughout the entire population. We expect participants to be able to better discriminate between visual and verbal problems because this distinction is more immediately obvious and familiar, and we expect this discrimination ability to be relatively equivalent for the population. The other three dimensions, active/reflective, sensing/intuitive, and sequential/global, are less familiar and instinctive, therefore, we expect lower discrimination ability from the participant population for problems in these dimensions. From an evaluator perspective, with knowledge of the criteria used for discrimination (listed in Table 3.1), a chemical engineer (not a chemical engineering student currently enrolled in the class, but one who has demonstrated mastery of the material, i.e., a chemical engineer who has completed
requisite coursework) would be able to discriminate between problem types in the same fashion we have.

The nature of chemical engineering problems offers a high resistance to guessing as they require conceptual knowledge and problem solving. Multiple choice, true and false, and other question types that are more prone to student guessing are seldom, if ever used. Thus, these exam problems offer a high degree of resistance to guessing, which is verified post-exam when we look over student work on the question of interest.

It is important to emphasize that each problem is analyzed separately, and problem characteristics and limitations that may have been present are defined. Raw data from one problem to another is not compared. However, comparisons between findings are made, in which case the problem characteristics and limitations would help support similar findings or explain contradictory observations.

**Statistical Analyses**

For continuous numeric variables (grades), the statistical analysis method used in this work is one-way analysis of variance (ANOVA), which evaluates whether the means of several groups (> 2) with one factor are equal. Doing multiple two-sample t-tests when comparing more than two sample means increases the chances of committing a statistical Type I error (rejecting the null hypothesis when it is true, i.e., mistakenly reporting statistical significance when there is none), and thus an ANOVA is preferred. If the null hypothesis is rejected through ANOVA, Tukey's range test of comparing all sample means to each other is used to identify which sample(s) are different from the others at a statistically significant level.
ANOVA assumes normal distribution and homogeneity of variance, which may not always be realistic, especially in cases of low sample sizes. When the sample size is less than 30, nonparametric methods may be preferred as they do not assume a normal distribution. However, nonparametric methods do assume data is from an independent random sample. The Kruskal-Wallis test for assessing variation in means is the nonparametric alternative to a one-way ANOVA, and the Steel-Dwass all pairs test is the nonparametric alternative to the Tukey test used in this study. All continuous numeric variables are tested at a significance level (α) of 0.05.

For categorical data, one of the most common methods of analysis is Pearson's Chi-squared test. This tests the null hypothesis (H₀) that categorical variables are independent against the alternative hypothesis (H₁) that they are dependent by comparing the data in question to a model. The test statistic, $\chi^2$, is,

$$
\chi^2 = \sum_{i=1}^{n} \frac{(O_i - E_i)^2}{E_i}
$$

where O is the observed frequency, and E is the expected frequency for a category. The expected frequency is calculated from the aforementioned model, which is derived from the original data set.

Pearson’s Chi-squared test is limited to data sets in which no cell in the contingency table (table of frequency distributions) has a value less than 5. For these contingency tables, a Fisher’s Exact Test is more appropriate. However, the statistical software available to investigators at the time of this study is limited to Fisher’s Exact Test with 2X2 contingency tables only, presenting strong limitations in statistical analysis of categorical data. Thus, categorical data is first analyzed on general trends, and
thorough statistical analysis is left for future work where more powerful statistical software may be utilized.

**Overview of Study Participation and Response**

In the Spring 2013 section, we attempted to ask students about multiple problems on every homework assignment. This resulted in an overwhelming number of repetitive surveys and extremely low response. In Fall 2013, we decreased the number of problems we studied, however, we continued to face the problem of repetitive surveys, too many surveys, and loss of student interest. While informed consent numbers were fairly high in each section of CBE 2200 participating, actual survey participation was low and at times non-existent. Spring 2014, one section of Fall 2014, and Spring 2015 yielded fairly high survey response rates (roughly 50% of class), and serve as the primary sources of data for this study. These are summarized in Table 3.2. In sum, while the study was conducted over five semesters and nine sections of CBE 2200 (in Fall 2013 one faculty chose not to participate), there are gaps in what data are available. Table 3.3 summarizes the data collected and available for analysis from each semester and respective faculty. Table 3.4 displays the number of problems on the exams given by each faculty that we had access to. Each of these exams had a survey administered with it (however, surveys were not administered during final exams), usually associated with a specific problem from the exam in question.
Table 3.2. Participation numbers for each component of study by faculty and term. Prior to Spring 2014, surveys were for homework assignments and are not included in this chart. In Spring 2014, Faculty B’s section had a survey associated with exams 2 and 3, but not 1 and 4. In Spring 2014, we administered surveys both immediately after the exam and after the exam was returned, as mentioned in the methods. This practice was discontinued. Fall 2014 had the highest enrollment observed to date, with both sections at about 80 students (compared to the typical 50 to 60).

<table>
<thead>
<tr>
<th>Semester</th>
<th>Faculty</th>
<th>Participation for Specified Study Component</th>
</tr>
</thead>
<tbody>
<tr>
<td></td>
<td></td>
<td>Consent</td>
</tr>
<tr>
<td>Spring 2013</td>
<td>A</td>
<td>50</td>
</tr>
<tr>
<td></td>
<td>B</td>
<td>35</td>
</tr>
<tr>
<td>Fall 2013</td>
<td>C</td>
<td>50</td>
</tr>
<tr>
<td>Spring 2014</td>
<td>B</td>
<td>56</td>
</tr>
<tr>
<td></td>
<td>D</td>
<td>57</td>
</tr>
<tr>
<td>Fall 2014</td>
<td>C</td>
<td>56</td>
</tr>
<tr>
<td></td>
<td>E</td>
<td>68</td>
</tr>
<tr>
<td>Spring 2015</td>
<td>D</td>
<td>40</td>
</tr>
<tr>
<td></td>
<td>F</td>
<td>49</td>
</tr>
</tbody>
</table>

Table 3.3. Data collected from each semester and faculty instructor. An ‘X’ indicates that data was collected, while ‘N/A’ indicates that the concept inventory was not performed during that semester.

<table>
<thead>
<tr>
<th>Semester</th>
<th>Faculty</th>
<th>ILS Responses</th>
<th>Grades</th>
<th>Exam Survey Responses</th>
<th>Concept Inventory</th>
</tr>
</thead>
<tbody>
<tr>
<td>Spring 2013</td>
<td>A</td>
<td></td>
<td></td>
<td></td>
<td>N/A</td>
</tr>
<tr>
<td>Faculty B</td>
<td></td>
<td></td>
<td></td>
<td></td>
<td>N/A</td>
</tr>
<tr>
<td>Fall 2013</td>
<td>C</td>
<td></td>
<td></td>
<td></td>
<td>N/A</td>
</tr>
<tr>
<td>Spring 2014</td>
<td>B</td>
<td></td>
<td></td>
<td></td>
<td>N/A</td>
</tr>
<tr>
<td>Faculty D</td>
<td></td>
<td></td>
<td></td>
<td></td>
<td>N/A</td>
</tr>
<tr>
<td>Fall 2014</td>
<td>C</td>
<td></td>
<td></td>
<td></td>
<td>N/A</td>
</tr>
<tr>
<td>Faculty E</td>
<td></td>
<td></td>
<td></td>
<td></td>
<td>N/A</td>
</tr>
<tr>
<td>Spring 2015</td>
<td>D</td>
<td></td>
<td></td>
<td></td>
<td>X</td>
</tr>
<tr>
<td>Faculty F</td>
<td></td>
<td></td>
<td></td>
<td></td>
<td>X</td>
</tr>
</tbody>
</table>
Table 3.4. Number of problems administered on each exam. ‘N/A’ indicates the exams that were not made available to investigators.

<table>
<thead>
<tr>
<th></th>
<th>Exam 1</th>
<th>Exam 2</th>
<th>Exam 3</th>
<th>Exam 4</th>
<th>Final Exam</th>
</tr>
</thead>
<tbody>
<tr>
<td><strong>Spring 2014</strong></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>Faculty B</td>
<td>3</td>
<td>2</td>
<td>3</td>
<td>2</td>
<td>N/A</td>
</tr>
<tr>
<td>Faculty D</td>
<td>4</td>
<td>6</td>
<td>4</td>
<td>4</td>
<td>N/A</td>
</tr>
<tr>
<td><strong>Fall 2014</strong></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>Faculty C</td>
<td>4</td>
<td>3</td>
<td>3</td>
<td>4</td>
<td>N/A</td>
</tr>
<tr>
<td>Faculty E</td>
<td>5</td>
<td>6</td>
<td>6</td>
<td>5</td>
<td>N/A</td>
</tr>
<tr>
<td><strong>Spring 2015</strong></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>Faculty D</td>
<td>4</td>
<td>6</td>
<td>5</td>
<td>4</td>
<td>6</td>
</tr>
<tr>
<td>Faculty F</td>
<td>4</td>
<td>3</td>
<td>3</td>
<td>4</td>
<td>4</td>
</tr>
</tbody>
</table>

Results and Discussion: Learning Style Profiles across Four Semesters

In all but Faculty C’s classes (Fall 2013 and Fall 2014), a high percent of the sample population took the ILS. This allows us to examine the learning styles profiles of classes across four different semesters. Figures 3.1-3.4 summarize the ILS profiles by dimension (with relative strength) for the four semesters for which data is available. In all but Fall 2014 (since only Faculty E’s class provided ILS results in this semester), these numbers are from an aggregate of the two sections of 2200 offered. Detailed ILS profiles for each section and faculty are provided in Appendix B.
Figure 3.1. Student learning styles profiles in active/reflective dimension across four semesters.

Figure 3.2. Student learning styles profiles in sensing/intuitive dimension across four semesters.
Figure 3.3. Student learning styles profiles in visual/verbal dimension across four semesters.

Figure 3.4. Student learning styles profiles in sequential/global dimension across four semesters.
In most dimensions, nearly 50% or more of the students report a balanced preference. The only exception is the visual/verbal dimension, in which more than 50% of students report being either a strong or moderate visual learner. Among the students that report a preference, sensing, visual, and sequential are the dominant preferences in all terms, consistent with the literature regarding engineer preferences in these dimensions. For the active/reflective dimension, only Spring 2013 shows a clear majority of active students among those with a preference. Since active is reported as the predominant preference among engineering students, this is an unexpected result and may suggest a unique feature of the population at our institution, or a developing shift in active/reflective preference among engineers. Overall, there is very little change in the preferences of the student populations from one term to another. Thus, we believe that our student population is fairly consistent with respect to learning styles.

Summary of Learning Style Profiles across Four Semesters

There was little variability in sample population learning styles profile from term to term. The predominant preferences for each dimension were: active/reflective balanced, sensing/intuitive balanced, visual, and sequential/global balanced. Among students that reported a distinct preference in dimensions where the majority of the population was balanced, sensors and sequential learners were more common. Active and reflective students were present in equal numbers in most semesters, with only Spring 2013 having a clear majority of active learners.

Results and Discussion: Student Performance and Learning Styles

When considering correlations between final overall grades and student learning styles, no meaningful statistical differences were observed in any semester except for
Spring 2015. However, upon closer inspection of grades for specific exams or exam problems, statistically significant differences in performance of students with different learning styles was observed in several semesters.

**Spring 2013**

Students were categorized by learning style preference within each dimension and the mean student grades within dimensions were compared. The results show no significant difference in grades of students with learning style preference.

Comparing the profiles of students in the upper quartile, lower quartile, and overall class with respect to final grade, there are a few observable differences. Upper quartile students had a greater percent of active/reflective balanced, strong sensing, strong verbal preferences, and global preferences. It should be noted that there were only two strong verbal students in the sample population. The lower quartile had fewer students with a sequential/global preference, most reporting a balanced preference for this dimension. This is summarized in Table 3.5, which has been abridged to highlight only these dimensions of interest.
Table 3.5. Percent of students in class, upper quartile of grades, and lower quartile of grades shown by strength of learning style preference in dimensions of interest.

<table>
<thead>
<tr>
<th>Learning Style Preference</th>
<th>Percent of Students</th>
<th>Class Responses</th>
<th>Upper Quartile</th>
<th>Lower Quartile</th>
</tr>
</thead>
<tbody>
<tr>
<td>Active/Reflective</td>
<td>Balanced</td>
<td>62</td>
<td>80</td>
<td>58</td>
</tr>
<tr>
<td>Sensing</td>
<td>Strong</td>
<td>19</td>
<td>35</td>
<td>16</td>
</tr>
<tr>
<td></td>
<td>Moderate</td>
<td>21</td>
<td>15</td>
<td>16</td>
</tr>
<tr>
<td>Verbal</td>
<td>Strong</td>
<td>3</td>
<td>10</td>
<td>0</td>
</tr>
<tr>
<td></td>
<td>Moderate</td>
<td>0</td>
<td>0</td>
<td>0</td>
</tr>
<tr>
<td>Sequential</td>
<td>Strong</td>
<td>8</td>
<td>10</td>
<td>11</td>
</tr>
<tr>
<td></td>
<td>Moderate</td>
<td>25</td>
<td>35</td>
<td>11</td>
</tr>
<tr>
<td>Global</td>
<td>Strong</td>
<td>0</td>
<td>0</td>
<td>0</td>
</tr>
<tr>
<td></td>
<td>Moderate</td>
<td>5</td>
<td>10</td>
<td>5</td>
</tr>
<tr>
<td>Sequential/Global</td>
<td>Balanced</td>
<td>62</td>
<td>45</td>
<td>74</td>
</tr>
</tbody>
</table>

Fall 2013

In Fall 2013, only 15 of the 49 students enrolled in CBE 2200 completed the ILS. For this reason, we do not report ILS results for this semester.

Spring 2014

As with the Spring 2013 data, learning styles did not reveal any statistical significance between overall course performance. However, comparing the ILS profiles of students in the upper and lower quartiles of final grade with the class profile revealed one commonality with the analysis of Spring 2013. In both terms, sequential learners are overrepresented in the upper quartile of students, as shown in Figures 3.6 and 3.7. Furthermore, as shown in Figure 3.8, Faculty B’s section in Spring 2014 has an even
greater overrepresentation of sequential learners in the upper quartile than either of the term aggregates.

Figure 3.5. Comparison of the percent of students in the upper quartile of final grade, lower quartile of final grade, and class totals with respect to sequential/global dimension for Spring 2013.
Figure 3.6. Comparison of the percent of students in the upper quartile of final grade, lower quartile of final grade, and class totals with respect to sequential/global dimension for Spring 2014.

Figure 3.7. Comparison of the percent of students in the upper quartile of final grade, lower quartile of final grade, and class totals with respect to sequential/global dimension for Spring 2014, Faculty B.
In a few instances, differences (statistically significant at $\alpha = 0.05$) in student performance that correlated with learning style were observed on exam problems. On specific problems (each instance a separate problem):

- Intuitors performed significantly more poorly than sensing and balanced learners
- A statistically significant difference was observed between students of visual and verbal preference
- Sequentially did significantly better than balanced or global learners

These observations largely corresponded to the inherent bias previously identified for that problem, and provide an interesting basis for further discussion. By evaluating the problems (to preserve the problems for future use by the faculty, they are not published in this dissertation), the following observations can be made regarding student performance:

- Sensing/Intuitive (Faculty B): On a pump problem presented visually and verbally, intuitors had significantly lower performance. The problem relied on a lot of numerical information, and required a numerical solution. As intuitors are categorized as preferring conceptual information over numerical solutions, this is not unexpected.
- Visual/Verbal (Faculty D): Verbal learners demonstrated lower performance than visual and balanced learners on a conceptual non-ideal gas problem that encouraged use of compressibility charts. Verbal learners may have experienced more difficulty interpreting the graphical data that was useful in solving the problem.
• Sequential/Global (Faculty B): On an ideal gas problem, sequential learners received higher scores than balanced and global learners. This problem was set up in three parts, and while each part was an independent problem that did not require the previous solution, they did become increasingly more complex. If performed sequentially, they would allow the student to “warm-up,” so to speak, as they progressed.

After three semesters (Fall 2013 yielding too few ILS response to analyze) and four sections of study, the sample size for several preferences remained too small to draw strong conclusions, however, interesting patterns in student performance were observed.

Data collected in Spring 2013 and Spring 2014 indicate that student learning style does not seem to have a strong correlation with overall performance. However, at least one case of learning styles correlating to individual problem performance was observed for three of the four dimensions (active/reflective being the dimension not observed).

Furthermore, the overrepresentation of sequential learners in the upper quartile of final grade, especially in Faculty B’s section of Spring 2014, is an interesting observation that prompted further investigation. Upon reviewing the inherent bias of the problems given on exams by each faculty in Spring 2014, it became very evident that there were strong differences in the manner students were being asked to solve problems. Faculty B’s problems were heavily sensing (numerical) and sequential (ordered), whereas Faculty D’s problems represented a broader range in learning styles in presentation and solution (i.e. broader range of inherent bias). Additionally, while
Faculty B did not impose a scale on the final calculated student grades, Faculty D scaled up the raw scores by more than 20% to produce a final class grade profile that is not noticeably different from Faculty B. That is, raw scores in Faculty D’s class were much lower than Faculty B. These results prompted adding a component investigating teaching styles to our study for Fall 2014 and Spring 2015, the results for which are presented later in this chapter (section entitled “Results and Discussion: Variations in Teaching Style”).

Fall 2014

In Fall 2014, only one section (Faculty E) had sufficient ILS responses to analyze learning styles and performance. Again, there was no overall correlation between student grades and learning styles preferences, nor were statistically significant meaningful differences in performance on specific exam problems observed.

Comparison between the ILS profiles of students in the upper and lower quartiles of final grade with the class did not reveal the same overrepresentation of sequential students in the upper quartile as seen in Spring 2013 and Spring 2014. However, sequential students were underrepresented in the lower quartile. Active and visual students were underrepresented in the upper quartile, an unexpected result based on literature showing the more dominant learning styles having higher performance. Sensing and visual/verbal balanced students were overrepresented in the upper quartile.

Spring 2015

As could be predicted from data gathered over the previous three terms of study, Spring 2015 also showed no correlation between overall grades and student learning style preferences. However, a few instances of specific problems where a statistically
significant difference (p < 0.05) in student scores with respect to learning style were observed. These are as follows:

- Sensors showed poorer performance than intuitors and sensing/intuitive balanced students.
- Visual/verbal balanced learners received lower scores than their visual or verbal peers.
- Global students outperformed their sequential and balanced peers.

Looking more closely at the associated problems in each of these instances, the following observations can be made regarding each dimension:

- Sensing/Intuitive (Faculty D): While the problem itself had a numerical (sensing) solution, the problem presentation was heavy in technical terminology that may have better suited intuitors. It is possible the sensors were less familiar with the theory, and thus the terms, essential to solving the problem.
- Visual/Verbal (Faculty B): The problem in question here had a verbal presentation but visual solution, balanced learners may have had an advantage in converting between these forms of working with information.
- Sequential/Global (Faculty D): Global students outperformed their peers on a global problem, in which after being given background information students were asked to simply solve for a final value of how long it will take for a process to occur. No intermediary steps were provided.

Looking once again at the ILS profiles of students in the upper and lower quartiles of final grade (and comparing them with each other and the class), we see that
Faculty D’s section showed intuitive and global students overrepresented in the upper quartile, and active and visual students underrepresented. Once again the trend in which sequential students are overrepresented in the upper quartile is not observed, but sequential students are underrepresented in the lower quartile as in Fall 2014. For Faculty F, reflective and visual students are overrepresented in the upper quartile. Sequential students are overrepresented in the lower quartile, which is an unexpected result.

Summary of Student Performance and Learning Styles

Overall, no strong correlations between student performance and learning style were observed. This contradicts several previous studies done with other learning (and personality) styles models, including the Kolb model\textsuperscript{23} and MBTI\textsuperscript{14,51,52} (as aforementioned, the MBTI is a personality indicator, but often considered among learning styles studies). Across the five sections in which data is available, only six specific instances of statistically significant differences in performance between students of differing learning styles was observed. The active/reflective dimension is not represented among these instances, suggesting that it may have the least relative influence on student exam performance. Not observing many instances of statistically significant difference in performance may be a result of having a small sample size, especially when looking at individual problems. The small standard deviation in scores that can exist with problems that have 5 or fewer points possible can require \( n > 50 \) to achieve a power of 0.95 (determined through prospective power analysis). For most problems (roughly 15 points possible), \( n \approx 30 \).

Analysis of the upper and lower quartiles of student performance against the respective class profile appeared to reveal a trend after Spring 2013 and Spring 2014,
but that trend was lost in subsequent terms. Thus, no clear trends or correlations are present with respect to learning styles and student performance. As Faculty B taught in both Spring 2013 and 2014, it is possible that the observed trend is a result of Faculty B’s teaching style.

Results and Discussion: (i) ILS, (ii) Student Perceptions, and (iii) Problem Solving Observations

Observational data on student perceptions and problem solving strategies are largely available from three semesters: Spring 2014, Fall 2014, and Spring 2015. These terms also had the highest student participation. Participation from the first term the study was conducted, Spring 2013, was very low, and participation in Fall 2013 waned as the semester progressed. Thus, results on student perceptions and problem solving are only from Spring 2014, Fall 2014, and Spring 2015.

Spring 2014

While survey responses were not in sufficient quantities to do a thorough statistical analysis, certain trends were observed in responses (cumulative response from Faculty B and D’s sections):

- Student confidence in their solution showed a positive correlation with grade.
- Intuitive students more often reported comfort with concepts in a problem.
- Active students more often reported remembering a similar problem from in-class experience (homework, worksheets, quizzes, etc.).
- While most students were not very comfortable with assumptions, global students reported slightly higher confidence.
Furthermore, student learning styles were seen to correlate with perceptions of and approaches to problems.

- Intuitors and globals disagreed with a statement of preferring “problems similar to (a) over (b),” when (a) was a numerical and (b) a conceptual problem.
- The majority of students, irrespective of learning style, reported agreement with preferring numerical solutions.
- Verbal students were less likely to develop a visual or graphical representation of a problem to aid them (when not explicitly asked to do so)

These results imply that the students surveyed have high metacognition (confidence and performance were correlated), but the discrepancy in intuitor responses between a generalized case of preferring numerical problems and a specific instance regarding a two part numerical and conceptual problem suggests that students may have low self-awareness regarding problem solving preferences. Verbal learners’ disinclination to use visual representations and graphs when not explicitly asked to do so, while in keeping with their reported preference, is a concern in engineering problem solving. Engineering is a highly visual field, so ensuring that our students are comfortable using and creating visual representations is critical.

As mentioned, most students reported being uncomfortable with assumptions. Whether this is something to be concerned about at this stage in their education may be debatable. The ability to make the necessary assumptions, and for those assumptions to be physically realistic, is an essential component of engineering problem solving. Instances where all necessary information is available are effectively nonexistent, and we must ensure our students graduate with the skill of making valid assumptions.
However, discomfort in making assumptions in their first semester of chemical engineering may be considered natural, and while it is important to incorporate principles of making assumptions throughout the curriculum, investigation of senior students’ comfort with and ability to make proper assumptions may provide better insight as to whether this is a curricular component that does need to be better addressed.

**Fall 2014**

Fall 2014 surveys from Faculty E’s section offered insights into student preferences and problem-solving approaches, some similar to Spring 2014 and others new. Faculty C’s section had too few survey responses to make extensive comments, however, a few observations are listed.

*Faculty E:*

- Most students agreed that they were confident in their solutions to problems of interest.
- In some instances nearly all students agreed that they began a problem by drawing a diagram (when not explicitly asked to do so), whereas in others most students disagreed.
- In most cases, students agreed that their solution was based on a solution from an in-class problem (homework, lecture example, etc.).
- Most students reported that they prefer numerical solutions, with the only students who disagreed being of visual preference.
- Most students agreed, including all global students, that they would have preferred a specific problem to be presented in multiple parts rather than a single solution.
• All but one student agreed to preferring problems presented in multiple parts (in general).

There were two instances of a statistically significant difference ($p < 0.05$) in specific scores between students of differing survey response. In one case, students who strongly agreed that their solution was based on an in-class example received higher marks than students who disagreed. In another instance, students who agreed that they were confident in their solution performed better than those who did not (similar to Spring 2014).

In multiple instances, students expressed a preference for sequential problems, likely based on the structure they provide in problem solving. This set of respondents was split regarding their tendency to draw a visual representation to aid in problem solving when not explicitly asked to do so. Engineering is a highly visual field and as instructors we must ensure our students are comfortable developing visual representations as a problem-solving tool. Consistently, the majority of students reported that their solutions were based on an example problem. This observation is supported by previous work that suggests students’ most common problem solving strategy is example problems.65

Faculty C:

Faculty C’s section showed very few trends in survey responses. Despite overall low student participation, in one instance, students who strongly agreed that an exam problem was easy to understand also performed better on the problem than those who disagreed. In another instance, students who were confident in their solution received
higher marks on a problem than those who reported that they were not. These instances were all statistically significant at $\alpha = 0.05$.

**Spring 2015**

Analysis of the survey responses in Spring 2015 revealed many common responses across students of different learning styles and different sections of the course. However, a few learning style or section-specific trends were also observed. These responses add to our knowledge of our student population and their perceptions toward chemical engineering problem solving.

*Faculty F:*

- Most students reported confidence in solution on problems in question.
- Intuitors were more likely than others to agree that they were confident in their answer when it was an explanation.
- No students disagreed that problems-of-interest were fair exam problems.
- Most students read verbal problems at least twice, regardless of learning style preferences.
- Most students agreed to prefer visual representations of problems over verbal, however, there was no observable trend to whether or not students would draw their own visual representations unprompted (in one instance they reported doing so, in another they did not, regardless of learning style).
- Most students agreed that they were comfortable with the concepts presented in a problem, but intuitors agreed more often.
- Most students disagreed to preferring conceptual problems on Survey 3, but on Survey 4 the students were more divided, and no intuitors disagreed.
• Most students reported high comfort with numerical solutions.

• Most students agreed that they were glad to be given sequential directions as to how to solve a problem.

• Relatedly, students were pretty split response to: “In general, I prefer problems that just ask me to solve for something (e.g., calculate the rate of heat transfer in a given system), rather than a series of defined steps that lead to a solution (e.g., draw a flow diagram, make assumptions, etc.),” (and all sequential learners disagreed, with no intuitors disagreeing), this response did not change when asked with respect to a specific problem.

• While most students reported mixed responses to the statement “I am uncomfortable making assumptions,” no student disagreed with the statement of being comfortable with assumptions.

These responses show high overall self-efficacy among the students in their solutions, and high self-efficacy with respect to numerical solutions. As expected, intuitors appear more comfortable with conceptual problems than their peers, and sequential learners prefer sequential problems. While these students were more confident in making assumptions than students in Spring 2014, errors in or omission of assumptions when required were a common reason for lost points on exams. This may indicate a misunderstanding on the part of the students regarding necessary, sufficient, and valid assumptions.

With respect to correlations between survey responses and grades, students who disagreed with being confident in a solution also showed statistically significant lower scores on the problem in question (p < 0.05). Students who disagreed that they
were comfortable with conceptual questions showed significantly higher marks on one problem with a sensing solution, which is not unexpected.

**Faculty D:**

- Students were split on whether or not they would draw a diagram to help solve a problem when not explicitly told to do so.
- Students largely reported preferring problems with numerical solutions over problems with conceptual solutions. This was true in both generalized form "I prefer problems with numerical…" and specific form "I prefer problems similar to a [numerical] over b [conceptual]."
- In cases where a question could be answered through conceptual means or numerical solution of a specific case, most students chose not to perform the calculations to guide their solution.
- Many students agreed that they read problems of verbal presentation twice before beginning.
- Students largely reported being comfortable with the vocabulary used on the exam problems of interest.
- Most students agreed that the concepts on problems of interest are important and relevant to their field.
- On Survey 3, most students agreed that they preferred being asked a single question (global) to a series of sequential questions that led to the same eventual answer (sequential). On the next survey (Survey 4), the response was more mixed. More than half of the students still agreed, however, active learners and sensors were 50/50 split on their responses, and more than half of the sequential learners disagreed.
In general, students who reported confidence in their solution also received higher scores on the problem in question. In some cases, students who reported that they did not remember the problem well enough to answer the survey questions received lower marks than their peers.

Students reported preferring numerical solutions, however, when presented with an intuitive question that could be answered through a numerical evaluation, most students did not perform the calculation. This may indicate that students are not fully aware of their problem-solving options when presented a problem, and perhaps feel constrained to the more obvious route of solution. Again, we see a split between students who draw a diagram to aid in solution when not explicitly asked to do so and those who do not use a diagram. The slight shift in response between survey 3 and 4 regarding preference for global over sequential among certain learning styles is an interesting observation. Having seen the question before, students may have had a greater chance to think about it and approached the item on survey 4 with a different perspective. It is possible that some students agreed without thinking through what the different types of problems were; a global problem may initially appear appealing as it suggests being a potentially shorter problem since it has only “one” part.

The survey responses from the two sections provide us with further insight into the CBE 2200 population. In both sections, students reported high student self-efficacy with respect to solutions, preference for numerical solutions over conceptual, and high inclination towards reading a verbal problem twice. Students were mixed in their response to preferring sequential or global problems, though we have reason to believe that they do prefer sequential problems from earlier semesters. Students did not consistently draw a diagram to aid in their solution when not explicitly asked to do so,
nor did they perform calculations that could provide the answer to a conceptual problem when not explicitly asked to do so. This suggests that students are either too early in their chemical engineering careers to fully grasp the means available to them in producing a solution, or that they are simply disinclined to do “extra work” if it is not required by the problem statement.

Summary of (i) ILS, (ii) Student Perceptions, and (iii) Problem Solving Observations

Several observations were repeated through the three semesters of surveys. Students often reported preferring numerical problems, fitting the stereotype that engineers prefer hard numbers and the ability to confidently check work. Students frequently reported a preference for sequential problems. This is also not surprising, as sequential problems double as problem-solving guides, lessening the cognitive load on the student.

Responses suggest that students may not be aware of the variety of problem solving strategies available to them for each problem. When not specifically asked to draw a diagram, only half of students would do so to aid in their solution. As chemical engineers, creating visual representations of processes should develop into a potential reaction to a problem. Also, when presented with an intuitive problem that could be aided by numerical calculations most students did not perform the calculations, despite a preference for numerical solutions. This further suggests that most students may not have the perceptiveness in problem solving at this stage to consider approaches beyond what is suggested in presentation. In developing the most astute problem solvers, it is important to ensure that our students are comfortable with and aware of the different techniques that may aid in their solution.
Results and Discussion: Variations in Teaching Style

After observing the differences in exam problems between Faculty B and Faculty D in Spring 2014, we became more interested in comparing performance and problem types among different sections of CBE 2200. Specifically, in Spring 2014, we noticed that Faculty D scaled up student grades by more than 20% (shown in Figure 3.9 later in this section), which was one of the first observations that prompted us to further study teaching styles. We also noticed, informally, that the exam problems written by Faculty D were quite different from those written by Faculty B (also taught in Spring 2014). In Spring 2015 we administered a standard concept inventory to the two sections of CBE 2200 in an effort to better compare student performance across sections.

Variations in Final Grade

Final grade data were gathered for six faculty (aforementioned Faculty A through F) over five semesters (Spring 2013, Fall 2013, Spring 2014, Fall 2014, and Spring 2015. Faculty B, C, and D taught CBE 2200 twice in this time period, whereas Faculty A, E, and F each taught the course once. Faculty A, B, C, and F have no statistically significant difference in mean final grade. In both semesters that Faculty D taught raw student scores were adjusted (scaled up) at the end of term. The final adjusted grades for Faculty D show no statistical difference with Faculty A, B, C, and F. However, the unadjusted (raw, calculated) grades are significantly different \( p < 0.05 \). As may be inferred from the occurrence of grades being scaled up, raw scores in Faculty D’s sections are much lower than other faculty. Faculty E’s final grades also show statistical significant difference from other faculty \( p < 0.05 \), with the highest frequency of scores being in the 70-79 range of scores (most sections had the highest frequency of scores in
the 80-89 range). The full set of figures summarizing faculty grade distributions for each faculty each semester are located in Appendix C.

Figure 3.8. Faculty D’s unadjusted and adjusted (scaled) grades in Spring 2014 semester.

Variations in Design and Structure of Exams

Without further assessment of the faculty approaches to the class, it is difficult to draw strong conclusions as to the cause of these differences in grades. Figures 3.10 (presentation) and 3.11 (solution) show the percent occurrence of different inherent bias among problems written by different faculty. It is important to note that Faculty E had several uncategorized problems, which are not represented in these figures. Also, there is no differentiation made in producing these figures between a full problem that represented the noted inherent bias or a portion/part of a problem (e.g., entire problem vs. part (b) of the problem). That information, along with comparisons of the presentation vs. solution of each faculty, can be found in Appendix D.
Figure 3.9. Occurrence of inherent bias in presentation on exam problems written by different faculty.

Figure 3.10. Occurrence of inherent bias in solution on exam problems written by different faculty.
Overall, trends appear similar among faculty with respect to favored types of problems, which is not unexpected given literature describing similarity among faculty teaching styles. Sensing, verbal, and sequential are the most common forms of presentation, and sensing, intuitive, and sequential are the most common forms of solution. Our initial observations from Spring 2014 regarding the differences in apparent problem types between Faculty B and D were not as obviously seen when we investigated problem inherent biases more closely.

Faculty E and D, the faculty with the lowest raw class scores, also have the fewest occurrence of sequentially presented problems. With regards to solutions, these faculty also have the fewest occurrence of visual solutions. Visual solutions often included an explicit statement in the problem directing the student to draw a process flow diagram, and as we have seen that only roughly half of students are inclined to draw a visual representation when not explicitly asked to do so, this may explain the lower scores associated with faculty who have fewer visual solutions. Students in these sections may have conducted their problem-solving without drawing the necessary diagram and been hindered in their solution. However, exams are not available from all faculty studied (no exams from Faculty A are available, and Fall 2013 exams from Faculty C are not available). While neither of these faculty had statistical significance in their final course grades, and it may be postulated that Faculty C’s exams in Fall 2013 would be similar to those in Fall 2014, data on Faculty A may help to support or contradict the above observations.

Both Faculty D and E have a greater number of questions per exam (4 to 6 as opposed to between 2 and 4) than Faculty B, C, and F, as shown in Table 3.4, which may imply that more concepts are covered on each exam. Detailed categorization of
concepts on exam problems (summary table in Appendix D) where each exam is considered separately indicate that Faculty D, E, and F have more concepts and use more terminology on their exams. Faculty B has what may be considered the most simple exams, with only a few questions usually covering similar concepts (few questions, few problems). Along with other factors influencing teaching style, the number of problems on an exam and concepts covered may be a contributor to variation in final course grades across sections.

Variation in Student Conceptual Knowledge based (Spring 2015 Concept Inventory)

At the end of the Spring 2015 term, we received IRB approval to administer a standard materials balance concept inventory to the two sections of CBE 2200 (taught by Faculty D and F). The inventory was developed by Ngothai and Davis and selected for its prior use, availability, and publication. As described in methods, it consists of 20 multiple choice questions covering a variety of material balances concepts. The 20 questions along with five choices, correct answers, and the distribution of student answers can be found in Appendix E.

The concept inventory was administered online through Carmen in the last week of classes and made available to both sections for the same period of five days. A time limit of two hours was imposed on the inventory so as to alleviate time constraints, but also ensure that students begin and complete the inventory in one sitting. Students working together was a concern with online administration, but because the inventory results were not used in student grade evaluation, students did not have an incentive to do so. Carmen records when students open and complete a task, which can provide information as to whether students may have inadvertently taken the inventory together. There was no indication that students may have taken the inventory together.
There are no common exams in CBE 2200 (with the exception of many years ago, prior to our studies, when two faculty teaching the same semester decided to administer common exams), thus, the concept inventory was administered to provide a standard exam from which we could evaluate student performance. This allows for not only analysis of student performance on different topics, but also for a more direct comparison between student knowledge among multiple sections/instructors. Figures 3.12 and 3.13 summarize the scores in Faculty D and F’s sections, respectively. It is important to note that the student who received a score of three in Faculty D’s section only spent two minutes on the inventory, and their score should not be considered representative of the population. Thirty-three and thirty-seven students in Faculty D and F’s sections completed the inventory, respectively. In both sections, 9 and 11 out of 20 are the most frequent scores. The results from students in Faculty F’s section follows a normal distribution more closely than that of Faculty D’s class.
Figure 3.11. Scores in Faculty D’s section of CBE 2200 on concept inventory (Spring 2015).

Figure 3.12. Scores in Faculty F’s section of CBE 2200 on concept inventory (Spring 2015).
Figure 3.14 compares the fraction of students who provided the correct answer for each question among the two sections. A horizontal line is shown at 0.50 to highlight which problems had less than 50% of students providing the correct answer. For five questions (i.e., one quarter of the inventory—questions 14, 15, 17, 18, and 20), both sections had fewer than half of the students provide the correct answer. For questions 7 and 12, Faculty D’s section had less than 50% of respondents provide the correct answer, and for questions 10 and 13 less than half of Faculty F’s students answered correctly.

![Bar chart showing student performance on each concept inventory question](image)

Figure 3.135. Comparison of student performance on each concept inventory question between Faculty D and F’s section.

For both question 14 (verbal and sensing presentation, intuitive solution) and 20 (visual, verbal, and sensing presentation, intuitive solution), the correct answer was
“insufficient information to solve the problem.” This was a provided answer, but it is possible that students at this stage in their academic career are accustomed to being given sufficient information to solve the problems they are faced, and thus, may not be prepared to consider that information may be lacking. It is, perhaps, a level of intuitive problem-solving that has not yet developed. Question 15 could be solved mathematically or conceptually, and referred to what operation would result in the greatest increase in energy of 1 kg of water. Questions 17 and 18 were presented both visually and verbally, a paragraph of text followed by a process diagram, and related to understanding process flows with a single global question. Question 17 was also an intuitive solution, as it required evaluation and estimation based on process conditions rather than direct calculation. Question 7 was conceptual (intuitive) and question 12 may appear numerical (sensing) at first, however, it required a conceptual understanding of process flow. Lastly, question 10 was a conceptual question on understanding absolute zero and question 13 required conceptual understanding of molecular composition. The highest performances is seen on question 8, a direct numerical unit conversion question, and question 9, which asks which operation results in the greatest change in energy for a kg of water. Question 9 could be solved conceptually or numerically.

While there are visible differences in student performance on different questions, only question 13 showed a statistically significant difference in student performance between the two sections (p < 0.05). Question 13 is a conceptual question on understanding molecular composition, which requires careful reading. In discussion on Question 13, CBE faculty and graduate students expressed concern about the wording of the question, and the possibility of multiple correct answers. For this reason, we do
not make further inferences from the difference in performance on this question. The question and response for Question 13 are shown in Figure 3.15.

Figure 3.6. Student answers for question 13, the question with statistically significant difference in scores between Faculty D and F.
Summary of Variations in Teaching Style

Closer examination of the exams administered suggests some variations in teaching style among faculty who have taught CBE 2200 in Spring 2013, Spring 2014, Fall 2014, and Spring 2015. While to a large extent, faculty do gravitate toward similar methods of problem presentation and solution, the faculty with the lowest class averages (D and E) also had the lowest occurrence of sequential problem presentation and visual problem solution. Faculty D and E also have the greatest number of problems per exam, and along with Faculty F appear to cover more concepts and use a greater variety of terminology on each exam.

Concept inventory results did not suggest any strong differences between Faculty D and F; however, closer inspection of questions where less than 50% of respondents answered correctly suggests that conceptual understanding (intuitive) and holistic process problems (global) may be needed areas of improvement for the student population. As these dimensions are thought to be associated, it is not surprising that both appear related to lower student performance.

Conclusions and Future Work

ILS profiles for the CBE 2200 student population were fairly consistent from term to term, with students being largely active/reflective balanced, sensing/intuitive balanced, visual, and sequential/global balanced. Sensing and sequential were the more common preferences for students who did report a distinct preference in the associated dimension. Active and reflective preferences were observed in near equal numbers most semesters. Literature reports that engineering students are active, sensing, visual, and sequential. Our results do not strictly agree with this, and may imply that our population is different or that learning styles in the greater population may be changing.
No strong differences have been observed in performance between students with different learning styles, differences in grades assigned by different faculty, as well as teaching styles. Select instances of statistically significant difference (p < 0.05) in student performance based on learning style dimension were seen, at least one instance for each dimension except active/reflective. In each case, the trend observed in performance was in line with what might be expected based on problem types. While these instances do suggest that learning styles may influence performance in certain situations, they are too few to draw stronger conclusions from. Because a greater number of samples is required to identify statistically significant differences on problems that have few points possible (e.g., 5 points) and thus, a low standard deviation (e.g., 1), for many instances our n is too low to achieve a power of 0.95 in this study. Prospective power analysis suggested that an n of 30 to 50+ (depending on the points possible and standard deviation for a problem) would be appropriate to identify statistical significance at $\alpha = 0.05$ and a power of 0.95. This is achievable if all students who consent go on to participate in the study (complete ILS, surveys, etc.).

Survey responses indicate that students have generally high self-efficacy and metacognition with respect to problem performance. Higher reports of confidence in their solution also correlate with higher scores in many instances. Students also report general preferences for sensing and sequential problems, as well as disinclination to use problem solving strategies that are not presented to them. That is, students presented an intuitive problem that could be solved numerically are unlikely to pursue the calculation, and students who are given a verbal description of a process that should then be sketched out may or may not create the visual representation. This may be because the students are at an early stage in their educational development as chemical
engineers and have not yet learned to consider the full array of problem solving approaches at their disposal. Whether students in later courses have the same disinclinations would be an interesting follow-up for comparison. Lastly, students in different terms reported different levels of comfort and/or confidence with making assumptions, while their exams regularly showed incorrect or poor assumptions. This may also be a side effect of the early stage in engineering educational development, however, being able to make valid assumptions is a critical engineering skill and it may be of interest to investigate mastery of assumptions among upper-class students.

Investigation of variations in teaching style and potential causes for the variability seen in final course grades assigned by different faculty showed a few trends. Students in both Faculty D and E’s sections had statistically lower scores (p < 0.05) than their colleagues. Both of these faculty had fewer sequential problems (reported to be preferred by students) and fewer visual solutions on their exams. They also had a greater number of problems per exam, and more concepts covered/terminology used than most other faculty. These factors may influence the final performance of students in their course.

Administration of the standard concept inventory showed fairly similar results between faculty, and some general trends across the CBE 2200 population. Problems where less than 50% of the respondents answered correctly were largely intuitive or global problems. This may suggest an area of weakness in the student population.

It is difficult to make strong conclusions without complete data from each semester studied, and further semesters of study are required to better understand the factors influencing student success in CBE 2200. At this juncture, there are many avenues of further investigation and it is up to the researchers to decide which questions
to examine further. The current undergraduate curriculum chair has expressed willingness and enthusiasm in continued collaboration on this work. Since I will soon be an external investigator at another university, the logistics of how the study is conducted will have to change to accommodate that, and the proper IRB approvals received to include a non-OSU investigator will need to be obtained. These are both very achievable endeavors.

Potential paths forward for this research that are recommended, and will be discussed in detail with the undergraduate curriculum chair before I leave OSU, include:

1. Continued investigation of the variability in instruction in CBE 2200. This should include not only categorizing exam problems for learning style and conceptual breadth, but also assessing if there are noticeable differences in homework problems assigned and evaluating teaching techniques used in class. Teaching techniques may be assessed through a self-report survey administered to the faculty, a teaching techniques survey of the students in the course at mid-term or the end of the term, and/or through collaboration with the University Center for Advancement in Teaching (UCAT). We would look for teaching techniques used, such as lecture, project based learning, problem based learning, demonstrations, classroom response systems, etc. It is recommended, at a minimum, that both the instructors and students are surveyed on instructor teaching techniques, as they may have differing perceptions (e.g., an instructor may believe they are engaging in active-learning style lectures, whereas the students report that they are not actually being actively engaged in class). It may be also interesting to obtain faculty feedback on the concept inventory used for CBE 2200, specifically what concepts they believe it covered well and what
concepts they believe were neglected. This may offer insight into different faculty schemata for what the essential concepts of material balances are.

Student outcomes are a natural measure of instructor success in this context, however, it is important to consider that high performance in the form of high grades does not necessarily correlate with higher understanding or greater knowledge. The concept inventory is considered a more reliable measure of relative student understanding as it is a standardized assessment that focuses on core concepts. Also, it must be noted that other factors may influence student performance in different sections. There may be self-selection among students for a particular section, potentially based on heresay from upperclassmen regarding the particular instructors, attempts to be in class with friends, or one section presenting a scheduling conflict with a course that may be of interest to a subset of the population (e.g., a specific honors course or elective).

2. Continued administration of a standard concept inventory at the end-of-semester to CBE 2200 students. This will provide not only a basis for comparison between sections taught by different instructors, but allow the department to track trends over time that may suggest differences in the background, experiences, and cognitive methods of students as they enter the program. It is becoming more and more commonly accepted that modern life is altering cognitive processes and younger generations have different attention spans, approaches, and expectations than previous generations. There may be a flux in conceptual understanding that has a generational component, and this would be one method of tracking that. The American Institute of Chemical Engineers (AIChE) is currently developing a Concept Warehouse, which once available should include
a standard concept inventory for material balances that may be preferred over the one used in Spring 2015.

3. A longitudinal cohort study of the Spring 2015 and subsequent CBE 2200 sections through their time in the OSU CBE program. This would include student attrition, time-to-graduation, performance in other courses, and post-graduation plans. This study would allow us to track student progress throughout their degree, and potentially identify factors that may influence their future success.

4. Deeper investigation of problem solving strategies by students of different learning styles and performance levels through narrated problem solving sessions. Much of this has been done by Douglas et al. in materials engineering on student problem solving, having a representative sample of students video-recorded (recording hands and paper only to track work) solving specific problems and narrating their problem-solving process real-time may offer greater insights into cognitive processes. Studying not only students at different performance levels (grades of A, B, C, D, etc.), but also of different reported learning style preferences, can further illuminate any relationships between learning styles and problem solving. Ideally, students would be asked to do problems that both match and mismatch with their learning styles. Students selected would be those enrolled in CBE 2200 the previous semester, but participation incentives may be necessary to have students partake in this study.

5. Development of materials for dissemination to faculty on learning styles and association with problem types. This would include an explanation of learning styles, their uses and limitations, as well as Table 3.1 or a similar resource that provides guidance in evaluating their own problem types. Also included would be
suggestions for short activities (bearing in mind that time is a faculty concern) that would address different learning styles. Our hope would be that faculty would use these resources for self-evaluation of their materials (to identify their own biases), and in developing their future exams and lesson plans (to better ensure that they are reaching a variety of learning styles and developing students who are more versatile problem solvers).
Chapter 4 : Study on the Team

While often stereotyped as preferring to work individually, teamwork is the crux of engineering, and an Accreditation Board for Engineering and Technology (ABET) student outcome.\textsuperscript{74} Traditional education is often individual-centric, with homework and exams being completed by and assessed for a single student. In their careers, however, engineers will be required to work in teams and evaluated on their ability to do so. While some courses in the chemical engineering curriculum encourage teamwork through group homework assignments and projects, these tasks often fall victim to the “divide-and-conquer” method, in which students avoid working together by delegating responsibilities among themselves and later combining the final product. Anecdotally, we were aware of varied team dynamics among students in our team-based courses (unit operations and senior design). Team composition has been suggested as a factor in team dynamics,\textsuperscript{38} and we became interested in investigating whether team composition with respect to learning styles may be one method of categorizing teams, and if this study could offer insight into team dynamics.

For our study on the team, we chose the core team-based laboratory course unit operations in chemical engineering. At most institutions it is taken as part of the senior year curriculum. At OSU the course which we studied was initially divided into a spring semester lecture (CBE 3630), taken by most students at the end of their third year, and a one-month laboratory course (CBE 4630) taken immediately following. Students complete
week-long laboratory assignments in teams of four following one of three tracks: classical, biological, or environmental. Team members take on specific roles (team leader, design engineer, operating engineer, or development engineer) that reflect the common components of industrial process teams. Roles rotate among the students so that each student serves in each role during the course. Students report to Teaching Assistants (TAs), who serve as supervisors, during their experiments. Requirements of each laboratory exercise include a daily summary report, data submission, design extension problem, and formal written laboratory report. Students are evaluated on the group laboratory reports, individual quizzes, and a final examination. A peer evaluation is also submitted by each group member for every laboratory. Starting in Spring 2015, unit operations was converted from a five week Maymester course into a two semester course. This was done by spreading out the content from the Maymester into two separate semesters, that is, teams now complete two unit operation laboratories each semester they are enrolled. The lecture portion runs concurrently with the laboratory. Different sets of laboratories run in the fall and the spring, thus, each student must take one fall and one spring semester of unit operations to fulfill graduation requirements.

**Objectives and Hypotheses**

We are looking for correlations between diversity of learning styles in a team, individual evaluation of collective efficacy and team dynamics from surveys and peer evaluations, and group performance through the analysis of groups performing chemical engineering unit operation laboratory tasks. Our hypothesis is that teams composed of students of differing learning styles (i.e., heterogeneous teams) will initially have more difficulty working together, as reflected in survey results, but will ultimately perform better than more homogenous teams.
Study Procedures (Methods)

The sample population is comprised of students enrolled in CBE 4630, Chemical and Biomolecular Engineering Unit Operations II. Annual enrollment is approximately 180 students, comprised of juniors and seniors.

This study aims to investigate the CBE 4630 students’ team dynamics without otherwise influencing the course content or design. The study, in brief, consists of the following:

1) Assignment of students into groups, done by faculty member teaching the course. The instructor strives to balance student GPAs across the course, or at least across teams within each track, and ensure that one identifiable honors student is on each team. We take no part in this process and are only interested in studying the teams as formed by the instructor.

2) Introduction of study to students and collection of consent.

3) Administration of ILS to students enrolled in CBE 4630.

4) Compilation of ILS data to determine make-up of student population enrolled in course with respect to learning styles dimensions.

5) Progression of course as usual, with administration of additional survey at the end of each laboratory to evaluate students’ perspective on their work as a team.

6) Collection and compilation of team grades, and analysis to determine whether a correlation exists with team composition.

7) Comparison of team performance as suggested by grades and students’ survey results.
Data collected include the ILS questionnaire results, the team assignments, individual laboratory assignment grades, overall individual final grade, post-laboratory surveys, and peer evaluations. All information is de-identified before analysis and saved in a de-identified form.

Internal Review Board Approval

In Maymester 2013, this study was run under internal review board (IRB) exemption (IRB did not monitor study). Since we decided to also incorporate the student peer evaluations that are a natural part of the course into the study, we filed for full IRB approval for Maymester 2014 and beyond.

All supplementary documents submitted to the IRB are included in Appendix F: the consent form, recruitment script, and master survey. Each document is the latest approved version. The informed consent document required the most revision by the IRB, as it appeared that each set of reviewers had differing opinions. The current IRB approval is valid through May 2016 and will be up for continuing review in Spring 2016.

Measurement / Instrumentation

The primary variables of interest are team composition with respect to student learning styles and individual evaluation of collective efficacy. We are interested in determining whether team composition has a significant effect on performance and collective efficacy, which is measured by team performance on each assignment as well as post-assignment surveys and peer evaluations. Learning style preferences are determined by the ILS questionnaire.

Post-laboratory surveys for CBE 4630 focus on identifying the individual evaluation of collective efficacy, how the group divided responsibilities, the extent to which they worked together, and the individual contribution to the team task. We are
interested in not only the team members' attitude towards how the group performed or would perform on laboratory-related tasks (collective efficacy), but also the extent to which the group worked together (completed the task as a group effort vs. approached the tasks in a “divide-and-conquer” manner) and precisely what each individual contributed. The surveys are comprised of Likert-type questions on the scale of “Strongly Disagree” (score of 1) to “Strongly Agree” (score of 5) as well as short answers that ask the student to enunciate what their contribution to the group was and what the most beneficial part of group work was for them. Surveys (master survey can be found in Appendix F) are made available the day the written laboratory report is due for a 48 hour period. Figures 4.1 and 4.2 show the course schedule in Maymester and semester, respectively.

Figure 4.1. Timeline of study associated course activities in Maymester.
Figure 4.2. Timeline of study related course activities in regular semester.

**Statistical Analyses**

Comparisons of average done were done with ANOVA, followed by a Tukey test when appropriate (see Chapter 3 for more complete description). All statistical tests were done with a significance level of 0.05.

**Categorization of Teams by Learning Styles**

To better differentiate between effects that may be dimension-specific, we developed a scheme for categorizing heterogeneous (mixed) and homogeneous (uniform) teams within each dimension. A homogeneous team with respect to a specific dimension is a team in which all members are of the same preference, whereas a heterogeneous team involves mixed preferences. Figure 4.3 shows potential team member compositions for the active/reflective dimension and their categorization as homogeneous or heterogeneous as an example.
Figure 4.3. Team categorization with respect to learning styles. Example dimension shows possible combinations leading to homogeneous teams. Preferences connected by a hyphen occur on the same team.

Results and Discussion

The study on the team with CBE 4630 was conducted three times: Maymester 2013, Maymester 2014, and Spring 2015. Unfortunately, participation was low in every term, leading to sparse results.

Maymester 2013

The May 2013 class had 180 students enrolled, resulting in 45 teams. Of these, 173 submitted ILS results as well as gave consent for our study. The summary of student ILS responses is given in Figure 4.4. These students do not show a dominant preference in the active/reflective dimension, however, they do show favor towards sensing, visual, and sequential (similar to students in CBE 2200). Again, except for the active/reflective dimension, this is similar to the commonly cited active, sensing, visual, and sequential preferences of engineers.20
Of the 45 student groups, there were 20 in which all members gave consent and submitted the ILS. Of these groups, almost all were heterogeneous (composed of mixed learning styles) across all dimensions. Two groups were homogeneous-balanced with respect to sensing/intuitive, one group was homogeneous visual, and four groups were homogeneous-balanced with respect to sequential/global. Because balanced students are characterized by being comfortable with both preferences within a learning styles dimension, these groups are not considered truly homogeneous but rather cases of special interest that could demonstrate homogeneous or heterogeneous behavior depending on which preference is “activated” by the members at the time. Thus, the only true homogeneity observed was in the one group that was homogeneous visual. The lack of homogeneous groups is a bit unexpected, as there is a large degree of homogeneity in the population at large.

Figure 4.4. Index of Learning Styles profile for Maymester 2013 unit operations class.
When analyzing learning styles and grade, no significant difference was found among groups ($\alpha = 0.05$). The average final grade of each group fell within a narrow 10 point range. This may be a reflection of how the groups are assigned, as they are selected by the faculty to balance average GPA across all teams.

Survey completion and submission was erratic in this first run of the study. Surveys were administered on paper intended to be submitted to a course TA or the investigator’s mailbox at the time of report submission. It was discovered that the majority of students were completing the surveys when they received them, at the beginning of their laboratory assignment, as opposed to after they had completed the laboratory. This invalidated survey responses, as students could not truthfully assess how their group conducted a laboratory before they had done so. For this reason, no observations can be made from this population.

Maymester 2014

The May 2014 study yielded disappointingly low participation. Fewer than 10 students completed the ILS, and survey responses were comparably sparse. Additionally, only 29 of the 200 students enrolled provided consent, and there was no group in which every member gave consent, making analysis not practical.

Spring 2015

Unfortunately, participation was again extremely low in Spring 2015. This was the first time unit operations was offered in a semester, rather than Maymester, and survey participation averaged about 20 students per survey (less than 15% of the class). Not a single student completed the ILS. Efforts at reminders and announcements regarding the study had no effect on participation. This may have, in part, been due to it being the first semester under the new course model. Also, graduating seniors were “doubled up”
on laboratories. In an effort to ensure their timely graduation despite the curricular change, graduating seniors completed all four required laboratories in their track in the semester. This curricular change coincided with a departmental move into a new building, and much of the equipment was being set up as the semester was progressing. All of these factors may have influenced student participation, as well as faculty engagement.

Of the 144 enrolled students, 105 did provide consent, allowing us to examine final team grades. The class had 32 groups, nine of which had every member provide informed consent. Of these, average group performance did not vary with team. Again, average final grades of the teams were within nearly a 10-point range, suggesting that the incoming GPA used to balance teams is a good predictor of unit operations final grade. Standard deviation of team member final grades were largely similar from team to team, most between six and twelve, however, two teams did have a standard deviation closer to 20, suggesting a wider range in student performance in those groups.

Summary of Results and Discussion

While we did not have approval to gather GPA data on students as part of this study, it can be postulated that student performance in this class had a positive correlation with student GPA entering the class, based on the low variability in average team scores. Further data collection (and subsequent analysis) is needed to incorporate team dynamics with performance data.

Future Work

After several unsuccessful attempts at studying unit operations, further study with this course under the current approach is not recommended. If the study is to proceed,
all study components must be integrated into the course requirements in order to assure participation. Maymester 2013 was the only term in which the ILS was given to the students as an assignment, and also correlates with the highest response rate, the response in 2014 and 2015 being negligible.

What may be more interesting is to investigate the correlation with prior team work experiences and whether the student has or is taking the senior design course with unit operations. Senior design, the course discussed in the next chapter, includes a focus on coaching students through working in teams that may impact their success as team players in unit operations (CBE 4630). Prior experiences working in teams, and especially in a technical/manufacturing setting, may be of interest to future studies, as well as whether or not the students have completed or are concurrently enrolled in senior design. Senior design, as will be described in the next chapter, provides a more structured teamwork setting. Teams are required to draft a team agreement before beginning their project, and team leaders and members meet with the instructional staff to discuss how the team is functioning. Such structure is recommended to guide students in developing into better team members, as well as optimize team performance\textsuperscript{36,75} and students who have been, or are concurrently in, senior design may have had an advantage from that experience.
Chapter 5 : Combinatorial Study

Process Design and Development (CBE 4764), colloquially known as senior design, is a one semester core course in OSU’s chemical engineering program. It is offered in both the fall and spring, and usually taken as part of the senior year curriculum. The course content focuses on completion of design projects (three each term), which provide real applications to chemical engineering theory. Two design projects are completed individually and one is completed as a team. For the team design project, each team member takes on the role of an expert with respect to a specific area (technical, simulation/modeling, economic, and safety/environmental) to better simulate industrial teamwork scenarios. Facilitated team and group leader meetings provide guidance in team dynamics to student groups. Progress in both individual and team projects is assessed through various assessments including quizzes and reports.

Much of a traditional curriculum is designed around individual assessment, but most engineers are more likely to be assessed as part of a team in their career. Having studied self-efficacy and learning styles trends in sophomore students for several semesters and noticing trends that may be explained by their early stage in career (see Chapter 3, Conclusions and Future Work), we began to wonder about our senior students. Are they entering the workforce with high self-efficacy and a command of chemical engineering theory and design principles? Are their unit operations and senior design courses, structured more to mimic real-life engineering environments, developing
their self-efficacy and preparing them for their careers? At this point we had twice implemented the study on the team described in Chapter 4, with disappointingly low participation and thus very few results. Whereas the focus of that study had been on collective efficacy, we became interested in better understanding our senior students’ self-efficacy, and the potential impact of teamwork on this self-efficacy. With these questions, we focused our attention on developing a new study for the senior design course (CBE 4764). The individual and team project structure of the course makes it ideal for tracking changes in self-efficacy throughout the term, and the regular lecture and computer lab time provides a more structured environment of faculty-student interaction that we believed may result in better participation than unit operations. Furthermore, the course provides structured guidance in teamwork, including developing a team contract, which is recommended in the literature regarding developing effective teams in the classroom.\textsuperscript{36,75} This provides a contrast to unit operations (CBE 4630), where little formal guidance in teamwork is provided.

**Objectives and Hypotheses**

The combinatorial study of the individual and team focuses on some of the aspects of the other two studies, but with an added component of comparing the students in both individual and team settings. We are interested in not only student self-efficacy on their individual projects, but also if (and how) their self-efficacy is influenced by their team experiences. We hypothesize that positive team experiences (reflected by positive reports on team dynamics) will result in higher self-efficacy, and negative team experiences in lower self-efficacy. We are also interested in continuing our investigation into student learning styles profiles and their influence in success. We hypothesize that students of heterogeneous team composition with respect to learning styles will report
lower team dynamics and performance earlier on, but demonstrate higher performance and report higher self-efficacy at the end of the term.

**Study Procedures (Methods)**

The sample population is comprised of students enrolled in CBE 4764, Chemical and Biomolecular Engineering Process Design and Development. This is a required core course for OSU undergraduate chemical engineering majors, and enrollment for the 2014-2015 academic year (two semesters) is about 150 students, comprised of juniors and seniors. This study aims to investigate the Spring 2015 semester taught by Faculty G (note: Faculty G did not teach CBE 2200 during our study of the course, and no faculty comparisons are being made, the notation Faculty G is used merely for convenience) by looking at the CBE 4764 students’ individual performance and team dynamics without otherwise influencing the course content or design. The study will consist of the following:

1) Introduction of the study and distribution/collection of informed consent.

2) Administration of ILS.

3) Compilation of ILS data to determine make-up of student population enrolled in course with respect to learning styles dimensions.

4) Progression of course as usual, with administration of survey throughout each design project (paired with progress assignments) to evaluate students’ perspective on their work individually or as a team.

5) Collection and compilation of individual and team grades, and analysis to determine whether a correlation exists with team composition.
6) Analysis for correlations between individual learning style preferences, performance, and self-efficacy as well as team composition with respect to learning styles, group performance, and self-efficacy.

Data collected are the ILS results, surveys, and student grades, and peer and instructor/TA evaluations of teams. All information is de-identified before analysis and saved indefinitely as data records only in de-identified form.

Internal Review Board Approval

As this is again human subjects research, IRB review is required. The supplementary documents submitted to the IRB are included in Appendix G. These include the consent form, recruitment script, and master survey. Each document is the current approved version. IRB approval will expire in December 2015 and will be up for continuing review in Fall 2015.

Measurement / Instrumentation

At the individual level, the primary variable of interest is student learning style, with each dimension considered separately. Learning styles will be evaluated by the ILS and analyzed with student performance and self-efficacy, measured by assignment grades and survey responses, respectively.

For the group level study, the primary variable of interest is team composition with respect to student learning styles. We are interested in determining whether team composition has a significant effect on performance and perception, as measured by team performance on each assignment as well as post-assignment attitude (and individual evaluation of collective efficacy) surveys. Furthermore, we are interested in
evaluating self-efficacy during the team design project, to better understand how variable group dynamics may influence student self-efficacy evaluation.

Surveys are administered periodically throughout the term. They are made available to coincide with project benchmarks (assessments, progress reports). Surveys are administered online through the Carmen website and available for one week when released. Students are notified by e-mail when a survey is made available. Self-efficacy items on the survey were selected from the instrument for evaluating student self-efficacy in senior design published by Carberry et al. As participation has been an ongoing issue, and previous experience has shown a decreased likelihood of participation with increased survey length, we were hesitant to use the full Carberry instrument. The full instrument evaluates the same nine items in the context of four self-concepts (self-efficacy, motivation, outcome expectancy, and anxiety). This creates a 36-item instrument, plus our questions of interest regarding future career plans, ability to recall previous coursework, and attitudes toward design and associated skills. Because there is no requirement or incentive to complete the survey, we chose to limit the survey items to avoid losing participation on account of a lengthy survey. The first survey had 16 items (self-efficacy and general perception items), and surveys 2 and 3 had 25 items (self-efficacy, general, and anxiety items). In future work, it is recommended that the surveys became a required component of the class and the Carberry instrument used in full.

Survey items were all five-point Likert type scales, with the scale varying depending on the question. Self-efficacy items evaluated confidence from “cannot do at all” (score of 1) to “highly certain can do” (score of 5), general perception questions had a scale from “strongly disagree” (score of 1) to “strongly agree” (score of 5), and anxiety
self-concept questions had the scale “not anxious at all” (score of 1) to “highly anxious” (score of 5). Carberry’s original instrument uses a 100 point scale in full or increments of 10, but there was concern that this would give the students too many options. For that reason, and to maintain consistency with our other work, we imposed the 100-point scale used by Carberry onto a five-point scale.

Three surveys were administered: (1) one early in the semester corresponding with a milestone on the students’ individual project, (2) one shortly after midterms while students were working both on an individual project and had begun working on their team project, and (3) one at the end of term after the team project had been completed. Thus, students are working entirely independently for a portion of the time between surveys 1 and 2, and combined the surveys track student self-efficacy changes as they progress from individual work through teamwork.

Team dynamics information was collected through CATME (Comprehensive Assessment of Team Member Effectiveness), a web-based teamwork management system unrelated to OSU’s design course. CATME provides summary and analysis of teams and individuals based on a set of algorithms. In certain cases, individuals may be flagged with one of several “exceptional conditions” codes denoting students whose evaluations suggest underconfidence, overconfidence, high performance, low performance, a potential conflict with a team member, etc. Evaluations are done on a scale of 1 to 5, where 5 indicated a high rating and 1 a low rating. The schedule of assignments, peer evaluations, and survey administration is depicted in Figure 5.1.
Statistical Analyses

For continuous numeric variables (grades), the statistical analysis method used in this work is one-way ANOVA for sample sizes greater than 30, as described in Chapter 3, Statistical Analyses. If the null hypothesis is rejected through an ANOVA, Tukey's range test of comparing all sample means to each other is used to identify which sample(s) are different from the others at a statistically significant level ($\alpha = 0.05$).

When the sample size is less than 30, the Kruskal-Wallis test for assessing variation in means is the nonparametric alternative to a one-way ANOVA, and the Steel-Dwass all pairs test is the nonparametric alternative to the Tukey test.

Results and Discussion: Class ILS Profile

Of the 78 students enrolled in senior design in Spring 2015, 46 completed the ILS (roughly 60% of the class). As was also seen in the 2200 study, around half of the students report a balanced preference in each dimension, except in the visual/verbal dimension where more than 50% of students report a visual preference (Figure 5.2).
Among the students that report a preference in the other dimensions, active, sensing, and sequential are the dominant preferences, consistent with literature reporting typical engineer preferences in these dimensions. Interestingly, these results are different from what we observed in the sample population in our CBE 2200 study (on the individual). For the CBE 2200 population, in all but one term the number of active and reflective students was near equal, whereas here in CBE 4764 all the typical dominant engineering dimensions are observed in the students reporting a preference within a given dimension (i.e., students who are not “balanced”). Based on a typical progression through the curriculum, some of the students in the Spring 2015 section of senior design would have encountered our CBE 2200 study as well. This suggests that we may be observing a potential shift in the learning styles profiles of our students as they advance through the curriculum. We do not have approval to compare ILS responses between...
CBE 4764 and 2200, which may be of interest for future study. If the students have shifted in preference to more closely agree with the literature reports on engineering student preferences, then this would further support that learning styles are malleable and influenced by education. Whether engineering draws a particular learning style population, or whether the curriculum develops these learning styles in the population is still a matter of discussion. It may be beneficial for faculty to be aware of these potential differences from class-to-class and year-to-year.

**Results and Discussion: Student Self-Efficacy**

In many areas, student self-efficacy increased during the term. In Table 5.1, items 1 to 9 represent self-efficacy items included on all three surveys. Items 10 to 16 are general perception items included on all three surveys, and items 17 to 25 are self-efficacy (related to anxiety, another self-concept, from Carrberry et al.’s instrument for design self-efficacy) items included on just surveys 2 and 3. Items marked with an asterisk before the question text (*) indicate that a significant difference was observed in student responses (matched pairs) between surveys 1 and 2 (p < 0.05). Items marked with a carrot (^) indicate that a significant difference was observed in student responses between surveys 2 and 3 (p < 0.05). For all self-efficacy items, this change was in the direction of increased self-efficacy. The only perception item to show a significant difference (item 10, p < 0.05) was in the direction of lessened agreement.
Table 5.1. Items on self-efficacy and perceptions instrument administered in senior design. An asterisk (*) indicates items where a statistically significant difference in matched pairs response was observed between Survey 1 and 2, and a carrot (^) represents items for which a statistically significant difference was observed between Survey 2 and 3. Items 17 to 25 were only administered on Surveys 2 and 3.

<table>
<thead>
<tr>
<th>Item #</th>
<th>Item Text</th>
</tr>
</thead>
<tbody>
<tr>
<td><strong>Self-Efficacy Items on All Surveys</strong></td>
<td></td>
</tr>
<tr>
<td>1</td>
<td>*^Rate your degree of confidence in performing the following task: conduct engineering design.</td>
</tr>
<tr>
<td>2</td>
<td>*Rate your degree of confidence in performing the following task: identify a design need.</td>
</tr>
<tr>
<td>3</td>
<td>Rate your degree of confidence in performing the following task: research a design need.</td>
</tr>
<tr>
<td>4</td>
<td>*Rate your degree of confidence in performing the following task: develop design solutions.</td>
</tr>
<tr>
<td>5</td>
<td>^Rate your degree of confidence in performing the following task: select the best possible design.</td>
</tr>
<tr>
<td>6</td>
<td>Rate your degree of confidence in performing the following task: develop a simulation for a design.</td>
</tr>
<tr>
<td>7</td>
<td>*^Rate your degree of confidence in performing the following task: evaluate and test a design.</td>
</tr>
<tr>
<td>8</td>
<td>*Rate your degree of confidence in performing the following task: communicate a design.</td>
</tr>
<tr>
<td>9</td>
<td>*Rate your degree of confidence in performing the following task: redesign.</td>
</tr>
<tr>
<td><strong>General Perceptions</strong></td>
<td></td>
</tr>
<tr>
<td>10</td>
<td>^Design skills are important for chemical engineers.</td>
</tr>
<tr>
<td>11</td>
<td>It is important to know the theory (governing equations and principles) behind engineering design.</td>
</tr>
<tr>
<td>12</td>
<td>I will use engineering design principles in my career.</td>
</tr>
<tr>
<td>13</td>
<td>I intend to pursue a career in chemical engineering.</td>
</tr>
<tr>
<td>14</td>
<td>I have been able to recall the theory I learned in previous courses and apply it to the design.</td>
</tr>
</tbody>
</table>

(continued)
I have had difficulty recalling the appropriate theory from previous courses that is needed to proceed with the design.

I intend to pursue a career that deviates from chemical engineering.

| 15 | I have had difficulty recalling the appropriate theory from previous courses that is needed to proceed with the design. |
| 16 | I intend to pursue a career that deviates from chemical engineering. |

Self-Efficacy Items on Surveys 2 and 3

| 17 | ^Rate your degree of anxiety in performing the following tasks: conduct engineering design |
| 18 | ^Rate your degree of anxiety in performing the following tasks: identify a design need. |
| 19 | Rate your degree of anxiety in performing the following tasks: research a design need. |
| 20 | Rate your degree of anxiety in performing the following tasks: develop design solutions. |
| 21 | ^Rate your degree of anxiety in performing the following tasks: select the best possible design. |
| 22 | Rate your degree of anxiety in performing the following tasks: develop a simulation for a design. |
| 23 | ^Rate your degree of anxiety in performing the following tasks: evaluate and test a design. |
| 24 | Rate your degree of anxiety in performing the following tasks: communicate a design. |
| 25 | Rate your degree of anxiety in performing the following tasks: redesign. |

Between surveys 1 and 2, there was a general increase in self-efficacy on/confidence in: conducting engineering design, identifying a design need, develop design solutions, evaluate and test a design, communicate a design, and redesign.

Between surveys 2 and 3, students reported an increased self-efficacy on/confidence in: conducting engineering design, select the best possible design, and evaluate and test a design. The overlapping items are conducting engineering design, and evaluate and test a design. For those two items, students reported a gain in self-efficacy both between the first and second survey, and the second and third. Several items that showed statistical...
significance ($p < 0.05$) between surveys 1 and 2 did not between 2 and 3, suggesting that the highest gains in self-efficacy for these items (identify a design need, develop a solution, communicate a design, and redesign) may be in the early portion of the class, potentially as a result of the steeper learning curve that students may be experiencing as they are introduced to design. Self-efficacy with respect to selecting the best possible design, however, only showed significant gains between surveys 2 and 3, suggesting that self-efficacy in selecting the design may be positively impacted by working in a team, as well as accumulating experience. Structured discussions that improve design selection, and possibly affirm students’ independent ideas, may lead to a group influenced gain in self-efficacy.

With respect to items only asked on surveys 2 and 3, students reported gains in self-efficacy (as a decrease in anxiety) on: conduct engineering design, identify a design need, select the best possible design, evaluate and test a design. Only three of these four items correspond with the gains in confidence reported between surveys 2 and 3 (the only one that does not is identifying a design need). This may be an artifact of differences that stem from the verb choice in the question (anxiety vs. confidence). Since anxiety influences self-efficacy, confidence (self-efficacy) and anxiety are not mutually exclusive self-concepts, and we would expect that higher self-efficacy would be related to lower-anxiety. However, as these students are early in their design careers they may be considered novices in the area, which may lead to feelings of anxiety despite confidence in ability with respect to a task.

These results suggest that either the nature of design and/or the course approach allows for time-dependent gains in self-efficacy. It may be that certain items showed a statistically significant difference in self-efficacy only in the first half of the term.
because those items are prerequisite to other gains and can be more easily grasped early in the education of design, and/or because these items are most directly related to what may be a steep learning curve for students entering design.

Item 10, “design skills are important for engineers,” is the one general perception item that showed a statistically significant result, specifically a decrease in agreement, between surveys 2 and 3. After examining the student peer-evaluation comments, several students reported in their final evaluation that they were frustrated with their client, communication, or lack of direction. While this is only a small handful of students, these frustrations with their project may have influenced their view toward design skills.

Results and Discussion: Student Population Characteristics

As just mentioned in the previous section, most students agreed with the statement, “design skills are important for chemical engineers,” however, this item did show a statistically significant change in response between surveys 2 and 3, in the direction of less agreement. As has been postulated, this may be a result of increasing student frustrations near the end-of-term projects, as several students expressed in their peer evaluations that they wished for more guidance from and/or interaction with their client. This item was the only one in which a statistically significant change in student responses occurred from one survey to another.

Most students agreed that it is important to know the theory behind engineering design, that they will use design principles in their career, and that they intend to pursue a career in chemical engineering. Fifty-eight percent of students agreed or strongly agreed that they were able to recall the theory learned in previous courses and apply it to design (item 14, shown in Figure 5.3), but a high number of students (32%) also reported being neutral or disagree/strongly disagree (10%) on this matter. Along the
same lines, in response to a statement regarding difficulty recalling the appropriate theory needed from previous courses (item 15, shown in Figure 5.4), about the same number of students responded with agree/strongly agree (38%), disagree (32%), and neutral (30%). While this result seems to contradict the earlier statement (item 14) of being able to recall theory and apply it to the design, it may indicate a subtle difference in what is being asked in each item. Item 14, “I have been able to recall the theory I learned in previous courses and apply it to the design,” implies recall and application. Item 15, “I have had difficulty recalling the appropriate theory from previous courses that is needed to proceed with the design,” strictly asks about recall. The former (item 14) may be interpreted as including not necessarily just the ability for rote recall, but also recalling enough to further look up the needed information and theory and apply it. The latter (item 15), on the other hand, may appear to focus on the ability to instantaneously recall relevant theory, and thus may lead to students agreeing to both (i) having the ability to recall theory and apply it, as well as (ii) having difficulty recalling theory.
Figure 5.3. Responses to Item 14, “I have been able to recall the theory I learned in previous courses and apply it to the design,” for survey 1.

Figure 5.4. Responses to Item 15, “I have had difficulty recalling the appropriate theory from previous courses that is needed to proceed with the design,” for survey 1.
The ability to recall and apply theory at the time of need is an essential engineering skill. Student reports of being unable to do so may suggest that the foundations from earlier classes are weaker than we would like, or that there is a problem of knowledge transfer. Knowledge transfer is a concern within the educational setting as students have been observed to have difficulty in applying material from one subject to another, and is also important in the workplace. A mismatch between types of knowledge gained (theoretical) and types of knowledge needed (practical) in industry can be part of the problem in professional knowledge transfer. Practicing application in a variety of contexts is considered important in developing strong knowledge transfer. For this reason, courses such as senior design (and unit operations) that bridge the theory-to-practice are essential to curricula, and evaluating these courses for improvement should be a priority.

A final observation from the surveys, while not statistically significant, “I intend to pursue a career that deviates from chemical engineering” (item 16), does show an interesting trend from survey 1 through 3 as shown in Figure 5.5 and 5.6. For survey 1, most students are neutral to (44%) or disagree/strongly disagree with (38%) the statement. By survey 3, a large portion of students again responded with disagree/strongly disagree (42%) with this statement, but more than a third also expressed agreement/strong agreement (39%). Again, this is not statistically significant, however, since fewer students responded to survey 3 than survey 1, it may provide some interesting insights into the population that continued to participate in all of the study surveys. There was no statistical significance in the change in student responses to item 16 between survey 1 and 3, and the change in each student’s response is minimal. However, the spread of the responses clearly has changed.
Figure 5.5. Student responses for Item 16, “I intend to pursue a career that deviates from chemical engineering,” on survey 1.

Figure 5.6. Student responses to Item 16, “I intend to pursue a career that deviates from chemical engineering,” on survey 3.
Closer inspection of item 13, “I intend to pursue a career in chemical engineering,” shows that while most students continued to agree/strongly agree from surveys 1 (74%) to 3 (69%) there is a small increase in the percent of students who disagree/strongly disagree (7 to 12%). Looking at the matched pairs of responses between items 13 and 16, most students who agree/strongly agree with item 13 disagree/strongly disagree with item 16, as would be expected, however, there is also a larger number of students who agree/strongly agree with item 13 but express “neutral” for item 16. This may indicate that while students do, in large, intend to pursue careers within chemical engineering they are not opposed to a career that deviates from chemical engineering. It may be beneficial to increase the pool of questions in this area to gather if the students have specific career aspirations that may be tangential to their chemical engineering degrees.

The rigor of and problem solving skills developed in an engineering program make engineer highly appealing to employers in a broad range of industries,\textsuperscript{84,85} and many students enter chemical engineering for this marketability with the intention of going into an alternative discipline. Student career aspirations, and specifically whether they are related to traditional chemical engineering, may influence motivation and performance in courses, especially as they near the completion of their degree and unrelated career paths cause the material to lose relevancy. If a team member is unmotivated as they find the subject matter irrelevant to their career, they may be less committed to the project at hand. It is also possible that frustrations in courses such as senior design may be dissuading some students from continuing in a chemical engineering career. If this is true, it is important that faculty are aware of this possibility, and work to keep student morale high throughout the course of their projects.
Results and Discussion: Role of Team Dynamics

In large part, most teams reported positive team dynamics. As a part of the regular course, peer evaluations are completed through CATME. As mentioned in the methods, in certain cases an individual may be flagged with one of several “exceptional conditions” codes, of which four were observed in our senior design course: “high” representing a high performer, “under” representing an underconfident individual, “over” representing an overconfident individual, and “conf” representing a potential conflict that may have existed between this team member and another. High performers are defined as individuals whose average rating is above a 3.5 (out of 5), and at least 0.5 points higher than the average team rating. Underconfident individuals are those whose teammates all rated above a 3, but their self-rating was at least one point lower. Overconfident individuals are those whose rating from their team members is less than a 3, but their self-rating is at least one point higher. Lastly, a conflict is flagged when a student’s evaluation of a specific team member does not agree with the other team members’ evaluation of that same individual. Specifically, if a student gives a 2 or lower to a team member who otherwise has an average rating of 3 or higher, this may be a sign of a personality conflict.

Exceptional Conditions

Four students were flagged as “underconfident” after their first peer evaluation, which was completed just before survey 2. Unfortunately, these four students did not complete all three surveys, however, two of the three who did complete surveys 1 and 2 showed a dip in self-efficacy between the two surveys, which may reinforce the results of the CATME evaluation. A summary of survey responses for all students flagged with exceptional conditions is provided in Table 5.2. As these same students were not
reported “underconfident” on the second peer evaluation at the end-of-term, it would have been very interesting to see if their reported self-efficacy in our surveys increased from survey 2 to 3. If there was an increase at survey 3, this could have been a very encouraging result to witness students developing into more confident chemical engineers, especially at a very crucial time just prior to embarking on their professional careers beyond OSU.

Table 5.2. Summary of survey responses for students flagged as “exceptional conditions” on CATME peer evaluations.

<table>
<thead>
<tr>
<th>Peer Evaluation #</th>
<th>Students Displaying Exceptional Conditions</th>
<th>Self-efficacy</th>
<th>Anxiety</th>
</tr>
</thead>
<tbody>
<tr>
<td></td>
<td></td>
<td>Survey 1</td>
<td>Survey 2</td>
</tr>
<tr>
<td></td>
<td>High Performer</td>
<td>2.2</td>
<td>2.7</td>
</tr>
<tr>
<td></td>
<td>Underconfident 1</td>
<td>3.0</td>
<td>4.0</td>
</tr>
<tr>
<td></td>
<td>Underconfident 2</td>
<td>4.9</td>
<td></td>
</tr>
<tr>
<td></td>
<td>Underconfident 3</td>
<td>3.6</td>
<td>2.9</td>
</tr>
<tr>
<td></td>
<td>Underconfident 4</td>
<td>3.4</td>
<td>3.2</td>
</tr>
<tr>
<td></td>
<td>Conflict 1</td>
<td>4.6</td>
<td>3.9</td>
</tr>
<tr>
<td></td>
<td>Conflict 2</td>
<td>2.4</td>
<td>3.4</td>
</tr>
<tr>
<td></td>
<td>CLASS AVERAGES</td>
<td>3.5</td>
<td>3.8</td>
</tr>
<tr>
<td></td>
<td>High Performer</td>
<td></td>
<td>3.7</td>
</tr>
<tr>
<td></td>
<td>Underconfident 1</td>
<td>4.0</td>
<td>4.7</td>
</tr>
<tr>
<td></td>
<td>Underconfident 2</td>
<td>3.6</td>
<td>3.9</td>
</tr>
<tr>
<td></td>
<td>Underconfident 3</td>
<td>3.6</td>
<td>2.9</td>
</tr>
<tr>
<td></td>
<td>Underconfident 4</td>
<td>2.6</td>
<td>3.1</td>
</tr>
<tr>
<td></td>
<td>Overconfident 1</td>
<td></td>
<td></td>
</tr>
<tr>
<td></td>
<td>Overconfident 2</td>
<td></td>
<td></td>
</tr>
<tr>
<td></td>
<td>Conflict</td>
<td></td>
<td></td>
</tr>
</tbody>
</table>

Most of the four students who were flagged “underconfident” in the second peer evaluation did not complete all three surveys. While three of these four students reported increased self-efficacy between surveys 1 and 2, only one provided survey 3 data with which to compare. The student who completed all three surveys consistently reported
lower than average self-efficacy, but they also showed increasing self-efficacy from surveys 1 to 3. With respect to anxiety, they reported an increase in anxiety between surveys 2 and 3. Underconfident 3 in Table 5.2 is the same student for both peer evaluation 1 and 2. This is the only student to have the same exceptional condition as defined by CATME in both evaluations.

One “conflict” student surfacing from peer evaluation 1 did experience a dip in self-efficacy score between surveys 1 and 2, which could be related to having an unfavorable team experience. However, the other “conflict” student reported an increase in self-efficacy between surveys 1 and 2, with no change between surveys 2 and 3. They also reported a decrease in anxiety between surveys 2 and 3.

There was one high performer on evaluation 1. This student showed both lower self-efficacy and higher anxiety than the class average for all three surveys. Their reported self-efficacy did increase over time, however, their anxiety did not change. The high performer on evaluation 2 only completed survey 2, and their self-efficacy and anxiety values were close to the class averages.

Although lack of complete survey data from students who were flagged as exceptional conditions impedes drawing conclusions from these students, it is interesting to observe the changes in self-efficacy and with more complete survey data may be able to draw conclusions on the possible correlations between student self-efficacy and exceptional conditions as reported by CATME.

**Team Dynamics**

Of the 21 senior design teams, three had members make comments in peer evaluation 1 that were indicative of conflict (communication problems, uneven workload, etc.). In peer evaluation 2, one third (7 of 21) of the teams had at least one comment
indicating a potential team dynamic or cohesion issue. The increase in the number of teams reporting negative cohesion may have to do with end-of-term stress and frustrations when working under pressure. Only one team, Team B, had report of team dynamic issues in both peer evaluations 1 and 2. This suggests that, perhaps, for other teams, issues that were evident early were dealt with and resolved between evaluations 1 and 2, while others did not begin experiencing issues until later on when they felt the urgency of final deadlines. These are all interesting observations, as professional chemical engineers will be constantly faced with deadlines and significant projects that, for example, can affect people's safety and/or a company's bottom line. Having the proper training on how to handle these situations, which can start in our senior design course, will enable students to spread their knowledge on overcoming conflicts when future conflicts occur.

Results and Discussion: Student Performance

Overall, there was little statistically significant difference among student scores. With respect to students of different learning styles, only the visual/verbal dimension showed statistical significance \( (p < 0.05) \) in two instances; balanced students performed better than visual students on both their (i) final reports and (ii) project 3. Since these assignments are related, it is not surprising that both would show the same trend. Balanced students may have had an advantage in dealing with the written and visual material that is necessary in compiling the final report and project. Unfortunately, out of the students who reported ILS preferences, none were verbal, so we do not have information on verbal students for this dimension.

Statistically significant differences in team scores (average of individual team members' scores) were found for the final report, final presentation, project 3, and final
grade (p < 0.05). Project 1 and Project 2, both individual projects, showed no statistically significant difference in mean score by team. This result implies that team effects may be at play in the final grade, as statistically significant differences in student performance by team are only evident in team assignments.

Because only one team had every member provide ILS information, we could not proceed with an analysis of team composition with respect to learning styles and its impact on performance. However, we were also interested in understanding the influence of team cohesion on performance, and upon closer inspection of the available team scores (only 9 of 21 teams had all members provide consent, allowing us to analyze them), it is clear that there is no strong correlation between whether a team dynamic issue was noticed and overall team performance (specifically on the grades that had a statistically significant difference in score by team mentioned above). However, the majority of cases in which teams that reported a conflict/dynamics issue also had a larger standard deviation in their team members’ scores. Furthermore, the standard deviation of individual scores within each team seems to be greatest for teams with lower performance and a reported cohesion problem. These results are summarized in the tables of Appendix H.

The differences in standard deviation indicate that teams describing dynamic issues are often composed of individuals with a greater variation in performance. Because peer evaluations are factored into the grades on team assignments (students who have low evaluations receive lower scores than their peers), this variation is not surprising. The next question becomes whether this variation in performance is innate to the team members, or a side-effect of poor team cohesion. That is, do teams composed of students with greater performance variation have poor team cohesion, or do teams
with poor cohesion end up with greater performance variation. However, no consistent correlation between individual team member scores throughout the term and cohesion was observed (i.e., no consistent variation in individual vs. team performance), suggesting that other factors are involved. Two of the six teams that reported conflict (and for which grade data is available) did have a 20 or more percent difference between the maximum and minimum average project grade of team members. After converting average project grades to letters, teams with reported cohesion problems also were more likely to have grades that were not within two-thirds of each other (a third referring to A vs. A-). That is, 5 of the 6 teams had at least one student whose score was more than two-thirds a letter grade below the team maximum. This may signal that performance differences among team members are not an effect of poor team cohesion, but perhaps a contributing factor. We did not have approval to collect pre-term core chemical engineering course GPA, however, this may serve as a source of information regarding students’ previous performance and allow us to better understand what causes the greater variability in scores among students with lower team cohesion.

**Conclusions and Future Work**

Similar to our study on the individual in CBE 2200, no strong correlations between learning style and student performance are observed. This is contradictory to findings of several other investigators and may be a result of not having full student participation in the ILS. Especially when evaluating team effects, it is crucial to have each team member's full participation and collection of individual information. Having only 9 of 21 teams provide full consent, and only one of those teams having full ILS information greatly hindered team analyses.
Self-efficacy gains were evident in most of the items measured, indicating that senior design does have a positive effect on student self-efficacy. Some items showed gains between all three surveys, while others only between surveys 1 and 2, or surveys 2 and 3. This may indicate that there is a time-dependent variable that affects self-efficacy development. More items showed self-efficacy gains between surveys 1 and 2, suggesting that the steeper learning curve of the first half of the course may result in high gains in self-efficacy here, and that this has a greater influence than team dynamics as fewer gains were observed between surveys 2 and 3. Confidence in conducting design and evaluating and testing a design showed gains between both surveys 1 and 2, and 2 and 3. It is not unexpected that students would experience increased confidence with increased experience, and the observation of continually increased self-efficacy throughout the term in these items is encouraging to the value of all three projects and the teamwork in developing self-efficacy. Student self-efficacy with respect to selecting the best possible design only showed statistical significance (in the direction of higher self-efficacy) between surveys 2 and 3, which is during the time at which projects go from more individual-focused to more team-based work. This may reflect that student confidence in making decisions such as design selection increases when discussed and validated by others (team members).

Scores for items where teamwork was a grade component (final report, final presentation, project 3, and final grade) showed that there were statistically significant differences between teams. These, however, did not clearly correlate with team cohesion information. Teams with reported cohesion issues did not perform worse than others. However, the standard deviation among team scores was greater in most cases for teams with a reported problem, and this trend was more strongly observed among
teams with lower performance (that is, lower team average performance and reported team cohesion problems resulted in a higher standard deviation in scores). As team member scores are a combination of the score received for the final team artifacts and individual efforts (peer evaluation, etc.), this may indicate that teams with higher cohesion result in greater consistency between individual and team performance. That is, teams with high cohesion may be composed of individuals who either previously have more similar performance history, or achieve more similarity in performance as a result of positive team influences. Results suggest that the former is likely, but further information is needed to establish performance history (e.g., pre-term core GPA).

One-third of students reported either being neutral or unable to recall the necessary theoretical principles from previous courses. As mentioned, knowledge transfer is an important professional and cognitive skill, and courses such as senior design are essential to its development. In recent years, some institutions have developed “Knowledge Transfer Partnerships” with industry to facilitate understanding of factors that promote knowledge transfer.86 This is something that the department might want to consider exploring.

**Future Work**

In our study, we administered three surveys: end of project 1, near the end of project 2, and end of the term. Administering four surveys (first day, during project 1, during project 2, and end-of-term) would provide a more complete record of change in student self-efficacy over the course of CBE 4764. Since this was the first time we were performing this study, we expected to learn how to improve the study for the future. For example, administering the same survey each time is recommended to ensure a full picture of self-efficacy changes over time is captured.
A continuing concern in this work has been student participation, and participation is inversely proportional to survey length. We are thus hesitant to administer a longer survey, and also have trepidations regarding repetitiveness, as that was a problem with the surveys in the early semesters of the individual level study. The complete engineering design self-efficacy instrument by Carberry et al. contains nine items under four self-concepts (self-efficacy, motivation, outcome expectancy, and anxiety), providing a 36-item inventory in which there are four groups of similar questions covering each of the self-concepts (see survey in Appendix G). In every study (individual, team, and combinatorial) we have undertaken, loss of participation has been observed, and how students will be motivated to take the full survey must be addressed before administering it. For this reason, we recommend that the study components (surveys and ILS) become integrated course components, with study participation optional. This would hopefully help students be motivated to take the surveys. Furthermore, if the study is integrated in the course, we would have less hesitation regarding length of survey impeding participation and could administer the Carberry instrument in full, maintaining its established validity and reliability.

With further investigation we may better understand the development of self-efficacy in our students during the course of their senior design experience, and the impact of team dynamics on self-efficacy development.
Chapter 6: Conclusions and Future Work for CBE Course Studies

Working with human subjects on an educational study without incentives for participation is a slow process. We are constrained not only by the semesters in which the course is offered, but also faculty willingness and interest in participating, and student participation. What we have seen is that students will more often than not consent if the consent form is given directly to them in class, and they can sign and return it immediately. Because the consent form only has an option for marking consent, no option for not giving consent, we have been unable to track which students may have missed class and never seen the consent form. Early versions of the consent form did have an option to give consent as well as decline participation, but when we moved from an exempt study to a fully reviewed study, the IRB asked us to remove the checkbox for declining participation. At the time, we did not push back on their request, however, in hindsight it would be good to require every student to give or decline consent so that we may be sure no one misses that the study is occurring. Thus, I recommend that future versions of the consent forms all include a line for “I consent to participate in this study” and “I decline study participation.”

Additionally, greater faculty support is needed to facilitate student participation. In some semesters, despite having more than 80% of the students give consent, less than 50% actually participated in the surveys associated with our study. While incentives are a recommended method of increasing survey participation, not all faculty are willing to
provide an incentive for completing study components (note: incentive is for participation regardless of consent). Observationally, faculty engagement did seem to help. Faculty who were more interested in the study, and perhaps more inclined to remind students to participate, had a higher percentage of students complete the surveys. For the success of future studies, it is recommended that study components become an integrated portion of the course. This requires faculty buy-in and cooperation, but as the study does not take much time from the students I believe this should be plausible, especially as results-to-date show that there are interesting effects at play that merit further investigation. Of course, study participation (i.e., whether a student gives consent or not) would not be a factor in the course. All students would be required to take the surveys as homework, but only data from students who consent would be used in the study. This would assist in breaking the activation energy barrier to participation we have repeatedly experienced.

In our effort to understand the factors that affect student success in chemical engineering, both individually and in teams, we have found some interesting results. Some of the most interesting results have stemmed from the study on individual students, which has shown correlations between learning style preferences and performance in specific instances. Even more interesting, evaluating and characterizing the learning styles that exam problems engage has shown strong variations in problem types by instructor. This presents new questions regarding how these variations may affect student understanding and subsequent performance. The concept inventory, first administered in Spring 2015, offers a standard measure against which to compare CBE 2200 sections. Some differences were observed between the two instructors, Faculty D and F, for Spring 2015. With continued administration of the concept inventory in
subsequent semesters, we can gather more data on potential differences in student conceptual understanding that may be a result of instructor.

It is also important to continue identifying different teaching/instructional styles in CBE 2200. Categorizing problem types by inherent bias with respect to learning style has been a preliminary effort to that end, and we have learned that Faculty D and E both give longer exams with a greater number of questions, and also have significantly lower final grades for their classes than other instructors. Of course, Faculty D’s final grades scale-up masks this effect. The next step is to further characterize each instructor by doing both an instructor and student survey of teaching style. In this, the instructor will self-report their teaching style (techniques, approaches, policies) and the students will also have a chance to report on their instructor’s teaching style. This dual survey will allow us to account for misperceptions on either side. Furthermore, we would like to do a greater investigation into the variability of content coverage in the course. That is, do faculty spend an equivalent time and assign a similar number of problems on the same concepts, or do different faculty favor different concepts?

To better understand how the variability in instruction affects our students, it is important to track them beyond the CBE 2200 course. Subsequent coursework and experiences may be a reflection of CBE 2200 background. A longitudinal cohort study of CBE 2200 students, beginning with the Spring 2015 cohort, will provide this information.

To further track instructor and cohort differences, continuing to administer the standard materials balances concept inventory at the end-of-semester is recommended. As the AIChE Concept Warehouse, an online repository of concept inventories for core chemical engineering courses, becomes available, it may be worthwhile to consider incorporating concept inventories into all core courses as part of program assessment.
(not student assessment). This would allow us to observe variations in instructor and student populations, and may help faculty better prepare for potential differences in student conceptual understanding at the beginning of each term.

As I am leaving Ohio State and can no longer spearhead the study on my own, I have spoken with the undergraduate curriculum chair regarding continuing this work after I have left. He has expressed high interest, and agreed to take point from the OSU side. This will require revisions to the current IRB protocols, as I will be an external investigator, however, I believe it is extremely worthwhile to continue this work and not lose the momentum we have built in exploring the factors that may influence student success in CBE 2200.

The team study has, to date, shown no interesting results, in large part due to low and inconsistent participation that does not allow us to fully analyze and draw conclusions. Additionally, it is difficult to distinguish between heterogeneous and homogeneous teams, as most are largely heterogeneous. While we do know that not all team’s function cohesively in the unit operations course, we have no data to support this from the students who consented. Lastly, teams are chosen in a manner that averages incoming chemical engineering core GPA across teams, and final grades within teams reflect this method. There is no significant difference in the average final grades of each team, though each team does show a variation of grades among its members. This suggests that incoming core GPA may be a strong predictor of unit operations performance.

It may be of interest to study the outcomes of the “low performer” and “high performer” in each unit operations group. Using incoming GPA as a reference, if we assume that students will achieve a unit operations final grade that directly correlates
with their CBE performance to date, then we may be able to determine whether the team performance has an impact on a student’s final grade. That is, do high and low performers do better, the same, or worse than would be predicted? The answer to this question may provide insight into whether this model of forming teams is in the students’ best interests for the course, and whether teamwork coaching may be a worthwhile addition to course content. Along those lines, studying whether there is a correlation with team cohesion and whether team members have previously taken senior design may offer insight into the potential benefits of more teamwork–oriented training in unit operations.

The combinatorial study, senior design, has shown some interesting preliminary results. In many measures of self-efficacy, students showed positive gains either between surveys 1 and 2, or surveys 2 and 3. This suggests that self-efficacy development may be time-dependent. Whether this development is an influence of teamwork or an effect of the change in learning curve and skills utilized throughout the term requires further study to determine. For future iterations, four surveys should be administered (beginning of term, project 1, project 2, and end of term), and each survey should contain the same items to allow for proper tracking throughout the term. Like the other studies, this would also benefit from full incorporation of the study into the course. In the first administration, team data has been incomplete, providing only a partial perspective into team effects on student self-efficacy development.

For future work, a more intentional focus on metacognition, an important factor in cognitive development and problem solving$^{89,90}$ may be of interest. There are two components to metacognition, metacognitive knowledge (self-awareness of knowledge), and metacognitive regulation (strategies for learning).$^{91}$ Metacognition regulation,
especially, may relate to learning styles and may provide greater insight to students’
cognitive processes and problem-solving approaches.

Like any research, education research does not have a clear end. Often,
research questions lead only to new questions, as we have seen in our studies. Also,
when studying specific courses during their progression, there is a structured time
component to when research may be conducted (both the course being offered, and
receiving proper IRB approval in time). The studies completed as a part of this
dissertation represent the beginnings of what will hopefully be a continued investigation
into factors for student success in CBE at OSU. This is a new area of research for the
department, and the most difficult part is gaining support for studies when they are not
part of the established department culture. Over the course of these studies, we have
begun the initial steps of revising the department culture with respect to educational
research, and shown that there are areas of study and potential improvement within our
curriculum.

Dissemination

To date, components of this work have been shared through conference papers
(Frontiers in Education (FIE), American Society for Engineering Education (ASEE)) and
presentations (FIE, ASEE, AIChE). We intend to continue presenting our progress with
this work at conferences, and thus continuing to keep our peers up-to-date with our
findings.

As more data is gathered in the coming terms, we will prepare the material for a
journal article. We may also consider preparing a communication or letter in a journal
that will summarize these results and suggest resources for faculty for developing more
robust courses, such as methods to incorporate different teaching styles or the criteria used in evaluating questions.
It is widely accepted that good communication skills are vital for success in any career. Unfortunately, engineers are often stigmatized as being poor communicators, and while this is merely a stereotype, many engineers and STEM students do express disinterest in formal writing and other forms of communication (e.g., public speaking). While communication is incorporated in many undergraduate chemical engineering courses through laboratory reports, oral presentations, and informal short answer questions, these items are generally evaluated for their technical accuracy, but not on specific aspects of their delivery and presentation. In the chemical engineering department at OSU, undergraduate students are required to take two courses in writing and communication. The first is a general English course, the second is an elective selected from a department approved list. While technical communication offered through the College of Engineering is an option for this elective, the list is designated as "writing and related skills" courses and also includes courses in programs such as Arabic, Dance, Film Studies, German, Psychology, and Yiddish. Thus, students are not explicitly required to take a course dedicated to technical communication, but rather "expected" to gain these skills needed for their future professional careers through other coursework and external experiences. While other departments at OSU offer discipline-specific courses in technical communication, informal observations of what might be
considered a lack of sufficient communication skills of senior-level undergraduate
chemical engineering students have suggested that our department may benefit from
adding such a course to the curriculum. In Spring 2014, we piloted an undergraduate
course, Technical and Professional Communication for Chemical Engineers, and with its
success the course was again offered in Spring 2015. Course focus is on all aspects of
communication, verbal (written and oral), non-verbal (body language and development
of visuals), and professional skills (e.g., resume development, formal e-mail writing). The
format of the course is heavily based on active teaching and inquiry-based learning, with
short lectures guiding the 80 minute sessions. A typical session generally consists of a
warm-up activity that gauges the student perceptions and knowledge of the topic of
interest, then a brief lecture and discussion on the topic, followed by a second activity
that allows the students to practice the concepts discussed in the lecture portion. This
model was adopted based on the expectation that students will enter the course with
varying schemata regarding communication, each derived from varied individual
experiences gathered over their lifetime. The warm-up activity not only gets students
engaged in the topic from the start of class, but also serves as a guide for the lecture
and discussion. Student responses to the course indicate that this is a high-value
offering applicable for any chemical engineering student regardless of intended career
path, and ideally the course will be established as a permanent offering in the
department. While the status of future offerings are currently uncertain as the developer
and instructor (myself) is moving on to the next step of their career, the value of the
class is undeniable and preliminary discussions with the Engineering Education
Innovation Center’s Technical Communication Division have taken place about the
potential for continuing the course through instruction from that division. If and when
course enrollment becomes large enough, it would be interesting to compare communication skills of students who have taken the course versus those who have not. This could be achieved through the addition of a communication specific evaluation of artifacts that students are already required to develop in other department courses (the aforementioned items where evaluation is generally focused on technical accuracy).

Motivation

The ability to communicate effectively is one of the ABET student outcomes, and arguably the most important skill for any professional, including engineers. In post-graduation surveys on the relevance of subjects and skills to career success, communication skills are identified as ones that graduates consider essential in several studies. It is a life-long learning process of practice and development. In our chemical engineering department, undergraduate students may graduate without ever having taken a formal course in technical communication. Laboratory and design reports, and associated oral presentations, are meant to provide students with essential technical communication experience, but often these artifacts are evaluated more strongly on their technical merit as opposed to presentation and clarity of communication. Clear and effective presentation, however, is vital to a successful engineering career. Noting an opportunity to expand our course offerings in an effort to develop more prepared chemical engineers, in the Spring of 2014 we piloted a 3-credit course entitled Technical and Professional Communication for Chemical Engineers.

Previous Experience with Research Communication at the Graduate Level

In my first year of graduate school, I took the department’s required core course Research Communication, and in both my second and third year of graduate school, I
was assigned to be the Instructional Assistant (IA) for it. IA assignments are made by the faculty and graduate studies coordinator, based on student and faculty preference, and student expertise. Upon first receiving my assignment, I met with the professor teaching the course and because of my interest in teaching was given the opportunity to develop course materials and deliver lectures (roughly 50% of the lectures in my first term as IA, and > 75% in my second term), and pilot active learning techniques. The changes, modifications, and updates I made to the Research Communication course during my tenure as IA included, but were not limited to:

- Development of in-class impromptu speech activities to focus on specific problem areas of oral presentation (such as filler word use or eye contact)
- Updating assignment descriptions for clarity and thoroughness
- Meeting with students one-on-one twice during the term to discuss their writing, oral presentations, and general growth as communicators (previously these meetings had been with the IA meeting with 3-4 students at once - a one-on-one meeting was favored because it eliminates the anxiety that may be caused by receiving personal feedback in front of peers)
- Reviewing student artifacts (oral presentations, papers, in-class activities) and providing structured and personalized feedback on strengths and areas of improvement
- Incorporating midterm feedback on course components and instructional methods
- Restructuring the least engaging lectures into active-learning class periods
- Adding a unit on poster presentations, a form of presentation common for graduate students
• Converting complicated assignments (where no active discussion between student and instructor occurs) into active-learning class periods where students can learn from the discussion rather than be frustrated on their own

• Developing grading rubrics for presentations and research proposals to ensure consistency in scoring

Undergraduate Course Inception

After two semesters (Spring 2012 and Spring 2013) of serving as the IA for the graduate-level Research Communication course, the changes and improvements to the course gained positive attention throughout the department. In Fall 2013, I was approached by the graduate studies chair, undergraduate studies chair, and an undergraduate academic advisor about designing a communication course for undergraduate chemical engineering students. Recognizing the value in a designated communication course for our students, there was interest in developing and piloting such a course. With my experience teaching technical and professional communication at the graduate level, and my known interest in education and course design, I was offered the opportunity to design, develop, and teach what has been titled Technical and Professional Communication for Chemical Engineers (TPC). The pilot run was in Spring 2014, and I had the opportunity to improve upon the course and teach it again in Spring 2015.

Backward Course Design

The approach used in developing TPC was backward course design (also commonly referred to as backward design). This approach begins with identification of course goals (more abstract) and measureable course learning objectives (more
concrete). The learning objectives are then used as a framework to develop course tasks (assignments and activities). Backward design challenges the course developer to identify what learning objectives directly correlate with each course task, eliminate unrelated tasks (well-intentioned “busy work”), and ensure that all learning objectives are covered. Especially in a less technical area such as communication, where evaluation is less concrete, developing tasks that allow evaluation of student understanding of communication principles, provide practice, and allow for comparisons to gauge improvement are essential.

As this was the first full course I have ever developed, to ensure readiness I applied for the Winter 2013 Course Design Institute (CDI) offered through the University Center for the Advancement of Teaching (UCAT). This five-day institute provided a structured environment in which to focus on, evaluate, and solidify my plans for the upcoming course. During the CDI, each participant works through the backward design process and is able to receive immediate feedback from other participants or the CDI instructors (UCAT staff) by working through a shared wiki platform and actively engaging in discussion each day. The five days of the CDI are summarized in Table 7.1.94

Table 7.1. Summary of five day CDI process.

<table>
<thead>
<tr>
<th>Day</th>
<th>Topic</th>
<th>Description</th>
</tr>
</thead>
<tbody>
<tr>
<td>1</td>
<td>Defining goals and objectives</td>
<td>Understanding the foundations of your course, defining the context, identifying constraints, and developing course goals and measureable learning objectives</td>
</tr>
<tr>
<td>2</td>
<td>Designing assignments</td>
<td>Discussion of different learning frameworks (e.g., Bloom’s Taxonomy) and development of a course skeleton with respect to topics and assignments</td>
</tr>
</tbody>
</table>

(continued)
Table 7.1 continued…

<p>| | | |</p>
<table>
<thead>
<tr>
<th></th>
<th></th>
<th></th>
</tr>
</thead>
<tbody>
<tr>
<td>3</td>
<td>Developing criteria for evaluation</td>
<td>Outlining criteria for evaluation for each assignment and developing appropriate rubrics</td>
</tr>
<tr>
<td>4</td>
<td>Organizing content and planning learning</td>
<td>Understanding how content is structured in your discipline versus your course and the benefits and limitations of different structures, reflection on teaching methods, development of integrated course plan combining everything from Days 1-4</td>
</tr>
<tr>
<td>5</td>
<td>Assessment plan</td>
<td>Discussion of how to assess course goals, and developing a specific plan for assessing whether each course goal is being (or has been) accomplished</td>
</tr>
</tbody>
</table>

**Course Goals and Objectives**

Since students will likely have highly variable communication and technical backgrounds and needs, the desire was to create a course with enough flexibility and focus on growth so that each student may improve in the areas most applicable to them, while continuing to develop and practice areas that are already strengths. The course goals and corresponding learning objectives (summarized in Table 7.2) were selected through perusal of similar courses at other institutions, discussions with chemical engineering colleagues in industry and academia regarding what communication skills are essential in college graduations and what may be missing, and personal experiences in communication through chemical engineering academia and industrial settings.
<table>
<thead>
<tr>
<th>#</th>
<th>Course Goals: Upon completion of this course, students will...</th>
<th>Learning Objectives</th>
</tr>
</thead>
<tbody>
<tr>
<td>1</td>
<td>understand the importance of effective communication in all aspects of their work and life.</td>
<td>Students will integrate concepts into their daily life and participate in communication building practices/activities. Students will evaluate communication experiences (through reflection) and predict possible outcomes of communication scenarios (positive and negative).</td>
</tr>
<tr>
<td>2</td>
<td>view themselves as qualified to provide constructive feedback in communication, and understand the importance of the constructive component.</td>
<td>Students will evaluate others' work and provide constructive feedback through peer evaluation of course artifacts.</td>
</tr>
<tr>
<td>3</td>
<td>understand the importance of identifying the significance of what they are communicating, both big and small picture and how they fit together.</td>
<td>Students will identify the significance of topic and differentiate between the big and small picture.</td>
</tr>
<tr>
<td>4</td>
<td>be comfortable in identifying the audience in their communication and appropriately address them (in content and choice of media, where choice is given).</td>
<td>Students will identify their audience and create communication appropriate for their audience.</td>
</tr>
<tr>
<td>5</td>
<td>be confident in their ability to communicate in a written, oral, or mixed media fashion.</td>
<td>Students will synthesize technical artifacts as appropriate for purpose (poster, proposal, mixed media presentation, etc.).</td>
</tr>
<tr>
<td>6</td>
<td>be aware of their strengths and areas of improvement in communication, and understand that this is a life-long learning process of practice and development. Ideally, they will pursue opportunities to practice varying types of communication (especially those that are not prominent in their position) to keep their skills sharp.</td>
<td>Students will identify their strengths and areas of improvement (demonstrate self-awareness) and actively seek practice of communication.</td>
</tr>
</tbody>
</table>
After two semesters of teaching the course, it became clear that the list of goals and objectives originally developed is not entirely complete in that it does not fully capture all intended course goals. Modifications to listed goals and additional items that I will incorporate into the listing of course goals for future offerings, and recommended for other instructors working off this course model, are summarized in Table 7.3.

Table 7.3. Modified and additional course goals and learning objectives to be used in future iterations, and recommended to other instructors.

<table>
<thead>
<tr>
<th>#</th>
<th>Course Goals: Upon completion of this course, students will...</th>
<th>Learning Objectives</th>
</tr>
</thead>
<tbody>
<tr>
<td>4</td>
<td>(modified) be comfortable in identifying the audience in their communication and appropriately address them (in content and choice of media, where choice is given).</td>
<td>(to add) Students will distinguish between different audiences and compare/contrast how communication may be most effectively presented to each.</td>
</tr>
<tr>
<td>7</td>
<td>(new) develop their own definition of quality in different modes of communication, and recognize the need for such a definition in the professional world.</td>
<td>Students will articulate their definitions of quality in different contexts, identifying “high quality,” “acceptable,” and “unacceptable” communication. Students will discuss and revisit their definitions throughout the term allowing opportunities to redefine and develop understanding of quality.</td>
</tr>
<tr>
<td>8</td>
<td>(new) understand the parameters that govern modern professional communication.</td>
<td>Students will discuss what professional communication entails, how it differs from other communication, and how it has evolved in the modern era. Furthermore, students will be expected to demonstrate professional communication throughout the course.</td>
</tr>
</tbody>
</table>
students will review and evaluate scientific literature, and present this through a review paper and oral presentation.

Students will develop an argument in the form of a technical proposal in which they must define the scope of their proposal, support their argument, and defend their ideas to “reviewers.”

It is also important to note that the learning objectives and subsequent assignments were designed to cover the full spectrum of Bloom’s Taxonomy of learning, as summarized in Table 7.4.

Table 7.4. Bloom’s Taxonomy of Learning.

<table>
<thead>
<tr>
<th>Taxonomy Level</th>
<th>Description</th>
</tr>
</thead>
<tbody>
<tr>
<td>Remembering</td>
<td>Ability to recall information</td>
</tr>
<tr>
<td>Understanding</td>
<td>Ability to explain ideas/concepts</td>
</tr>
<tr>
<td>Applying</td>
<td>Ability to use information in a novel way</td>
</tr>
<tr>
<td>Analyzing</td>
<td>Ability to distinguish</td>
</tr>
<tr>
<td>Evaluating</td>
<td>Ability to justify and defend</td>
</tr>
<tr>
<td>Creating</td>
<td>Ability to develop new artifacts</td>
</tr>
</tbody>
</table>

Course Policies

The approach to developing course policies highlights the “professional” communication component. It is meant to reflect how students may communicate in their post-graduate careers and emphasize shared responsibility between the student and
instructor. Students are told in the first week that this course is analogous to their job, and their grade(s) analogous to their salary. Students are expected to be present and engaged in the course, thus both attendance and participation are components of the final grade. Attendance points cannot be earned outside of class (i.e., students must be in-class to receive them), regardless of reason for absence, but participation points can always be earned through make-up activities. The make-up activities are designed to highlight similar points as the missed lecture, and emphasize to the students that every class period is important. This can be considered akin to being held responsible for what happens in a work meeting missed on account of any reason. The make-up activities are only offered if explicitly requested in a timely fashion around the absence. Not all students are interested in make-up activities, and this policy saves the instructor from developing them for students who do not intend to complete them.

Absences are expected to be communicated no less than 24 hours in advance, barring emergency situations where they are expected to be communicated as soon as possible. This allows the instructor to plan activities accordingly, such as when assigning groups for activities in preparation of the lecture or timing lecture components. The analogy provided here is again taken from the workplace—most individuals would not miss a meeting at work with their boss or colleagues without giving notice either before in the event of a known conflict or as soon as possible in event of an emergency.

The policy regarding late work is seemingly strict at first glance, but also emphasizes (and rewards) responsibility and communication, much like is necessary for success in a chemical engineering career. While all formal assignments must be submitted to receive a grade in the course, late assignments receive no credit after three business days. For each day during these first three business days, the deduction is
10% from the total points possible. Students are encouraged to formally approach the instructor in person or through e-mail if they are having difficulty with a deadline, and that something will be worked out if that is the case. The “late penalty” is reduced when a formal extension request or voicing of concern is made 24 hours or more in advance of the assignment due date. In select cases, the deadline may be extended without penalty if concerns are communicated well in advance, and the due date may formally change if multiple students express the same concerns regarding an assignment. Even though no credit may be earned for work that is more than three business days late, it is still required as each assignment evaluates student mastery of communication concepts and ability to produce specific artifacts. Missing an assignment hinders the instructor’s ability to provide constructive feedback and monitor what concepts/items individual students or the class as a whole may be struggling with, and robs the student of important feedback that can benefit their subsequent work.

For that same reason, while not a formal policy, students are encouraged to not be remiss in collecting their graded/reviewed work from the instructor. Assignments are generally handed back either during activities or at the end of class, and students that are absent or in a hurry may miss collecting them. While efforts are made to ensure all assignments are returned to all students, students must also be conscientious of whether or not they have collected something. Failure to retrieve a reviewed assignment can be especially detrimental to students who receive a “re-do” on an assignment, where a re-do indicates that they may have misinterpreted or otherwise not achieved the assignment intentions and an opportunity is presented to try again before a grade is assigned.
A Day in the Course

TPC met for 80-minute sessions twice a week for 15 weeks (one semester).

Each 80 minute session (except for presentation days) includes:

- “Items for the good of the order”—important updates, deadlines, and general instructor feedback regarding trends from class performance or engagement
- Introduction to the topic of the day
- Activity or open-ended question to establish the students’ existing schemata towards the topic of the day
- Lecture and discussion on topic (emphasis on discussion)
- Activity to reinforce lecture and discussion points, as well as evaluate student gains from class
- Re-visiting any points deemed necessary from results of activity

Summary of Topics

Like many technical communication courses, the focus is on both oral and written communication. Audience analysis and communicating significance are two overarching themes that are woven into all topics throughout the course. These two topics are considered the most ubiquitous to effective communication, and important considerations in any communication task. A full description of lectures and corresponding activities from Spring 2015 is provided in Table 7.5. The Spring 2015 syllabus and schedule can be found in Appendix I.
<table>
<thead>
<tr>
<th>Week</th>
<th>Topic</th>
<th>Description</th>
<th>Assignment Given (not due date)</th>
</tr>
</thead>
<tbody>
<tr>
<td>1</td>
<td>Introduction/Expectations</td>
<td>Icebreaker, activity on types of communication (verbal-oral, verbal-written, non-verbal-pictoral, and non-verbal-body language), review of course syllabus and goals, first day survey</td>
<td></td>
</tr>
<tr>
<td></td>
<td>Audience Analysis</td>
<td>Discussion of audience and in-class time to begin preparation for first presentation (presenting on a technical incident to a variety of audiences)</td>
<td>Reflection 1 -- audience</td>
</tr>
<tr>
<td>2</td>
<td>Resume and Cover Letter</td>
<td>Discussion of resumes and cover letters, peer-review of student resumes (15 second memory test activity)</td>
<td>Reflection 2 -- resume</td>
</tr>
<tr>
<td></td>
<td><strong>Presentation 1</strong></td>
<td>Student presentations (groups)</td>
<td></td>
</tr>
<tr>
<td>3</td>
<td>Memos</td>
<td>Introduction to memo-writing</td>
<td></td>
</tr>
<tr>
<td></td>
<td>Significance</td>
<td>Discussion of significance, activity (students split into their Presentation 1 groups and re-do introduction to presentation focusing on significance)</td>
<td>Reflection 3 -- significance</td>
</tr>
<tr>
<td>4</td>
<td>The Interview</td>
<td>Discussion of interviews, interview questions worksheet, mock interviews</td>
<td></td>
</tr>
<tr>
<td></td>
<td>Building a Convincing Case</td>
<td>Discussion on developing arguments, activity in which students develop a proposal outline (unguided) for a given scenario, then class combines outlines and discusses what should be included ultimately</td>
<td>Annotated bibliography Review paper</td>
</tr>
<tr>
<td>5</td>
<td>Strategies for Delivery</td>
<td>Discussion on delivering effective presentations</td>
<td>Reflection 4 — presentation skills</td>
</tr>
<tr>
<td></td>
<td>Nonverbal Communication</td>
<td>Highly interactive class period on nonverbal communication</td>
<td></td>
</tr>
<tr>
<td>6</td>
<td>Poster Presentations</td>
<td>Discussion of poster presentations, activity of developing a poster mock-up for a given scenario, followed by student’s sharing mock-ups and developing a better mock-up together.</td>
<td>Term topic (review paper and proposal topic) due</td>
</tr>
</tbody>
</table>

(continued)
<table>
<thead>
<tr>
<th>7</th>
<th>Citation Software/Plagiarism</th>
<th>Discussion of plagiarism, including activity for evaluating plagiarism, introduction to citation softwares</th>
<th>Outline</th>
</tr>
</thead>
<tbody>
<tr>
<td></td>
<td>Introductions &amp; Pitches</td>
<td>Discussion of introductions and pitches, activity on developing an introduction for the same talk using different strategies (e.g., humor, facts, anecdotes)</td>
<td></td>
</tr>
<tr>
<td></td>
<td>Presentation 2</td>
<td>Poster presentation, Chemical and Biomolecular Engineering graduate students serve as judges in mock poster session</td>
<td></td>
</tr>
<tr>
<td>8</td>
<td>Formatting and Mid-term evaluations</td>
<td>Exercise on formatting and developing word processor proficiency, mid-term evaluations of instructor and course</td>
<td></td>
</tr>
<tr>
<td></td>
<td>Writing Workshop</td>
<td>Discussion of technical writing</td>
<td></td>
</tr>
<tr>
<td>9</td>
<td>Feedback loops</td>
<td>Working in trios, first students independently develop an argumentative essay (20 minutes), then they exchange papers and peer-review (10 minutes), next they exchange papers once again and provide feedback to the reviewer on the review (5 minutes) (e.g., were the comments helpful, do they need to elaborate, etc)</td>
<td></td>
</tr>
<tr>
<td></td>
<td>Eliminating fillers</td>
<td>Impromptu speech activity (filler words)</td>
<td></td>
</tr>
<tr>
<td>10</td>
<td>Building rapport</td>
<td>Impromptu speech activity (eye contact)</td>
<td></td>
</tr>
<tr>
<td></td>
<td>Editing</td>
<td>Peer review, practice with collaborative editing features of Microsoft Office</td>
<td></td>
</tr>
<tr>
<td>11</td>
<td>Presentation 3</td>
<td>Individual presentations on review paper</td>
<td>Pre-proposal</td>
</tr>
<tr>
<td></td>
<td>Strategies for revision and presenting data</td>
<td>Discussion of evaluating and revising own work, in class time to do so, as well as discussion of interpreting and presenting data</td>
<td>Revisions</td>
</tr>
</tbody>
</table>

(continued)
Table 7.5 continued…

<table>
<thead>
<tr>
<th>12</th>
<th>The Abstract</th>
<th>Definition and discussion of abstracts, in-class practice developing abstracts and outlines</th>
<th>Abstract</th>
</tr>
</thead>
<tbody>
<tr>
<td></td>
<td>Communication for Daily Use</td>
<td>Discussion of daily professional and business communication</td>
<td></td>
</tr>
<tr>
<td>13</td>
<td>Mis-communication</td>
<td>Discussion of why miscommunication occurs and best practices to avoid it in professional settings</td>
<td>Reflection 5—revisiting argumentative essay from week 9 class</td>
</tr>
<tr>
<td></td>
<td>Conversing with your audience</td>
<td>Impromptu speeches (eye contact/not looking at slides)</td>
<td></td>
</tr>
<tr>
<td>14</td>
<td>Semester Review</td>
<td>Students develop “ultimate guide to communication”</td>
<td></td>
</tr>
<tr>
<td></td>
<td>Course Debrief</td>
<td>End of term evaluations and discussion of class</td>
<td></td>
</tr>
<tr>
<td>15</td>
<td>Final Exams</td>
<td>Final presentations (proposal)</td>
<td></td>
</tr>
</tbody>
</table>

The topic of oral communication includes a variety of presentations, from impromptu to PowerPoint/Prezi and posters. While students are sometimes required to use a specific form of media for their presentation so they may gain experience with different options, there are also assignments in which they are asked to simply present using whatever media they deem most appropriate. Thus, guidelines for different forms of media and how to choose the most effective one for a certain purpose are discussed. Oral communication skills are further enhanced by activities that focus on specific common presentation problems and difficulties.

Topics in technical written communication include active vs. passive voice, an overview of common grammar / spelling problems and conventions, presenting and
interpreting data, critical reading and analysis of technical work, and plagiarism. These are covered through lectures and activities throughout the term, with a mixture of short (1/2 to 1 page reflections) and longer (3 or more pages) writing assignments.

Professional communication contains a large breadth of topics, including writing resumes and cover letters, as well as interview skills. What is deemed business communication involves discussion of proper etiquette through e-mails, as well as basics of executive summaries, memos, and other reports students may encounter in their chemical engineering careers.

On the first day of class, students are given a survey on communication background and self-efficacy. The survey aims to understand student perspectives on communication, experiences, career goals, and course expectations. The self-efficacy component of the survey provides information regarding the individual student’s comfort with and attitude towards different aspects of communication, and this is repeated at the end-of-semester in a final survey. This before-and-after administration of the survey provides a means for measuring student growth during the course.

Peer/instructor feedback and opportunities for revision are built into the course structure, providing students opportunities to develop skills in becoming more effective in providing and receiving constructive criticism. Students provide peer-feedback both through structured routes where a set of guidelines is provided, and unstructured routes in which their own innate guidelines can be identified and expanded upon. Instructor feedback is provided on all tasks, either individually or in aggregate as general comments to the entire class. In the event that only aggregate feedback is provided, students are encouraged to seek their individualized feedback from the instructor. In
these instances, the instructor readily makes time to meet with the interested student to further discuss their feedback and provide more detail.

**Technical Emphasis**

While many principles of communication are universal, there are discipline-specific conventions and common areas of difficulty that must be addressed in a communication course designed for chemical engineers. Students must be able to interpret, relay, as well as produce technical communications. In the course, this is addressed through emphasis on technical contexts for examples, activities, and assignments. Lectures and activities that emphasize the technical aspects of communication include:

- Understanding of audience background and expectations, and ability to modify the same technical material for different audiences
- Student-led discussion of characteristics of technical communication (common descriptors students give include “data-driven,” “jargon heavy,” and “boring) and best practices to create clean, engaging communication on technical topics
- Discussion and practice in using data in communication (how to design figures, as well as reference them in written or oral communication)
- Reviewing others’ technical communication and discussing interpretations of audience, significance, and main points with peers in the class

Assignments throughout the course focus on developing technical communication skills as well as evaluating and reflecting on communication as a concept. The reflections referenced in Table 7.5 challenge students to think critically
about others’ communication, the annotated bibliography and review paper test students’ ability to process and repurpose information, condensing the review paper into the background of their proposal allows students an opportunity to re-evaluate what is truly relevant information, and the proposal challenges students to develop a thorough argument for a technical idea. These assignments are further described in the next section.

Through the literature review and proposal assignments, and their respective oral presentations, students are exposed to a variety of topics in their peers’ work. Peer evaluation is integrated into the course, and students are tasked with not only copy editing (grammar/spelling) but evaluating their classmate’s work for clarity and logic. They are required to ask questions of peers when presenting, challenging them to engage in and think about a variety of topics critically in a single lecture period. Student topics for the literature review and proposal have included topics related to:

- **Energy**
  - Carbon capture technologies
  - Hydraulic fracturing technologies
- **Biological Applications**
  - Vaccine development
  - Nanotweezers
  - Targeted drug delivery
- **Food Science Applications**
  - Biofilm development and prevention on packaged foods
  - High-pressure processing technology for food packaging
- **Polymers**
Membrane technology for water filtration or other applications)

Types of Assignments

Coursework consists of formal graded assignments, as well as informal exercises (both during and outside of class) graded for participation. Several formal assignments lead into developing a brief proposal on a topic of student choice. The proposal assignment is open-ended; it may have a research, industry, business, or other STEM-related focus based on student interest. The topic is chosen by the student (and approved by the instructor) during the first third of the semester.

The formal assignments are listed and described below:

- Reflections—these consist of brief responses to a prompt and a series of questions related to a recent in-class topic. Students may be asked to revise a document and reflect on the process, watch a recording of a talk and comment on speaker delivery/style, critically analyze a piece of writing, etc. Reflection assignments are designed to reinforce important concepts from the week and challenge students to think more deeply about communication outside of the classroom. They are approximately ½ to 1-page, single spaced in paragraph form, and should at a minimum address the provided guiding questions. Grading for grammar and spelling is not strictly enforced on reflections, as they are meant to provide students a medium in which to freely write and express their thoughts. Emphasis of grading is on the understanding of concepts, depth of reflection, and clarity of expression (which may be impacted by grammar and spelling).

- Oral Presentations—a variety of oral presentation assignments occur throughout the term, providing students different opportunities to practice speaking in front of varying audiences.
a) Audience (Group)—the first formal presentation is a group assignment, allowing the students to feel less of the pressure of speaking in front of their class while providing the instructor an opportunity to learn about their oral presentation skills and styles. It occurs in the second or third week of class, and students are provided a prompt on which to focus their presentation. This presentation highlights being aware of different types of audiences, emphasizing the concepts introduced in the first lecture of the class. Each group is assigned a different audience (but given the same prompt) and are free to choose their presentation persona. Groups are encouraged to be creative and have some fun with this assignment.

b) Poster (Partner)—poster design and presentation, and situations where posters may be required or appropriate, is covered in the first half of the course. Pairs of students are tasked with creating a poster. For this assignment, the prompt asks the students to take on the role of K-12 science educators seeking funding to enhance their curriculum. Students are asked to prepare a 30 second pitch of their proposal and five minute follow-up presentation, which they present in a mock poster session to reviewers (graduate students in the department).

c) Powerpoint/Prezi (Individual)—slide design (graphics, backgrounds, font, etc.) is a topic covered in presentation delivery, and thus, in one individual presentation students are required to use PowerPoint or Prezi. The topic for this presentation is the same as the student’s review paper.

d) Pitch / Proposal (Individual)—this final presentation of the course goes hand-in-hand with the written proposal assignment described below. Students are
asked to present their proposal to a defined set of reviewers, as applicable to
the topic, using the medium they deem most appropriate. Evaluation is on
building a convincing argument, choice and development of appropriate
media, and presentation skills.

- Critical Reading and Research Summary—similar to an annotated bibliography,
  this assignment requires students to begin the literature review for their proposal.
  Literature review, proposal writing, and developing an argument is discussed
  prior to this assignment. Students are asked to summarize three pieces of
  literature relevant to their topic, as well as comment on the relevance and how it
  may be useful in supporting their developing proposal.

- Abridged Review Paper—this is a summary of prior research related to their
  proposal that will then be revised as the background information for the student’s
  proposal assignment.

- Short Proposal (sometimes referred to as pre-proposal)—an open-ended
  assignment where students are asked to develop a proposal for research,
  industry, business, or another area of interest. Emphasis is on clear, concise
  technical writing and building a convincing argument with use of relevant
  supporting information and emphasis on significance of the proposal.

All formal assignments used in 2014 and/or 2015 are included in Appendix J.

**Active Learning and Inductive Teaching Activities**

Students have been communicating their entire lives and often have a strong
pre-existing schemata in topics of communication. Since personal experience tends to
be the best educator, active learning\textsuperscript{96-98} and inductive teaching\textsuperscript{99,100} are the primary lecture methods used in this course.

As previously mentioned, early in each lecture there are opportunities for students to share their own pre-existing schemata for the topic of the day. This may manifest through open inquiry and discussion as a class, think-pair-share (individual time to process, followed by discussion with a partner, then sharing with class), or a structured activity with a minimal prompt. Extracting pre-existing schemata allows the instructor to realize what the students already know and believe, and build upon this to strengthen concepts and combat misconceptions. In many cases, the instructor serves as a mediator and guide for the students in developing conceptual understanding.

Examples of activities (some described in detail in Appendix K) designed to draw out students’ existing schemata and develop a common schemata include:

- **Poster Drafting**—students are given a prompt for a poster to draft. With a partner, they work on an 8.5 X 11” mock-up of their poster, with no prior discussion as to the purpose or design of posters. Pairs then translate their mock-ups onto the board for their peers, and the class discusses common components and key differences between designs before establishing a new “best mock-up” together. This activity is guided by discussion of why certain components are necessary for the poster, why they are arranged where they are, what else needs to be considered, and how a different prompt may result in a different poster. The final outcome is a general set of guidelines for poster design that the students developed themselves, with mediation from the instructor.

- **Proposal Writing**—students are given a topic on which to write a proposal and asked to develop a proposal outline. They are next asked to pair up with a
partner and compare/contrast their outlines. After some discussion, partners share differences and similarities with the class while the instructor captures components of the students’ outlines on the board. At this point, the students are asked what the purpose of the proposal is, and following discussion and agreement, told to revise their proposal outline to better emphasize the purpose. This is again done in think-pair-share, and at the completion of sharing, the class will have generated their own outline of the components of a proposal, and will have participated in instructor-led discussion regarding what each component entails.

To improve communication skills, practice is essential, and many active-learning activities are focused around the opportunity to practice and immediately respond to feedback. These activities are mainly focused on oral presentation skills, but include a few writing activities as well. Examples are:

**Oral Presentation Skills:**

- **Eliminating Fillers**—a series of impromptu speeches is used to help students focus on identifying their use of spoken fillers (“uh,” “umm…,” “you know,” “so,” etc.). Early in the semester, students are asked to submit a list of five topics they consider themselves knowledgeable in. This activity uses these topics, and in the first round the instructor randomly picks a topic for each student to speak about. The student is given 30 seconds to think before the clock begins, after which they speak for two minutes and their filler words are counted. This provides their “filler words per minute” baseline. In the second round, students are told that their goal is now to go one full minute without saying a filler word. If they succeed, they are exempt from future rounds and get to observe other students. Before each
second round speech begins, the student is given their “fillers per minute” score from round one and their new topic. As soon as a filler word is uttered or one minute elapses, whichever comes first, time is recorded and the speech is over. This activity promotes student awareness of fillers, and has been effective in helping students who have high use of fillers improve over the semester. Discussion of practices that helped students reduce fillers usually highlights slower and more deliberate speech as key strategies.

- Reading off Slides—this is another set of impromptu speeches in which slides are prepared by the instructor on the campus/community topics students consider themselves to know well (also provided to the instructor at the beginning of the semester). The slides include a variety of designs, including text-heavy, visuals-heavy, good contrast, and poor contrast. The slides are compiled into a single presentation. The bottom of each slide has the words “Up next: [speaker’s name],” with the next student speaker’s name. When it is a student’s turn, they advance to their slide (which they have never seen before), have 15 seconds to look at the slide, and then 30 seconds to speak without looking back at the slide. The number of “look backs” are recorded and reported after each round, and then there is discussion of what caused the students to look back. Common themes include simple unfamiliarity with the slide and factors of slide design, such as being text-heavy. Sometimes students succeed in not looking back at the slide, but their speech is unrelated to slide content; this is discussed as well. The activity reinforces the importance of deliberate preparation of any supplemental materials, like slides, for presentations, and the concept of making slides work for you. Often students limit themselves to reproducing slide designs
they have seen in the past, rather than producing slide designs that allow them to present more comfortably.

- **Eye Contact**—this activity involves impromptu speeches in which speakers are tasked with making eye contact with every audience member (their peers and the instructor). After each student speaks, the class is asked if anyone felt that eye contact was not made with them, and this is noted. For this activity, the class is assigned specific seats, which are re-assigned after each round, to alter where the speaker must look. In some cases, students are seated right under the nose of the speaker, in others they are mostly focused on one area of the room with one or two placed elsewhere, away from the general mass of the class audience. This challenges the students to examine where their audience is seated before speaking, and to remember to engage the full classroom, not only where the greatest density lies.

**Writing Assignments:**

- **Caption Writing**—students are presented with a figure or set of data to write a caption for. This is done in think-(write)-pair-share, and after discussion on the data and what the caption should include, they are given time to revise their initial caption. Before ending the activity, students are asked for what audience they wrote the caption, and why they chose that audience. This is followed by a brief discussion of how the caption would change for a more, or less, technical audience, and whether the figure/data presentation itself would have to change as well.

- **Business Communication Scenario, E-mail Version**—students are presented with a workplace scenario which requires an e-mail to either a hypothetical boss,
peer, or intern. Students compose a mock e-mail, then get in groups of three in which each person has written to a different audience (boss, peer, intern). In groups, they discuss the similarities and differences between their constructed e-mails, and summarize the purpose of each communication. After sharing, each group rewrites all three e-mails together.

Active learning activities were developed by the instructor. Impromptu speeches are a commonly used form of practicing oral presentation skills, which provided the basis for the oral presentation skills activities. The basic format of an impromptu speech was modified to focus on specific areas of need identified in earlier teaching experience (instructional assistant for the graduate-level Research Communication course). The areas of need, poor eye contact and abundance of filler-words, are common “presentation pitfalls” that may cause speakers to inadvertently lose credibility by appearing nervous or unprepared. Writing activities were developed from student feedback in Spring 2014; students reported desiring an increased number of short writing assignments to complete in class. New curricular ideas may also stem from growing networks as we continue to seek and build relationships with other institutions, departments, and individuals working to build active-learning in communication courses.

**Parameters for Student Evaluation**

Students are evaluated both against a rubric identifying features that define the quality of a communication artifact and on personal growth in communication throughout the semester. Because communication development requires active participation, and because the class period involves a high degree of active learning, both attendance and participation are components of the final grade, as previously mentioned. To reiterate, in
the event of an absence, attendance points cannot be gained; however, participation points may be earned through completion of an alternative task that covers the learning objectives of the course. This reinforces the importance of attending class (i.e., professional situations), while understanding that perfect attendance is not always feasible (i.e., life is a continual balancing-act in which occasionally other things may require precedence over work, but this does not justify neglecting work responsibilities).

The parameters on which students are evaluated expands throughout the semester, allowing students to focus on building effective communication skills from one task to the next. In structured peer-feedback, the guidelines that students receive for evaluating their peers not only change to reflect the purpose of the assignment, but also expands as the term progresses, allowing students to strengthen their evaluation skills without overwhelming them in the beginning. Students may then better understand that evaluation is not a “one-size-fits-all” task, but rather something that is dynamic and directly influenced by what is being evaluated. In communication, the audience and significance of the topic are primary components of that.

**Feedback-Revision Cycles**

Feedback is an essential component of learning, and most effective when students are subsequently given a chance to respond to feedback. Opportunities for feedback and revision are built into the course model through drafting, peer review, and informal exercises (in class activities) that are reviewed by the instructor. Feedback may be directed to an individual or given to the class as a whole in aggregate. All in-class exercises and activities are collected and/or otherwise reviewed by the instructor, after which aggregate feedback may be given to the class regarding points well understood and concepts that appear to have been missed. Individual feedback is provided regularly
on all assignments, and required peer reviews offer another opportunity to receive feedback and to revise an assignment. While not all assignments have a draft and final version, students are given an opportunity to re-do all assignments that would otherwise receive low marks (previously described as a “re-do”). The theory is that the student will learn more (and receive higher marks on subsequent assignments) by working through revisions and discussing any points of confusion or disagreement with the instructor than they would by receiving a low grade, tossing their paper in the recycle or trash bin, and forgetting about it.

In the second half of the semester there are required one-on-one meetings with the instructor to discuss communication and professional development. While students are welcome to meet with the instructor at any point in the semester, the required one-on-one meetings ensure that each student actually does meet with the instructor and has the opportunity to discuss their progress in the course. The meetings are scheduled after the formal in-class individual oral presentations are given, and begin with asking the student to share their thoughts on how the presentation went and what areas of improvement they identify for themselves. Presentations are video-recorded, which allows the instructor to call attention to specific examples from the presentation while sharing both their own and peer feedback with the student. While the meeting focuses on the most recent presentation, this also serves as a time to check in with the student regarding overall growth in communication and experience in the course. Each meeting concludes with a breakdown of goals for the student to work toward for their next (final proposal and respective oral presentation) assignment, and feedback from the students may provide new or modified lecture/course items in the following weeks. For the final presentation, students receive individualized feedback via e-mail as this is done during
the final exams week and meeting is no longer feasible. While the individual meetings take a substantial amount of time, they are considered to be a valuable course component by the students, and if feasible, adding such a meeting to the first half of the course would be beneficial. This was the model in the graduate level Research Communication course (two one-on-one meetings), however, it is very time-intensive and was difficult to schedule and thus only one such meeting was incorporated into the undergraduate course.

**Student Response—Spring 2014**

In Spring 2014, 12 students enrolled in and completed the course. With an enrollment cap of 20, and the course introduced to the students right as class scheduling began, this was considered an encouraging number for the pilot run.

The 2014 students reported varying degrees of satisfaction with course components, as can be expected in a communication course when students have (completely) different backgrounds and needs. Several course components received unanimous praise, including the in-class presentation skills-development activities, and no components received unanimous disapproval. That is, every course component benefitted at least some portion of the students. Student evaluation of course goals unanimously reported that all course goals were addressed, and in only a few select cases did 1 of the 12 students think a goal was not achieved.

On the end-of-term survey, nearly all students reported increased confidence and notable improvement in technical writing and oral presentation skills, and most reported increased comfort with business communication. Table 7.6 compares the results from the first day and end-of-term survey for the applicable questions as class averages. These results are from a Likert-type survey, where 1 corresponds to “Strongly Disagree”
and 5 corresponds to “Strongly Agree.” In most categories, there was an average increase in agreement with the prompt, with the notable exceptions of “giving oral presentations makes me nervous” and “I would like to improve my oral presentation skills.” This suggests that students recognized a positive change in their oral presentation skills during the course, and this is further corroborated by the qualitative feedback discussed below. The greatest positive change reported is in student confidence of producing professional documents and providing peer feedback. In reporting class averages, the changes in individual self-efficacy are lost in the population. Thus, a matched-pairs student’s t-test was performed to identify which areas showed a statistically significant difference in student response between the first and end-of-term surveys. For eight of the twelve prompts, the difference in student responses was significant at $\alpha = 0.10$. These are indicated by an asterisk (*) before the question.

Table 7.6. Average of class responses to first day and end-of-term surveys. Single asterisk (*) next to question indicates that student responses were significantly different between the first day survey and the end-of-term survey by a matched pairs student’s t-test with $\alpha = 0.10$.

<table>
<thead>
<tr>
<th>Question</th>
<th>Class Average</th>
<th>Difference</th>
</tr>
</thead>
<tbody>
<tr>
<td></td>
<td>First Day</td>
<td>End-of-Term</td>
</tr>
<tr>
<td>*I am comfortable speaking in front of a small audience (2 to 15 individuals).</td>
<td>4.00</td>
<td>4.42</td>
</tr>
<tr>
<td>*I am comfortable speaking in front of a medium to large audience (&gt; 15 individuals).</td>
<td>3.33</td>
<td>3.83</td>
</tr>
<tr>
<td>*I can develop visual material (e.g., charts, graphs, cartoons) with confidence.</td>
<td>4.00</td>
<td>4.50</td>
</tr>
<tr>
<td>Giving oral presentations makes me nervous.</td>
<td>3.17</td>
<td>2.96</td>
</tr>
</tbody>
</table>

(continued)
I understand how my body language, voice, and personal presentation affects my communication.  

<table>
<thead>
<tr>
<th>I would like to improve my oral presentation skills.</th>
<th>4.17</th>
<th>4.54</th>
<th>0.38</th>
</tr>
</thead>
<tbody>
<tr>
<td>I am confident in my technical writing skills.</td>
<td>4.58</td>
<td>3.91</td>
<td>-0.67</td>
</tr>
<tr>
<td>I can produce professional documents for job searching (resume, cover letter) with ease.</td>
<td>3.33</td>
<td>3.92</td>
<td>0.58</td>
</tr>
<tr>
<td>*I am confident and comfortable in daily professional communication (e.g., e-mail writing, informal presentations to a project team, progress updates to supervisor).</td>
<td>4.08</td>
<td>4.50</td>
<td>0.42</td>
</tr>
<tr>
<td>*I am confident in editing and providing constructive feedback of my peers’ work.</td>
<td>3.67</td>
<td>4.33</td>
<td>0.67</td>
</tr>
<tr>
<td>I would like to improve my writing skills.</td>
<td>3.75</td>
<td>3.88</td>
<td>0.13</td>
</tr>
</tbody>
</table>

The main course improvement suggested by the 2014 students was a greater number of short writing assignments. Overall, the class agreed that they believed their presentation skills to have improved to a greater degree than their writing. Thus, the 2015 version of the course offers more short writing assignments with enhanced focus on technical writing components (interpreting/explaining/presenting data, summarizing, etc.).

**Student Response—Spring 2015**

The Spring 2015 section had 18 students. The 50% increase in enrollment serves as a positive indicator regarding student response in 2014. On the 2015 first day survey, several students reported that they registered for the course based on recommendation from other students.

Similar to 2014, students gave mixed responses to the individual course components. Again, not every component was perceived beneficial by every student, but
every component was of reported value for at least one student. Again, course goals
evaluation showed that they were all addressed, and mostly achieved, though some
students expressed that the course goals did not reflect their own goals. This mismatch
of goals may have resulted in the 2015 students being more critical in their qualitative
feedback as is described later. Comparing the first day and end-of-term self-efficacy
surveys for the students in 2015 show a significant change in self-efficacy regarding a
number of items (same statistical analysis as the 2014 class), many of which are
comparable to the results from 2014. These are summarized in Table 7.7, where an
asterisk before the question represents an item where student responses were
significantly different between the first day and end-of-term (α = 0.10).

Table 7.7. Average of class responses to first day and end-of-term surveys. Single
asterisk (*) next to question indicates that student responses were significantly different
between the first day survey and the end-of term survey by a matched pairs student’s t-

<table>
<thead>
<tr>
<th>Question</th>
<th>Class Average</th>
<th>Difference</th>
</tr>
</thead>
<tbody>
<tr>
<td></td>
<td>First Day</td>
<td>End-of-Term</td>
</tr>
<tr>
<td>*I am comfortable speaking in front of a small audience (2 to 15 individuals)</td>
<td>3.44</td>
<td>4.22</td>
</tr>
<tr>
<td>*I am comfortable speaking in front of a medium to large audience (&gt; 15 individuals)</td>
<td>3.17</td>
<td>3.83</td>
</tr>
<tr>
<td>I can develop visual material (e.g. charts, graphs, cartoons) with confidence</td>
<td>4.39</td>
<td>4.61</td>
</tr>
<tr>
<td>Giving oral presentations makes me nervous</td>
<td>3.56</td>
<td>3.39</td>
</tr>
<tr>
<td>*I understand how my body language, voice, and personal presentation affects my communication</td>
<td>4.00</td>
<td>4.53</td>
</tr>
<tr>
<td>I would like to improve my oral presentation skills</td>
<td>4.39</td>
<td>4.28</td>
</tr>
</tbody>
</table>

(continued)
Table 7.7 continued…

| *I am confident in my technical writing skills | 3.50 | 3.88 | 0.38 |
| *I can produce professional documents for job searching (resume, cover letter) with ease | 3.50 | 4.11 | 0.61 |
| *I am confident and comfortable in daily professional communication (e.g. e-mail writing, informal presentations to a project team, progress updates to supervisor) | 3.78 | 4.33 | 0.56 |
| I am confident in editing and providing constructive feedback of my peers' work | 3.67 | 3.89 | 0.22 |
| *I would like to improve my writing skills | 4.56 | 3.83 | -0.72 |

**Comparisons Between 2014 and 2015 Student Responses**

From the self-efficacy surveys summarized in Tables 7.6 and 7.7, students in 2014 and 2015 show largely similar changes in self-efficacy. At the end of both semesters, students reported higher self-efficacy with respect to presenting to audiences of varying sizes, their technical writing, their ability to produce professional documents, and daily professional communication. The 2014 students also reported stronger belief in their ability to develop visual materials, confidence in peer editing abilities, as well as a decrease in their desire to improve oral presentation skills. The 2015 students did not have statistically significant differences in their responses to these items, but did report increased awareness of body language and decreased desire to improve their writing. These differences may reflect the differences in the student populations’ communication backgrounds and goals, as well as slight variations in instruction. Particularly, the 2014 students had suggested more attention be paid to practicing writing, but the 2015 students (though many reported being interested in improving writing skills on their first
day survey) expressed that there was too much focus on writing at the end-of-term, both through anonymous evaluations and class discussion.

Certain items, listed in Table 7.8 below, were only on the end-of-term survey. These items are intended to evaluate student perception of their own improvements and understanding during the term. Comparisons between the 2014 and 2015 classes are shown in Table 7.8. Observationally, students in large agree that they have experienced some improvement during the term, and while 2015’s class responses do appear lower for every question, this difference is not statistically significant.

Table 7.8 Comparison of self-efficacy responses in 2014 and 2015.

<table>
<thead>
<tr>
<th>Question</th>
<th>Class Average</th>
<th>Difference</th>
</tr>
</thead>
<tbody>
<tr>
<td>My presentation skills have improved this term</td>
<td>4.42</td>
<td>-0.42</td>
</tr>
<tr>
<td>I understand the importance of proper citation</td>
<td>4.50</td>
<td>-0.17</td>
</tr>
<tr>
<td>I am better able to develop appropriate visual material (than at the beginning of this term)</td>
<td>3.83</td>
<td>-0.17</td>
</tr>
<tr>
<td>I can identify and articulate the significance of a topic</td>
<td>4.25</td>
<td>-0.17</td>
</tr>
<tr>
<td>My writing skills have improved this term</td>
<td>3.75</td>
<td>-0.14</td>
</tr>
</tbody>
</table>

In the final class period, the instructor performed led a de-brief on the course, and the main difference noted was the difference in student attitudes toward the writing component. Spring 2015 students, as previously mentioned, were of the opinion that the writing assignments were too frequent, too long, and not purposeful. The students of 2014 had suggested increasing the short writing assignments and to provide greater
opportunities for practice and feedback. One student in 2015 expressed belief that the course tried to cover too much, and may benefit from greater focus. It thus becomes the instructor’s duty to decide what topics to cover, and how to balance breadth and depth. The current model was developed to provide a large breadth and be applicable for a diverse student population, and student evaluations show that it has succeeded in doing so.

There is another (observational) difference that may be noted between the feedback from the 2014 and 2015 sections, and that is in the nature of feedback students provided both at midterms (formally collected around week 7 or 8) and at the end of the semester. Students in 2014 were, in large, constructive in their criticisms of the course, whereas students in 2015 ranged from constructive to purely critical. Students in 2014 also reported an increase in comfort with providing constructive peer feedback between the beginning and end of the term, whereas the 2015 students did not. This suggests that the 2015 students were not as strong in their ability to provide constructive feedback, whether through poor coverage of this component in the course or innate characteristics of the population that result in less inclination to be constructive. This highlights the difficulties in developing and teaching such a class, as it is not only dynamic from one year to another as the course size and student population changes, but also within a semester as students one year may have different needs or working speeds than others. In fact, one of the student complaints in 2015 was the changing assignment due-dates, which were a result of the instructor trying to accommodate the needs of the student population. The 2015 students demonstrated needing more practice with certain concepts, which affected the course schedule, and not all students were proactive in keeping up on schedule changes.
**Recommendations to Other Instructors**

The differences between the student populations of Spring 2014 and Spring 2015 offered valuable insight as to how the course may be better approached in the future.

This includes a more thorough approach to establishing course policies with the students, and more transparent objectives for specific tasks so as to further convince all students of the value in course tasks.

It is crucial that the students review and understand the syllabus for this course. The structure and policies are unlike any other course in the CBE department, and it is imperative that students are aware of this. Student inquiries and circumstances throughout the Spring 2015 term indicated that despite going over the syllabus in class, many students were still unaware of the policies, and students who missed the first day showed signs of never opening it. An often-used tactic to ensure students review the syllabus is a “syllabus quiz,” which I will be utilizing in future offerings of this course and recommend any instructors teaching variations of the course do as well. Syllabus quizzes often are simple multiple choice or true/false questions that cover basic items from the syllabus. To further ensure that students read the syllabus and understand, I will include short course scenarios (Jack turns in an assignment two days late, if the assignment is worth 20 points, what is the highest grade he can receive? Jill has an emergency and is unable to complete her term paper on time, what should she do? True or False: The instructor is responsible for reminding me of assignment due dates that are posted on the course schedule) that evaluate whether students are prepared for the expectations of the course. A score of 100% on the syllabus quiz will be a requirement for “unlocking” course materials beyond the syllabus, and students may take it as many times needed to achieve a perfect score.
As is the crux of backward design, each course assignment was developed to provide practice for and measure student performance with respect to the learning objectives. Spring 2015 suggested that these connections were not always clear to students, as they may not be reviewing the learning objectives throughout the term. To help clarify the relevance of each course task, as well as alleviate student frustrations associated with tasks when they are mistakenly perceived as “busy work,” future iterations of task descriptions are being modified to incorporate the relevance to either (i) the larger, culminating course projects, i.e., the proposal, or (ii) topics recently covered in class, and to explicitly identify which course goals are addressed in the task. (Note: students are given the course goals in the syllabus, not the specific learning objectives.)

It is also important to establish how course communication will be handled (through a Learning Management System such as Carmen, through e-mail, etc.) and hold firm to that. Students must explicitly know where they are expected to watch for updates or schedule changes, and agree that they are accountable for being aware of posted changes. The common practice of using the course number in all e-mail correspondences is one that has been utilized, and additionally helps students get accustomed to professional e-mail subject lines.

Future Outlook

To become a permanent offering in the department, the course must be taught by a faculty member. As the developer and inaugural instructor of this course, providing this detailed outline offers a framework for future instructors. The 50% increase in enrollment between the first and second offering of the course implies that it provides a value that is recognized by the students. The instructor has been in discussion with other engineering departments that offer a similar communications-focused course both in an
effort to leverage successful course components from each and discuss a potential path forward for making this a permanent offering in the chemical engineering department. If the course does become a permanent offering, there may also be an opportunity to leverage the overlapping components with the graduate research communication course in a way that is mutually beneficial to both student populations (e.g., if the classes met at the same time, lectures could be coordinated so that activities are synchronized and groups may be across classes, allowing graduate students and undergraduates to work together and gain from each other’s insights). Another option, in lieu of a permanent offering, would be to embed applicable course components throughout the undergraduate course curriculum, and ensure that evaluation is done more deeply on presentation as well as technical content. However it is incorporated in the future, TPC has been a valuable step in developing the CBE graduates of today into the chemical engineering (or other) professionals of tomorrow.
Chapter 8: Afterword

The path to my Ph.D. degree has not been a direct one, nor a typical one. Starting in technical research, doing an intensive fellowship through the medical school, and making a bold decision to pursue education research in the latter portion of my degree has been a unique progression. I have performed genetic engineering, infectious disease, epidemiology, teaching, and education research all in a matter of five short years. Some have said, I started off by choosing technical research when I began my Ph.D., but education chose me. I have had the opportunity to present at the Frontiers in Education conference (2011, 2013, 2014), American Institute of Chemical Engineering Annual Meeting (2012-2014), and the American Society for Engineering Education conference (2015). These conferences have served as a great opportunity for peer review of my work, constructive feedback, and encouragement on my career aspirations. The early conferences especially had a role in developing my interest in education, and developing my self-efficacy in believing I could enter that area of work.

Impact of Dissertation Work

Understanding inherent biases in the CBE 2200 curriculum and their effect on student success would open an avenue for more informed curriculum development in the context of chemical engineering that is translatable to other fields. By developing curriculum and respective teaching materials that are adapted to a variety of learning
styles, we not only can make our disciplines more diverse and inclusive with respect to learning styles in the students (later to become professionals), but also help to develop students with an ability to process information presented in a greater variety of ways. This would help cultivate a generation of more versatile problem solvers. The interest this work has generated from the faculty involved (most who have no previous educational research experience), and the continuation of the work after my graduation, is a testament to the impact of the work on the department.

Understanding the relationship between team learning style make-up and team dynamics and performance will establish a foundation for improved curriculum with respect to teaching effective collaborative skills. Our team and combinatorial studies provide a foundation for future work that will further develop our incorporation and instruction of teamwork in the curriculum. Teamwork is a prominent component of only select courses, such as laboratories or design, which is not reflective of its value in an engineering career. A greater emphasis on incorporating an understanding of learning styles and their role in team dynamics in not only classes such as CBE 4630 and 4764 but throughout the curriculum may prove to be a valuable component to undergraduate engineering education as we prepare students to enter the global workforce.

Concern over the amount of time needed to develop and implement a new instructional strategy is among the biggest barriers in changing education. Simple interventions in the undergraduate curriculum could lead to significant improvements in student learning and development. Small adjustments to methods used in CBE 2200 can guide students in better interpretation of problems, especially along the visual/verbal scale. These can be done through short in-class activities or homework problems that focus on specific styles of information presentation, and these activities could be woven
into coursework throughout the CBE curriculum. Continued emphasis on professional
development, like through the CBE 4194 (Technical and Professional Development for
Chemical Engineers) course, can provide a forum in which we ensure that we are
guiding the development of not only technically proficient engineers, but also
professionals. The next iteration of the course could be modified to incorporate more
specific material on team dynamics, and variations of this material could be provided for
students in each team experience they have encounter, from CBE 2200 group
homework problems to senior design project. With the information gathered from these
continued studies and openness to small, easily adoptable curricular adjustments, we
can continue to further ensure the development of versatile chemical engineering
professionals.

Looking to the Future: Short and Long Term Research Goals as a Faculty Member

My background has provided me with a strong foundation in technical science
and chemical engineering, with a unique focus and understanding of education and
student populations. After my matriculation from The Ohio State University, I am taking
on my first faculty role. As I look to my future career ambitions, I aspire to continue
pursuing education research. My interest in technology remains high. Technology and
education are becoming ever more united, and addressing the proper use of technology
in engineering is crucial to the future of our programs. In this area, my overlying research
goals are two-fold (i) understand what technologies are most widely used in (chemical)
engineering education both as teaching tools (e.g., automated response systems) and
as problem-solving tools (e.g., Aspen HYSYS for modeling chemical systems), and (ii)
more broadly establish the potential impact technological advancement has on student
cognitive processes. My graduate work regarding learning styles and self-efficacy
provides me a foundation for understanding student cognition that will translate well into this work.

The first goal of my research will require administering a widely disseminated survey to chemical engineering departments at regional universities of similar structure. The survey will target both students and faculty, and focus on recording what technology and software they use in their program, for what purposes, and their experiences with this software. This will form a basis for understanding the degree to which technology has been adopted in chemical engineering programs, and what, if any, variability exists. My hypothesis is that while most programs have likely adopted similar technologies, I expect to discover exceptions that will provide interesting insights into best practices in use of technology and some of its limitations.

The second goal involves a collaborative study regarding student cognitive processes. This will engage chemical engineering faculty and instructors, education researchers, and neuroscientists/psychologists. Based on knowledge of the variation in cognitive processes caused by media (written word, internet, etc.), we will design a study to assess variation in student processing and problem-solving strategies when using different forms of media for information gathering or obtaining solutions. To establish differences in cognitive processes of chemical engineering students over time, we will analyze results (performance and emotional/physical state of student) from students completing representative chemical engineering problems designed to assess discipline-specific knowledge at a particular year of their undergraduate study. This study will track how student performance changes over time using repeated studies across multiple years.
Over the long-term, I intend to continue allowing my observations of student performance and course structures to inspire new research projects (e.g., seemingly poor student retention of material from specific courses). While technology is a strong research interest, the especially exciting aspect of my interests is their inherent flexibility and local motivation. The project examining the CBE 2200 Process Fundamentals course developed from a simple curiosity as to why our students were performing so poorly in this course, after they had successfully completed pre-requisites and been accepted into the chemical engineering major. This has led to a wider interest from professors throughout the OSU department on how they can begin to mold their classroom based on results of this study.

Developing Those that Follow: Mentoring Future Engineers and Researchers

A common thread throughout my career has been my involvement in outreach and mentoring. I strongly believe in the importance of engaging K-12 students in STEM concepts in new and unique ways, and aspire to continue doing so throughout my career, while engaging graduate and undergraduate students in pedagogical research. Educational work involves a great deal of understanding pedagogies, study design with constraints that are somewhat different from technical studies, and extensive data compilation and analysis. I am enthusiastic about exposing students to this type of work and providing opportunities for interested students. In my career I have served as a mentor for individuals from a variety of backgrounds and age groups. Together, my mentoring and outreach experience provide me a foundation for working with students of very diverse backgrounds and developing the next generation of researchers, scientists, as well as educators.
References

12. Pease, L. F. in *American Institute of Chemical Engineers Annual Meeting*.
32 Soloman, B. A. & Felder, R. M. Index of Learning Styles Questionnaire.
33 Zywno, M. S. in American Society for Engineering Education Annual Conference and Exposition (2003).
39 Bandura, A. Self-efficacy : the exercise of control. (W.H. Freeman, 1997).
41 Bandura, A. Social foundations of thought and action : a social cognitive theory. (Prentice-Hall, 1986).


49 Bandura, A. in *Self-efficacy beliefs of adolescents* (eds Frank Pajares & Timothy C Urdan) Ch. 14, (IAP, 2006).


54 Punch, K. F. *Introduction to social research: Quantitative and qualitative approaches*. (Sage, 2013).


Ohland, M. W. et al. in Proceedings of the 2006 ASEE Annual Conference.


Appendix A  Compilation of Documents Submitted to Institutional Review Board and Study Materials for CBE 2200, Process Fundamentals

Script for Recruitment of Students to Participate in Study

Hello ChBE 2200 Students,

My name is Elif Miskioglu; I am a graduate student in the ChBE department and part of my research involves studying the correlations between learning styles, problem statement perception, and student performance in the interest of developing better teaching techniques and materials in the chemical engineering department.

We are interested in collecting data from your class (student learning styles, grades, and assignment/exam/course content perceptions) throughout this term. Participation is entirely voluntary and will neither affect your grade nor course content. The class will continue to be conducted normally as if this study is not occurring, with the exception that you will receive surveys related to your homework assignments and exams to complete. We hope that these surveys, along with information about student performance, can help us better understand the curriculum as it is and develop better course materials.

Further details are outlined in the consent document (attached), also available on Carmen under the "Learning Styles Study" module on the content page.

We ask for your cooperation in completing the following two tasks by <insert date>:

1) Please accept or decline participation via the Carmen Dropbox labeled "Informed Consent" (per instructions in the attached document) or by returning a hardcopy to the mailbox of Elif Miskioglu in KL 125A.

2) Additionally, please take the "learning styles questionnaire" found at http://www4.ncsu.edu/unity/lockers/users/f/felder/public/ILSpage.html and submit your results as a PDF or screen capture to the "ILS Results" dropbox also on Carmen. Directions for this are also outlined in the "Learning Styles Study" module. This questionnaire should only take 10 to 15 minutes to complete.

Thank you for your time and consideration! Please feel free to respond to this email (contact miskioglu.1@osu.edu) with any questions that you might have.

Elif Eda Miskioglu
Informed Consent Form

This is a consent form for research participation. Participation is voluntary. We are interested in investigating the effect of learning styles on homework/course performance and perception. We will be utilizing your learning style preferences, homework and exam grades, and feedback surveys in search of correlations between performance, perceptions, and learning styles. Data will be de-identified (names removed) and analyzed in aggregate, and no identifiable data will be released or retained.

Raw survey information collected will not be shared with the instructor and in no way be used in grade determination, nor will participation in this study effect course material/content. Results of the study may be shared in de-identified, aggregate form, after the course is over. Efforts will be made to keep your study-related information confidential. However, there may be circumstances where this information must be released. For example, personal information regarding your participation in this study may be disclosed if required by state law. Also, your records may be reviewed by the following groups (as applicable to the research):

- Office for Human Research Protections or other federal, state, or international regulatory agencies;
- The Ohio State University Institutional Review Board or Office of Responsible Research Practices;
- The sponsor, if any, or agency (including the Food and Drug Administration for FDA-regulated research) supporting the study.

Results will be used to improve future teaching methods and materials. Survey and other non-grade data are being collected purely for informational reasons, and will not be used in any type of student evaluation.

By consenting to participate, you agree to allow access to and use of your ChBE 2200 homework and exam grades, survey results, and learning styles indicator results.

Again, participation is voluntary, refusal to participate will involve no penalty or loss of benefits and you may discontinue participation at any time without penalty or loss of benefits. If you decline to participate in the study, we will not incorporate your information in the study. Your course grade and content will not be affected.

Please fill out the form below and return to the mailbox of Elif Miskioglu in KL 125A. By doing so, you are confirming that you have read this consent form.

If you have questions or feel you were harmed as a result of study participation you may contact Elif Miskioglu at miskioglu.1@osu.edu.

For questions about your rights as a participant in this study or to discuss other study-related concerns or complaints with someone who is not part of the research team, you may contact Ms. Sandra Meadows in the Office of Responsible Research Practices at 1-800-678-6251.

Thank you for your time.

I consent to participate

Signature___________________________ Date________________

Printed Name_________________________
Directions for Taking Index of Learning Styles (ILS) Questionnaire

Go to:

http://www.engr.ncsu.edu/learningstyles/ilsweb.html and take the survey.

After hitting submit, make sure to create a record of your results to submit by either:

1) Dropbox on Carmen (“ILS Results”)—“Print results” to a PDF file. If printing to PDF is unavailable, take a screen capture (ctrl + PrtScrn) and paste into a word document. Save with your first initial and last name (e.g. Joe Brown would be jbrown).

Do not copy/paste. This distorts the table of results generated.

2) Hard copy—print a hard copy and submit to the mailbox of Elif Miskioglu in KL 125A.
**Example Survey Used to Gather Student Data**

Submit to Dropbox or mailbox of Elif Miskioglu in KL125

1 = Strongly Disagree   2 = Disagree   3 = Neutral   4 = Agree   5 = Strongly Agree

**Problem 2:**

<table>
<thead>
<tr>
<th></th>
<th>1</th>
<th>2</th>
<th>3</th>
<th>4</th>
<th>5</th>
</tr>
</thead>
<tbody>
<tr>
<td>I am confident solving problems similar to 2 (a).</td>
<td></td>
<td></td>
<td>3</td>
<td></td>
<td></td>
</tr>
<tr>
<td>I am confident solving problems similar to 2 (c).</td>
<td></td>
<td>2</td>
<td>3</td>
<td>4</td>
<td></td>
</tr>
</tbody>
</table>

**Problem 5:**

<table>
<thead>
<tr>
<th></th>
<th>1</th>
<th>2</th>
<th>3</th>
<th>4</th>
<th>5</th>
</tr>
</thead>
<tbody>
<tr>
<td>Problem 5 was easy to understand.</td>
<td></td>
<td></td>
<td>3</td>
<td></td>
<td></td>
</tr>
<tr>
<td>I am confident in my solution for problem 5.</td>
<td></td>
<td></td>
<td>3</td>
<td></td>
<td>4</td>
</tr>
<tr>
<td>Problem 5 would make a fair exam problem.</td>
<td></td>
<td></td>
<td>3</td>
<td>4</td>
<td></td>
</tr>
<tr>
<td>I am uncertain I have the correct answer for problem 5.</td>
<td></td>
<td></td>
<td>3</td>
<td></td>
<td>4</td>
</tr>
<tr>
<td>I am confident solving problems similar to problem 5.</td>
<td></td>
<td></td>
<td>3</td>
<td>4</td>
<td></td>
</tr>
</tbody>
</table>

**Problem 6:**

<table>
<thead>
<tr>
<th></th>
<th>1</th>
<th>2</th>
<th>3</th>
<th>4</th>
<th>5</th>
</tr>
</thead>
<tbody>
<tr>
<td>It was clear what problem 6 is asking.</td>
<td></td>
<td></td>
<td>3</td>
<td></td>
<td>4</td>
</tr>
<tr>
<td>I am not sure my answer to problem 6 is correct.</td>
<td></td>
<td></td>
<td>3</td>
<td>4</td>
<td></td>
</tr>
<tr>
<td>I would like to see problems similar to 6 on exams.</td>
<td></td>
<td></td>
<td>3</td>
<td></td>
<td>4</td>
</tr>
<tr>
<td>I believe I accurately solved problem 6.</td>
<td></td>
<td></td>
<td>3</td>
<td>4</td>
<td></td>
</tr>
<tr>
<td>I am confident solving problems similar to problem 6.</td>
<td></td>
<td></td>
<td>3</td>
<td>4</td>
<td></td>
</tr>
</tbody>
</table>

**Comparing Problems:**

<table>
<thead>
<tr>
<th></th>
<th>1</th>
<th>2</th>
<th>3</th>
<th>4</th>
<th>5</th>
</tr>
</thead>
<tbody>
<tr>
<td>I prefer solving problems similar to 5 over 6.</td>
<td></td>
<td></td>
<td>3</td>
<td></td>
<td>4</td>
</tr>
<tr>
<td>I prefer solving problems similar to 2 (a) over 2(c).</td>
<td></td>
<td></td>
<td>3</td>
<td>4</td>
<td></td>
</tr>
</tbody>
</table>

**Other:**

<table>
<thead>
<tr>
<th></th>
<th>1</th>
<th>2</th>
<th>3</th>
<th>4</th>
<th>5</th>
</tr>
</thead>
<tbody>
<tr>
<td>I began solving problem 5 by drawing a process flow diagram.</td>
<td></td>
<td></td>
<td>3</td>
<td></td>
<td>4</td>
</tr>
<tr>
<td>I lost focus while reading the problem statement for problem 7.</td>
<td></td>
<td></td>
<td>3</td>
<td></td>
<td>4</td>
</tr>
<tr>
<td>I discussed potential solutions to problem 5 with my peers.</td>
<td></td>
<td></td>
<td>3</td>
<td>4</td>
<td></td>
</tr>
<tr>
<td>I read problem 7 at least twice through before beginning.</td>
<td></td>
<td></td>
<td>3</td>
<td>4</td>
<td></td>
</tr>
<tr>
<td>My solution to problem 3 is based on an example problem.</td>
<td></td>
<td></td>
<td>3</td>
<td>4</td>
<td></td>
</tr>
<tr>
<td>The concepts in problem 4 are important and relevant to my field.</td>
<td></td>
<td></td>
<td>3</td>
<td>4</td>
<td></td>
</tr>
</tbody>
</table>

**Multiple Choice:**

I solved problem 8: A) graphically B) Numerically

On problem 7, I: A) discussed potential solutions with my peers B) proceeded independently

Further comments:
Appendix B  Compilation of ILS Student Responses for CBE 2200, Process Fundamentals

Figure B.1. Number of students displaying the strength of each learning style dimension as determined by the ILS from the sum of two separate sections taught by Faculty A and B in Spring 2013 CBE 2200.

Figure B.2. Percentage of students displaying the strength of each learning style dimension as determined by the ILS from the compilation of two separate sections taught by Faculty A and B in Spring 2013 CBE 2200.
Figure B.3. Number of students displaying the strength of each learning style dimension as determined by the ILS from the sum of two separate sections taught by Faculty B and D in Spring 2014 CBE 2200.

Figure B.4. Percentage of students displaying the strength of each learning style dimension as determined by the ILS from the compilation of two separate sections taught by Faculty B and D in Spring 2014 CBE 2200.
Figure B.5. Number of students displaying the strength of each learning style dimension as determined by the ILS from the sum of two separate sections taught by Faculty C and E in Fall 2014 CBE 2200.

Figure B.6. Percentage of students displaying the strength of each learning style dimension as determined by the ILS from the compilation of two separate sections taught by Faculty C and E in Fall 2014 CBE 2200.
Figure B.7. Number of students displaying the strength of each learning style dimension as determined by the ILS from the sum of two separate sections taught by Faculty D and F in Spring 2015 CBE 2200.

Figure B.8. Percentage of students displaying the strength of each learning style dimension as determined by the ILS from the compilation of two separate sections taught by Faculty D and F in Spring 2015 CBE 2200.
Figure B.9. Number of students displaying the strength of each learning style dimension as determined by the ILS from the section taught by Faculty A in Spring 2013 CBE 2200.

Figure B.10. Percentage of students displaying the strength of each learning style dimension as determined by the ILS from the section taught by Faculty A in Spring 2013 CBE 2200.
Figure B.11. Number of students displaying the strength of each learning style dimension as determined by the ILS from the section taught by Faculty B in Spring 2013 CBE 2200.

Figure B.12. Number of students displaying the strength of each learning style dimension as determined by the ILS from the section taught by Faculty B in Spring 2014 CBE 2200.
Figure B.13. Percentage of students displaying the strength of each learning style dimension as determined by the ILS from the section taught by Faculty B in Spring 2013 CBE 2200.

Figure B.14. Percentage of students displaying the strength of each learning style dimension as determined by the ILS from the section taught by Faculty B in Spring 2014 CBE 2200.
Figure B.15. Number of students displaying the strength of each learning style dimension as determined by the ILS from the section taught by Faculty C in Fall 2014 CBE 2200.

Figure B.16. Percentage of students displaying the strength of each learning style dimension as determined by the ILS from the section taught by Faculty C in Fall 2014 CBE 2200.
Figure B.17. Number of students displaying the strength of each learning style dimension as determined by the ILS from the section taught by Faculty D in Spring 2014 CBE 2200.

Figure B.18. Number of students displaying the strength of each learning style dimension as determined by the ILS from the section taught by Faculty D in Spring 2015 CBE 2200.
Figure B.19. Percentage of students displaying the strength of each learning style dimension as determined by the ILS from the section taught by Faculty D in Spring 2014 CBE 2200.

Figure B.20. Percentage of students displaying the strength of each learning style dimension as determined by the ILS from the section taught by Faculty D in Spring 2015 CBE 2200.
Figure B.21. Number of students displaying the strength of each learning style dimension as determined by the ILS from the section taught by Faculty E in Fall 2014 CBE 2200.

Figure B.22. Percentage of students displaying the strength of each learning style dimension as determined by the ILS from the section taught by Faculty E in Fall 2014 CBE 2200.
Figure B.23. Number of students displaying the strength of each learning style dimension as determined by the ILS from the section taught by Faculty F in Spring 2015 CBE 2200.

Figure B.24. Percentage of students displaying the strength of each learning style dimension as determined by the ILS from the section taught by Faculty F in Spring 2015 CBE 2200.
Appendix C  Compilation of Final Student Grades for CBE 2200, Process Fundamentals

Figure C.1. Number of students whose final grade fell within each range from the section taught by Faculty A in Spring 2013 CBE 2200.
Figure C.2. Number of students whose final grade fell within each range from the section taught by Faculty B in Spring 2013 CBE 2200.

Figure C.3. Number of students whose final grade fell within each range from the section taught by Faculty B in Spring 2014 CBE 2200.
Figure C.4. Number of students whose final grade fell within each range from the section taught by Faculty C in Fall 2013 CBE 2200.

Figure C.5. Number of students whose final grade fell within each range from the section taught by Faculty C in Fall 2014 CBE 2200.
Figure C.6. Number of students whose final grade fell within each range from the section taught by Faculty D in Spring 2014 CBE 2200 (histogram displays grades that are unadjusted).

Figure C.7. Number of students whose final grade fell within each range from the section taught by Faculty D in Spring 2014 CBE 2200 (histogram displays grades after they were adjusted by the faculty member).
Figure C.8. This is the same as Figure C.7, with the x-axis now displaying a different range.

Figure C.9. Number of students whose final grade fell within each range from the section taught by Faculty D in Spring 2015 CBE 2200 (histogram displays grades that are unadjusted).
Figure C.10. Number of students whose final grade fell within each range from the section taught by Faculty D in Spring 2015 CBE 2200 (histogram displays grades after they were adjusted by the faculty member).
Figure C.11. This is the same as Figure C.10, with the x-axis now displaying a different range.

Figure C.12. Number of students whose final grade fell within each range from the section taught by Faculty E in Fall 2014 CBE 2200.
Figure C.13. Number of students whose final grade fell within each range from the section taught by Faculty F in Spring 2015 CBE 2200.
Appendix D  Compilation of Concepts and Inherent Biases on Exams by Various Faculty Members Teaching CBE 2200

Figure D.1. Inherent biases observed on exam problems administered by Faculty B during Spring 2014 CBE 2200.
Figure D.2. Inherent biases observed on exam problems administered by Faculty C during Fall 2014 CBE 2200.

Figure D.3. Inherent biases observed on exam problems administered by Faculty D during Spring 2014 CBE 2200.
Figure D.4. Inherent biases observed on exam problems administered by Faculty D during Spring 2015 CBE 2200.

Figure D.5. Inherent biases observed on exam problems administered by Faculty E during Fall 2014 CBE 2200.
Figure D.6. Inherent biases observed on exam problems administered by Faculty F during Spring 2015 CBE 2200.
Table D.1. Compilation of concepts on CBE 2200 examinations administered by various faculty.

<table>
<thead>
<tr>
<th>Exam</th>
<th>Faculty B</th>
<th>Faculty C</th>
<th>Faculty D (Sp14)</th>
<th>Faculty D (Sp15)</th>
<th>Faculty E</th>
<th>Faculty F</th>
</tr>
</thead>
<tbody>
<tr>
<td>1</td>
<td>Mixture</td>
<td>Linearization</td>
<td>Dimensional analysis</td>
<td>Linearization</td>
<td>Dimensional analysis</td>
<td>Dimensional analysis</td>
</tr>
<tr>
<td></td>
<td>Least squares</td>
<td>Single unit mass balance</td>
<td>Dimensional analysis</td>
<td>Single unit process</td>
<td>Dimensional analysis</td>
<td>Percent Error</td>
</tr>
<tr>
<td></td>
<td>Dimensional analysis</td>
<td>Dimensional analysis</td>
<td>Dimensional analysis</td>
<td>Reaction stoichiometry</td>
<td>Dimensional analysis</td>
<td>Mixtures</td>
</tr>
<tr>
<td></td>
<td>Derivation</td>
<td>Reynolds number – units</td>
<td>Pressure-manometer</td>
<td>Reaction stoichiometry</td>
<td>Percent error</td>
<td>Conversion factors</td>
</tr>
<tr>
<td></td>
<td></td>
<td></td>
<td></td>
<td>Two unit process</td>
<td>Density</td>
<td>Linearization</td>
</tr>
<tr>
<td></td>
<td></td>
<td></td>
<td></td>
<td>(reactor, separation</td>
<td>Mass balance</td>
<td>Least squares</td>
</tr>
<tr>
<td></td>
<td></td>
<td></td>
<td></td>
<td>with recycle)</td>
<td>Mass balances with</td>
<td>PFD – 1-unit</td>
</tr>
<tr>
<td></td>
<td></td>
<td></td>
<td></td>
<td>reaction</td>
<td>reaction</td>
<td></td>
</tr>
<tr>
<td></td>
<td></td>
<td></td>
<td></td>
<td>Due to equilibrium</td>
<td>Chemical equilibrium</td>
<td></td>
</tr>
<tr>
<td></td>
<td></td>
<td></td>
<td></td>
<td>Mass balance with reaction-</td>
<td></td>
<td></td>
</tr>
<tr>
<td>2</td>
<td>Mass balance</td>
<td>Mass balance with reaction</td>
<td>Single unit mass balance</td>
<td>Mass flow rate</td>
<td>Mass balance with reaction-</td>
<td>DoF Mass balance</td>
</tr>
<tr>
<td></td>
<td></td>
<td>(distillation column)</td>
<td>Reaction stoichiometry</td>
<td>Specific gravity</td>
<td>Mass flow rate</td>
<td>PFD 2-unit distillation, 2-</td>
</tr>
<tr>
<td></td>
<td></td>
<td>Species balance</td>
<td>Reaction stoichiometry</td>
<td>Dimensional analysis</td>
<td>flow rate to molar flow rate</td>
<td>unit recycle + conversion)</td>
</tr>
<tr>
<td></td>
<td></td>
<td>Extent of reaction</td>
<td>Reaction stoichiometry</td>
<td>Mass balances</td>
<td>Reaction stoichiometry</td>
<td>DoF</td>
</tr>
<tr>
<td></td>
<td></td>
<td>(reaction stoichiometry)</td>
<td>Two unit process</td>
<td>Reaction</td>
<td>Three unit process</td>
<td>Process (distillation, mixer, distillation)</td>
</tr>
<tr>
<td></td>
<td></td>
<td>Mass balances with reaction</td>
<td>(reactor, separation</td>
<td>with recycle)</td>
<td>DoF</td>
<td>Mass balance</td>
</tr>
<tr>
<td></td>
<td></td>
<td>Mass balance with reaction</td>
<td>with recycle</td>
<td>Mass balances with reaction</td>
<td>Chemical equilibrium</td>
<td></td>
</tr>
<tr>
<td></td>
<td></td>
<td>Mass balance with reaction-conversion</td>
<td>Reaction</td>
<td>Chemical equilibrium</td>
<td></td>
<td></td>
</tr>
<tr>
<td>3</td>
<td>Psychometric properties</td>
<td>Heat (calculate Q)</td>
<td>PFD</td>
<td>Gibbs phase rule</td>
<td>Non-ideal gas concept</td>
<td>Gibbs phase rule for DoF</td>
</tr>
<tr>
<td></td>
<td></td>
<td></td>
<td>Psychometric properties</td>
<td>Gas law specific volume</td>
<td>Vapor-liquid</td>
<td>Gauss pressure</td>
</tr>
<tr>
<td></td>
<td></td>
<td></td>
<td></td>
<td>Gas (Raoult’s) mixtures</td>
<td>equilibrium</td>
<td>Single Unit</td>
</tr>
<tr>
<td></td>
<td></td>
<td></td>
<td></td>
<td>Compressibility</td>
<td>Vaporization (phase change)</td>
<td>Vaporization (phase change)</td>
</tr>
<tr>
<td></td>
<td></td>
<td></td>
<td></td>
<td>Combustion</td>
<td>extent, excess</td>
<td></td>
</tr>
<tr>
<td></td>
<td></td>
<td></td>
<td></td>
<td>mass balance</td>
<td></td>
<td></td>
</tr>
<tr>
<td></td>
<td></td>
<td></td>
<td></td>
<td>(extent, excess)</td>
<td></td>
<td></td>
</tr>
<tr>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>4</td>
<td>Energy balance</td>
<td>Enthalpy</td>
<td>Energy balance on steam</td>
<td>Process understanding</td>
<td>Heat changes</td>
<td>Mixtures (gaseous)</td>
</tr>
<tr>
<td></td>
<td></td>
<td></td>
<td>Enthalpy</td>
<td>Power understanding</td>
<td>(steam tables)</td>
<td>Gas laws (Raoult’s)</td>
</tr>
<tr>
<td></td>
<td></td>
<td></td>
<td>Energy balance (vaporization)</td>
<td>PFD</td>
<td>Energy balance</td>
<td>Mixtures</td>
</tr>
<tr>
<td></td>
<td></td>
<td></td>
<td>Specific enthalpy</td>
<td>Assumptions</td>
<td>Heat capacity/enthalpy</td>
<td>PFD</td>
</tr>
<tr>
<td></td>
<td></td>
<td></td>
<td>Rate of heat</td>
<td>Assumptions</td>
<td>Psychometric properties</td>
<td>Assumptions</td>
</tr>
<tr>
<td></td>
<td></td>
<td></td>
<td>Assumptions</td>
<td>Energy balances</td>
<td>(dry bulb, relative humidity)</td>
<td>Energy balances</td>
</tr>
<tr>
<td></td>
<td></td>
<td></td>
<td>Mass Balance</td>
<td>Energy balances</td>
<td>Efficiency</td>
<td>Four unit process</td>
</tr>
<tr>
<td></td>
<td></td>
<td></td>
<td>Heat of reaction</td>
<td>Energy balances</td>
<td></td>
<td>(extractor, filter, evaporator, condenser)</td>
</tr>
<tr>
<td></td>
<td></td>
<td></td>
<td>Enthalpy</td>
<td>Energy balances</td>
<td></td>
<td>with accumulation and recycle</td>
</tr>
<tr>
<td></td>
<td></td>
<td></td>
<td>Internal energy</td>
<td>Energy balances</td>
<td></td>
<td>Power</td>
</tr>
<tr>
<td></td>
<td></td>
<td></td>
<td>Mixing of steam</td>
<td>Energy balances</td>
<td></td>
<td></td>
</tr>
<tr>
<td></td>
<td></td>
<td></td>
<td>(superheated and saturated)</td>
<td>Energy balances</td>
<td></td>
<td></td>
</tr>
<tr>
<td></td>
<td></td>
<td></td>
<td>Steady state</td>
<td>Adiabatic</td>
<td>Power</td>
<td></td>
</tr>
<tr>
<td></td>
<td></td>
<td></td>
<td>Energy balances</td>
<td>Energy balances</td>
<td></td>
<td></td>
</tr>
<tr>
<td></td>
<td></td>
<td></td>
<td>Expansion</td>
<td>Energy balances</td>
<td></td>
<td></td>
</tr>
<tr>
<td></td>
<td></td>
<td></td>
<td>Internal energy</td>
<td>Energy balances</td>
<td></td>
<td></td>
</tr>
<tr>
<td></td>
<td></td>
<td></td>
<td>of ideal gas</td>
<td>Energy balances</td>
<td></td>
<td></td>
</tr>
<tr>
<td>Final Exam</td>
<td>N/A</td>
<td>N/A</td>
<td>N/A</td>
<td>N/A</td>
<td>N/A</td>
<td>N/A</td>
</tr>
</tbody>
</table>
Appendix E  Compilation of the Concept Inventory Questions and Answers
Administered at the End of Spring 2015 CBE 2200

*Question #1:* At 300 kPa a substance boils at 70°C. The substance is observed to boil when the pressure is increased to 600 kPa. At a pressure of 600 kPa, the substance will boil at:

Table E.1. Percent of student respondents that selected each possible answer for Question #1 on the concept inventory administered in the sections taught by Faculty D and F at the end of Spring 2015 CBE 2200. The bottom panel shows each of the possible answers with the correct answer shaded gray.
**Question #2**: A small beaker containing an acid solution which is 5% $\text{H}_2\text{SO}_4$ and 95% water is mixed with a solution in a large beaker which contains some $\text{H}_2\text{SO}_4$ and water. The resultant mixture is 11% $\text{H}_2\text{SO}_4$ and 89% water. What was the composition of the solution in the larger beaker before mixing occurred?

![Selected Answer Legend](image)

**Selected Answer Legend**

<p>| | |</p>
<table>
<thead>
<tr>
<th></th>
<th></th>
</tr>
</thead>
<tbody>
<tr>
<td>A</td>
<td>Less than 5% $\text{H}_2\text{SO}_4$.</td>
</tr>
<tr>
<td>B</td>
<td>Between 5% $\text{H}_2\text{SO}_4$ and 11% $\text{H}_2\text{SO}_4$.</td>
</tr>
<tr>
<td>C</td>
<td>Greater than 11% $\text{H}_2\text{SO}_4$.</td>
</tr>
<tr>
<td>D</td>
<td>Exactly 5% $\text{H}_2\text{SO}_4$.</td>
</tr>
<tr>
<td>E</td>
<td>Impossible to say as there is insufficient information.</td>
</tr>
</tbody>
</table>

**Figure E.2.** Percent of student respondents that selected each possible answer for Question #2 on the concept inventory administered in the sections taught by Faculty D and F at the end of Spring 2015 CBE 2200. The bottom panel shows each of the possible answers with the correct answer shaded gray.
**Question #3**: Generally if the pressure is held constant the density of a gas does what with increasing temperature?

![Graph showing the percentage of student respondents for each answer](image)

<table>
<thead>
<tr>
<th>Selected Answer Legend</th>
</tr>
</thead>
<tbody>
<tr>
<td><strong>A</strong></td>
</tr>
<tr>
<td><strong>B</strong></td>
</tr>
<tr>
<td><strong>C</strong></td>
</tr>
<tr>
<td><strong>D</strong></td>
</tr>
<tr>
<td><strong>E</strong></td>
</tr>
</tbody>
</table>

Figure E.3. Percent of student respondents that selected each possible answer for Question #3 on the concept inventory administered in the sections taught by Faculty D and F at the end of Spring 2015 CBE 2200. The bottom panel shows each of the possible answers with the correct answer shaded gray.
**Question #4:** Which ball in the list below has the highest potential energy relative to the ground? Assume that all the balls have the same mass.

<table>
<thead>
<tr>
<th>Selected Answer Legend</th>
</tr>
</thead>
<tbody>
<tr>
<td>A</td>
</tr>
<tr>
<td>B</td>
</tr>
<tr>
<td>C</td>
</tr>
<tr>
<td>D</td>
</tr>
<tr>
<td>E</td>
</tr>
</tbody>
</table>

Figure E.4. Percent of student respondents that selected each possible answer for Question #4 on the concept inventory administered in the sections taught by Faculty D and F at the end of Spring 2015 CBE 2200. The bottom panel shows each of the possible answers with the correct answer shaded gray.
**Question #5:** You use breath to blow up an ordinary party balloon at home. Which of the pressures listed below is closest to the absolute pressure inside the balloon?

<table>
<thead>
<tr>
<th>Selected Answer Legend</th>
</tr>
</thead>
<tbody>
<tr>
<td>A 100 Pa</td>
</tr>
<tr>
<td>B 1000 Pa</td>
</tr>
<tr>
<td>C 10,000 Pa</td>
</tr>
<tr>
<td>D 100,000 Pa</td>
</tr>
<tr>
<td>E 1,000,000 Pa</td>
</tr>
</tbody>
</table>

Figure E.5. Percent of student respondents that selected each possible answer for Question #5 on the concept inventory administered in the sections taught by Faculty D and F at the end of Spring 2015 CBE 2200. The bottom panel shows each of the possible answers with the correct answer shaded gray.
Question #6: A gas is flowing along through a pipe at a rate 150 liter/min when it enters a heater. When it leaves the heater the temperature of the gas has increased by 50°C. The pressure is approximately atmospheric. What is the volumetric flow rate of the gas leaving the heater?

Selected Answer Legend

<p>| | |</p>
<table>
<thead>
<tr>
<th></th>
<th></th>
</tr>
</thead>
<tbody>
<tr>
<td>A</td>
<td>Less than 150 L/min.</td>
</tr>
<tr>
<td>B</td>
<td>150 L/min.</td>
</tr>
<tr>
<td>C</td>
<td>Greater than 150 L/min.</td>
</tr>
<tr>
<td>D</td>
<td>Either less than or equal to 150 L/min.</td>
</tr>
<tr>
<td>E</td>
<td>Impossible to say as it depends on the nature of the gas.</td>
</tr>
</tbody>
</table>

Figure E.6. Percent of student respondents that selected each possible answer for Question #6 on the concept inventory administered in the sections taught by Faculty D and F at the end of Spring 2015 CBE 2200. The bottom panel shows each of the possible answers with the correct answer shaded gray.
Question #7: Which one of the following statements is false?

Figure E.7. Percent of student respondents that selected each possible answer for Question #7 on the concept inventory administered in the sections taught by Faculty D and F at the end of Spring 2015 CBE 2200. The bottom panel shows each of the possible answers with the correct answer shaded gray.

<table>
<thead>
<tr>
<th>Selected Answer Legend</th>
</tr>
</thead>
<tbody>
<tr>
<td>A</td>
</tr>
<tr>
<td>B</td>
</tr>
<tr>
<td>C</td>
</tr>
<tr>
<td>D</td>
</tr>
<tr>
<td>E</td>
</tr>
</tbody>
</table>
**Question #8:** What is 100°C expressed in °F?

---

**Selected Answer Legend**

<p>| | |</p>
<table>
<thead>
<tr>
<th></th>
<th></th>
</tr>
</thead>
<tbody>
<tr>
<td>A</td>
<td>100°F</td>
</tr>
<tr>
<td>B</td>
<td>180°F</td>
</tr>
<tr>
<td>C</td>
<td>212°F</td>
</tr>
<tr>
<td>D</td>
<td>180°F or 212°F</td>
</tr>
<tr>
<td>E</td>
<td>32°F</td>
</tr>
</tbody>
</table>

---

Figure E.8. Percent of student respondents that selected each possible answer for Question #8 on the concept inventory administered in the sections taught by Faculty D and F at the end of Spring 2015 CBE 2200. The bottom panel shows each of the possible answers with the correct answer shaded gray.
Question #9: Which one of the operations listed below involves the greatest change in energy of a kilogram of H₂O? Assume all operations are conducted at atmospheric pressure.

<table>
<thead>
<tr>
<th>Selected Answer Legend</th>
</tr>
</thead>
<tbody>
<tr>
<td>A Heating 1 kg of water from 10°C to 30°C.</td>
</tr>
<tr>
<td>B Heating 1 kg of water from 70°C to 90°C.</td>
</tr>
</tbody>
</table>
| C Turning 1 kg of water at 100°C into 1 kg of steam at 100°C. | *Correct Answer*
| D Heating 1 kg of water from 110°C to 130°C. |
| E Heating 1 kg of water from 170°C to 190°C. |

Figure E.9. Percent of student respondents that selected each possible answer for Question #9 on the concept inventory administered in the sections taught by Faculty D and F at the end of Spring 2015 CBE 2200. The bottom panel shows each of the possible answers with the correct answer shaded gray.
**Question #10:** It is not possible to cool a substance below absolute zero (i.e., 0 K) because:

<table>
<thead>
<tr>
<th>Selected Answer Legend</th>
</tr>
</thead>
<tbody>
<tr>
<td>A</td>
</tr>
<tr>
<td>B</td>
</tr>
<tr>
<td>C</td>
</tr>
<tr>
<td>D</td>
</tr>
<tr>
<td>E</td>
</tr>
</tbody>
</table>

Figure E.10. Percent of student respondents that selected each possible answer for Question #10 on the concept inventory administered in the sections taught by Faculty D and F at the end of Spring 2015 CBE 2200. The bottom panel shows each of the possible answers with the correct answer shaded gray.
Questions 11 and 12 refer to the diagram below. The flow rate of stream 3 is greater than the flow rate of stream 1, and the composition of streams 2 and 5 are identical.

**Question #11**: What are the directions of flow between points X and Y, and between points Y and Z?

![Diagram of flow between points X, Y, and Z with flow rates and compositions indicated.]

**Selected Answer Legend**

<p>| | |</p>
<table>
<thead>
<tr>
<th></th>
<th></th>
</tr>
</thead>
<tbody>
<tr>
<td>A</td>
<td>X to Y and Y to Z.</td>
</tr>
<tr>
<td>B</td>
<td>X to Y and Z to Y.</td>
</tr>
<tr>
<td>C</td>
<td>Y to X and Y to Z.</td>
</tr>
<tr>
<td>D</td>
<td>Y to X and Z to Y.</td>
</tr>
<tr>
<td>E</td>
<td>Insufficient information is supplied to answer the question.</td>
</tr>
</tbody>
</table>

Figure E.11. Percent of student respondents that selected each possible answer for Question #11 on the concept inventory administered in the sections taught by Faculty D and F at the end of Spring 2015 CBE 2200. The bottom panel shows each of the possible answers with the correct answer shaded gray.
Question #12: Which one of the following statements is correct?

Figure E.12. Percent of student respondents that selected each possible answer for Question #12 on the concept inventory administered in the sections taught by Faculty D and F at the end of Spring 2015 CBE 2200. The bottom panel shows each of the possible answers with the correct answer shaded gray.
**Question #13:** Refrigerant 123 or 2-2-dichloro-1-1-1-trifluoroethane has the formula CCl$_2$HCF$_3$. Which one of the following statements is false?

![Selected Answer Legend](image)

<table>
<thead>
<tr>
<th></th>
<th>Statement</th>
</tr>
</thead>
<tbody>
<tr>
<td>A</td>
<td>1 mol of CCl$_2$HCF$_3$ contains 4 different elements.</td>
</tr>
<tr>
<td>B</td>
<td>1 mol of CCl$_2$HCF$_3$ contains 8 mol of atoms.</td>
</tr>
<tr>
<td>C</td>
<td>1 mol of CCl$_2$HCF$_3$ contains 1 mol of CCl$_2$H.</td>
</tr>
<tr>
<td>D</td>
<td>1 mol of CCl$_2$HCF$_3$ contains 3 mol of F$_3$.</td>
</tr>
<tr>
<td>E</td>
<td>1 mol of CCl$_2$HCF$_3$ contains 2 mol of Cl.</td>
</tr>
</tbody>
</table>

Figure E.13. Percent of student respondents that selected each possible answer for Question #13 on the concept inventory administered in the sections taught by Faculty D and F at the end of Spring 2015 CBE 2200. The bottom panel shows each of the possible answers with the correct answer shaded gray.
**Question #14:** A gaseous mixture of hydrogen and helium enters a non-insulated pipe at a rate of 2.00 m\(^3\)/h. A distance 300 m down the pipe, the pipe branches. Within the pipe network the temperature and pressure of the gas vary considerably. If 0.90 m\(^3\)/h of the gas leaves along branch A, what is the flow rate of the gas leaving branch B?

Figure E.14. Percent of student respondents that selected each possible answer for Question #14 on the concept inventory administered in the sections taught by Faculty D and F at the end of Spring 2015 CBE 2200. The bottom panel shows each of the possible answers with the correct answer shaded gray.

<table>
<thead>
<tr>
<th>Selected Answer Legend</th>
<th></th>
</tr>
</thead>
<tbody>
<tr>
<td>A 1.10 m(^3)/h.</td>
<td></td>
</tr>
<tr>
<td>B Less than 1.10 m(^3)/h.</td>
<td></td>
</tr>
<tr>
<td>C Greater than 1.10 m(^3)/h.</td>
<td></td>
</tr>
<tr>
<td>D Less than or equal to 1.10 m(^3)/h.</td>
<td></td>
</tr>
<tr>
<td>E Impossible to say as there is insufficient information.</td>
<td></td>
</tr>
</tbody>
</table>
Question #15: The energy of a material increases when its velocity, height or temperature is increased. Suppose you have 1 kg of water. Which of the following operations listed below will increase the water's energy by the greatest amount?

![Figure E.15. Percent of student respondents that selected each possible answer for Question #15 on the concept inventory administered in the sections taught by Faculty D and F at the end of Spring 2015 CBE 2200. The bottom panel shows each of the possible answers with the correct answer shaded gray.](image)

<table>
<thead>
<tr>
<th>Selected Answer Legend</th>
</tr>
</thead>
<tbody>
<tr>
<td>A</td>
</tr>
<tr>
<td>B</td>
</tr>
<tr>
<td>C</td>
</tr>
<tr>
<td>D</td>
</tr>
<tr>
<td>E</td>
</tr>
</tbody>
</table>
**Question #16:** Two chemicals, A and B, react in the gas phase to produce a gas C, according to the reaction: \( \text{A(g)} + \text{B(g)} \rightarrow 3\text{C(g)} \).

The reaction is exothermic meaning that heat is evolved within the reaction. The reaction occurs with a perfectly insulated reactor so that no heat may enter or leave the reactor through the reactor walls. If reactants A and B enter the reactor at a temperature of \( 150^\circ\text{C} \), at what temperature will the product gases leave the reactor?

![Diagram of a reactor with reactants entering at 150°C and product gases leaving.]

<table>
<thead>
<tr>
<th>Selected Answer Legend</th>
</tr>
</thead>
<tbody>
<tr>
<td>A</td>
</tr>
<tr>
<td>B</td>
</tr>
<tr>
<td>C</td>
</tr>
<tr>
<td>D</td>
</tr>
<tr>
<td>E</td>
</tr>
</tbody>
</table>

Figure E.16. Percent of student respondents that selected each possible answer for Question #16 on the concept inventory administered in the sections taught by Faculty D and F at the end of Spring 2015 CBE 2200. The bottom panel shows each of the possible answers with the correct answer shaded gray.
Question #17: Consider the process shown below.

A stream consisting of three components, A, B and C, enters a separator. The composition of the stream is 20% A, 30% B and 50% C. The separator produces three streams of differing compositions, and of differing flow rates. The composition of one of the three streams leaving the separator is 56% A, 28% B and 16% C. The composition of another of the three streams is 58% A, 10% B and 32% C. Which of the compositions listed below is a possible composition of the third product stream?

<table>
<thead>
<tr>
<th>Selected Answer Legend</th>
</tr>
</thead>
<tbody>
<tr>
<td>A 2% A, 35% B, and 63% C.</td>
</tr>
<tr>
<td>B 10% A, 25% B, and 65% C.</td>
</tr>
<tr>
<td>C 22% A, 25% B, and 53% C.</td>
</tr>
<tr>
<td>D 28% A, 12% B, and 60% C.</td>
</tr>
<tr>
<td>E 30% A, 45% B, and 25% C.</td>
</tr>
</tbody>
</table>

Figure E.17. Percent of student respondents that selected each possible answer for Question #17 on the concept inventory administered in the sections taught by Faculty D and F at the end of Spring 2015 CBE 2200. The bottom panel shows each of the possible answers with the correct answer shaded gray.
**Question #18**: Carbon monoxide at a temperature of 88°C enters a pipe network at a flow rate of 32 kg/min. The carbon monoxide flows 150 m along a length of pipe before being mixed with a stream of hydrogen. The hydrogen entered the pipe network at a temperature of 65°C with a flow rate of 4 kg/min a distance 80 m from the mixer. Within the pipe network the temperature and pressure of the gases varies significantly. What is the flow rate of the mixed gas stream at a point 200 m from the mixer?

![Diagram of gas flow](image)

**Selected Answer Legend**

<p>| | |</p>
<table>
<thead>
<tr>
<th></th>
<th></th>
</tr>
</thead>
<tbody>
<tr>
<td>A</td>
<td>Less than 36 kg/min.</td>
</tr>
<tr>
<td>B</td>
<td>36 kg/min.</td>
</tr>
<tr>
<td>C</td>
<td>Greater than 36 kg/min.</td>
</tr>
<tr>
<td>D</td>
<td>Impossible to say as it depends on the relative diameters of the pipes.</td>
</tr>
<tr>
<td>E</td>
<td>Impossible to say as it depends on the nature of the gas.</td>
</tr>
</tbody>
</table>

Figure E.18. Percent of student respondents that selected each possible answer for Question #18 on the concept inventory administered in the sections taught by Faculty D and F at the end of Spring 2015 CBE 2200. The bottom panel shows each of the possible answers with the correct answer shaded gray.
**Question #19**: Which ball in the list below has the lowest kinetic energy relative to a platform on top of a high tower? Assume that all the balls have the same mass and density.

<table>
<thead>
<tr>
<th>Selected Answer Legend</th>
</tr>
</thead>
<tbody>
<tr>
<td><strong>A</strong></td>
</tr>
<tr>
<td><strong>B</strong></td>
</tr>
<tr>
<td><strong>C</strong></td>
</tr>
<tr>
<td><strong>D</strong></td>
</tr>
<tr>
<td><strong>E</strong></td>
</tr>
</tbody>
</table>

Figure E.19. Percent of student respondents that selected each possible answer for Question #19 on the concept inventory administered in the sections taught by Faculty D and F at the end of Spring 2015 CBE 2200. The bottom panel shows each of the possible answers with the correct answer shaded gray.
Question #20: An insulated vessel contains 200 ml of water at 60°C. Into the vessel, 200 ml of an acid at 20°C are poured. The contents of the vessel are then well mixed. If no heat is lost or gained through the walls of the container whilst the liquids are being mixed what will be the temperature of the mixture? Assume no chemical reactions take place.

![Selected Answer Legend]

<p>| | |</p>
<table>
<thead>
<tr>
<th></th>
<th></th>
</tr>
</thead>
<tbody>
<tr>
<td>A</td>
<td>Less than 40°C.</td>
</tr>
<tr>
<td>B</td>
<td>40°C.</td>
</tr>
<tr>
<td>C</td>
<td>Greater than 40°C.</td>
</tr>
<tr>
<td>D</td>
<td>Less than or equal to 40°C.</td>
</tr>
<tr>
<td>E</td>
<td>Impossible to say as the temperature will depend on the properties of the mixture.</td>
</tr>
</tbody>
</table>

Figure E.20. Percent of student respondents that selected each possible answer for Question #20 on the concept inventory administered in the sections taught by Faculty D and F at the end of Spring 2015 CBE 2200. The bottom panel shows each of the possible answers with the correct answer shaded gray.
Appendix F  Compilation of Documents Submitted to Institutional Review Board and Study Materials for CBE 4630, Unit Operations Laboratory

Script for Recruitment of Students to Participate in Study

Hello CBE 4630 Students,

My name is Elif Miskioglu; I am a graduate student in the CBE department and part of my research involves studying the correlations between learning styles, problem statement perception, and student performance in the interest of developing better teaching techniques and materials in the chemical engineering department.

We are interested in collecting data from your class (team learning styles, performance, and team dynamics) throughout this term. Participation is entirely voluntary and will neither affect your grade nor course content. The class will continue to be conducted normally as if this study is not occurring, with the exception that you will receive surveys related to your laboratory assignments to complete. We hope that these surveys, along with information about team performance, can help us better understand team dynamics among chemical engineering students and provide a basis for improving our curriculum with respect to how we approach teaching teamwork skills.

Further details are outlined in the consent document (attached).

We ask for your cooperation in completing the following two tasks by <insert date>:

1) Please review the informed consent document I will be handing out. If you decide to give consent to participate, please fill out the form after reviewing it and return to me (Elif Miskioglu, mailbox in KL 125A).

2) Additionally, please take the "learning styles questionnaire" found at http://www4.ncsu.edu/unity/lockers/users/f/felder/public/ILSpage.html and submit your results as a PDF or screen capture to the "ILS Results" dropbox also on Carmen. Directions for this are also outlined on Carmen under <insert location>. This questionnaire should only take 10 to 15 minutes to complete.

Thank you for your time and consideration! Please feel free [to respond to this email (contact miskioglu.1@osu.edu)] with any questions that you might have.

Elif Eda Miskioglu
Informed Consent Form

This is a consent form for research participation. Participation is voluntary. We are interested in investigating the effect of learning styles on group performance and dynamics. We will be utilizing your learning style preferences, unit operations laboratory grades in the Maymester, group evaluation surveys, and peer evaluations in search of correlations between performance, perceptions, and learning styles. Data will be de-identified (names removed) and analyzed in aggregate, and no identifiable data will be released or retained. There are no foreseeable risks or discomforts associated with participation.

Raw survey information collected will not be shared with the instructor and in no way be used in grade determination, nor will participation in this study affect course material/content. Results of the study may be shared in de-identified, aggregate form, after the course is over. Efforts will be made to keep your study-related information confidential. However, there may be circumstances where this information must be released. For example, personal information regarding your participation in this study may be disclosed if required by state law. Also, your records may be reviewed by the following groups (as applicable to the research):

- Office for Human Research Protections or other federal, state, or international regulatory agencies;
- The Ohio State University Institutional Review Board or Office of Responsible Research Practices;
- The sponsor, if any, or agency (including the Food and Drug Administration for FDA-regulated research) supporting the study.

Data collection will occur through Carmen. We will work to make sure that no one sees your survey responses without approval. But, because we are using the Internet, there is a chance that someone could access your online responses without permission. In some cases, this information could be used to identify you.

Participation in the study involves minimal time commitment. We expect that completion of the surveys (the only item not a component of your regular coursework) should take no more than a total of 75 minutes, spread throughout the term. That is, approximately, 15 minutes per week. There are no incentives for study participation.

Results will be used to improve future teaching methods and materials. Survey and other non-grade data are being collected purely for informational reasons, and will not be used in any type of student evaluation.

By consenting to participate, you agree to allow access to and use of your CBE 4630 grades, survey results, peer evaluations, and learning styles indicator results.

Again, participation is voluntary, refusal to participate will involve no penalty or loss of benefits and you may discontinue participation at any time without penalty or loss of benefits. If you decline to participate in the study, we will not incorporate your information in the study. Your course grade and content will not be affected.

You should have two copies of this document. Please fill out the form below (next page) for one of them and return to the mailbox of Elif Miskioglu in KL 125A. By doing so, you are confirming that you have read this consent form. The second copy is for you to keep.
If you have questions or feel you were harmed as a result of study participation you may contact Elif Miskioglu at miskioglu.1@osu.edu.

For questions about your rights as a participant in this study or to discuss other study-related concerns or complaints with someone who is not part of the research team, you may contact Ms. Sandra Meadows in the Office of Responsible Research Practices at 1-800-678-6251.

Thank you for your time.

[Signature] I consent to participate

Signature_____________________________      Date_______________
Printed Name_________________________

Investigator/Research Staff

I have explained the research to the participant or his/her representative before requesting the signature(s) above. There are no blanks in this document. A copy of this form has been given to the participant or his/her representative.

Printed name of person obtaining consent

Signature of person obtaining consent

AM/PM

Date and time
Directions for Taking Index of Learning Styles (ILS) Questionnaire

Go to:

http://www.engr.ncsu.edu/learningstyles/ilsweb.html and take the survey.

After hitting submit, make sure to create a record of your results to submit by either:

3) Dropbox on Carmen (“ILS Results”)—“Print results” to a PDF to create a PDF file. If printing to PDF is unavailable, take a screen capture (ctrl + PrtScrn) and paste into a word document. Save with your first initial and last name (e.g. Joe Brown would be jbrown).

Do not copy/paste. This distorts the table of results generated.

4) Hard copy—print a hard copy and submit to the mailbox of Elif Miskioglu in KL 125A.
**Example Survey Used to Gather Student Data**

Please take a moment to evaluate your group performance and dynamics.

1= Strongly Disagree 2= Disagree 3=Neutral 4=Agree 5= Strongly Agree

<table>
<thead>
<tr>
<th></th>
<th>1</th>
<th>2</th>
<th>3</th>
<th>4</th>
<th>5</th>
</tr>
</thead>
<tbody>
<tr>
<td>Group members worked well together.</td>
<td>1</td>
<td>2</td>
<td>3</td>
<td>4</td>
<td>5</td>
</tr>
<tr>
<td>Group members all contributed to assignment</td>
<td>1</td>
<td>2</td>
<td>3</td>
<td>4</td>
<td>5</td>
</tr>
<tr>
<td>Group members were able to communicate clearly</td>
<td>1</td>
<td>2</td>
<td>3</td>
<td>4</td>
<td>5</td>
</tr>
<tr>
<td>Group members all contributed to the execution of the lab protocol</td>
<td>1</td>
<td>2</td>
<td>3</td>
<td>4</td>
<td>5</td>
</tr>
<tr>
<td>Execution of laboratory protocol benefitted by work as a team (<em>i.e.</em>, tasks were performed at a higher quality or with greater ease than if working individually)</td>
<td>1</td>
<td>2</td>
<td>3</td>
<td>4</td>
<td>5</td>
</tr>
<tr>
<td>Group members all contributed to writing lab report</td>
<td>1</td>
<td>2</td>
<td>3</td>
<td>4</td>
<td>5</td>
</tr>
<tr>
<td>I would have preferred to complete the lab protocol by myself.</td>
<td>1</td>
<td>2</td>
<td>3</td>
<td>4</td>
<td>5</td>
</tr>
<tr>
<td>I would have preferred to write the report by myself.</td>
<td>1</td>
<td>2</td>
<td>3</td>
<td>4</td>
<td>5</td>
</tr>
<tr>
<td>Group members did not listen to each others’ contributions.</td>
<td>1</td>
<td>2</td>
<td>3</td>
<td>4</td>
<td>5</td>
</tr>
<tr>
<td>My group members helped me better understand the experiment and result.</td>
<td>1</td>
<td>2</td>
<td>3</td>
<td>4</td>
<td>5</td>
</tr>
<tr>
<td>The burden of labor/tasks was divided unevenly among group members.</td>
<td>1</td>
<td>2</td>
<td>3</td>
<td>4</td>
<td>5</td>
</tr>
<tr>
<td>I completed more than my share of the assignment.</td>
<td>1</td>
<td>2</td>
<td>3</td>
<td>4</td>
<td>5</td>
</tr>
<tr>
<td>We divided tasks among group members.</td>
<td>1</td>
<td>2</td>
<td>3</td>
<td>4</td>
<td>5</td>
</tr>
<tr>
<td>Most tasks were completed as a unit.</td>
<td>1</td>
<td>2</td>
<td>3</td>
<td>4</td>
<td>5</td>
</tr>
<tr>
<td>Final product (lab report) is high quality</td>
<td>1</td>
<td>2</td>
<td>3</td>
<td>4</td>
<td>5</td>
</tr>
<tr>
<td>Final product was improved by contributions of all group members</td>
<td>1</td>
<td>2</td>
<td>3</td>
<td>4</td>
<td>5</td>
</tr>
<tr>
<td>I am confident in my group’s performance on this assignment.</td>
<td>1</td>
<td>2</td>
<td>3</td>
<td>4</td>
<td>5</td>
</tr>
<tr>
<td>I am confident in my group’s sustained performance on upcoming protocols.</td>
<td>1</td>
<td>2</td>
<td>3</td>
<td>4</td>
<td>5</td>
</tr>
<tr>
<td>I am hesitant about completing upcoming laboratories with this group.</td>
<td>1</td>
<td>2</td>
<td>3</td>
<td>4</td>
<td>5</td>
</tr>
</tbody>
</table>

In a few words please describe:

What were your specific tasks/contributions to the group? Please list and elaborate as appropriate.

What was the primary group contribution that benefitted you?
Appendix G  Compilation of Documents Submitted to Institutional Review Board and Study Materials for CBE 4764, Process Design and Development

Script for Recruitment of Students to Participate in Study

Hello CBE 4764 Students,

My name is Elif Miskioglu; I am a graduate student in the CBE department and part of my research involves studying the correlations between learning styles, self-efficacy (confidence in ability) and collective efficacy (confidence in team ability), and student/team performance in the interest of developing better teaching techniques and materials in the chemical engineering department.

We are interested in collecting data from your class (individual and team learning styles, performance, perceptions, and team dynamics, grades) throughout this term. Participation is entirely voluntary and will neither affect your grade nor course content. The class will continue to be conducted normally as if this study is not occurring, with the exception that you will receive short surveys related to your design projects to complete. We hope that these surveys, along with information about team performance, can help us better understand team dynamics among chemical engineering students and provide a basis for improving our curriculum with respect to how we approach teaching chemical engineering design and teamwork skills.

Further details are outlined in the consent document (attached).

We ask for your cooperation in completing the following two tasks by <insert date>:

1) Please review the informed consent document I will be handing out. If you decide to give consent to participate, please fill out the form after reviewing it and return to me (Elif Miskioglu, mailbox in KL 125A).

2) Additionally, please take the "learning styles questionnaire" found at http://www4.ncsu.edu/unity/lockers/users/f/felder/public/ILSpage.html and submit your results as a PDF or screen capture to the "ILS Results" dropbox also on Carmen. Directions for this are also outlined on Carmen under <insert location>. This questionnaire should only take 10 to 15 minutes to complete.

Thank you for your time and consideration! Please feel free [to respond to this email (contact miskioglu.1@osu.edu)] with any questions that you might have.

Elif Eda Miskioglu
Informed Consent Form

This is a consent form for research participation. Participation is voluntary. We are interested in investigating the effect of learning styles on individual and team performance and team dynamics. We will be utilizing your learning style preferences, grades for 4764, individual evaluation surveys, group evaluation surveys, and peer evaluations in search of correlations between performance, perceptions, and learning styles. Data will be de-identified (names removed) and analyzed in aggregate, and no identifiable data will be released or retained. There are no foreseeable risks or discomforts associated with participation.

Raw survey information collected will not be shared with the instructor and in no way be used in grade determination, nor will participation in this study affect course material/content. Results of the study may be shared in de-identified, aggregate form, after the course is over. Efforts will be made to keep your study-related information confidential. However, there may be circumstances where this information must be released. For example, personal information regarding your participation in this study may be disclosed if required by state law. Also, your records may be reviewed by the following groups (as applicable to the research):

- Office for Human Research Protections or other federal, state, or international regulatory agencies;
- The Ohio State University Institutional Review Board or Office of Responsible Research Practices;
- The sponsor, if any, or agency (including the Food and Drug Administration for FDA-regulated research) supporting the study.

Data collection will occur through Carmen. We will work to make sure that no one sees your survey responses without approval. But, because we are using the Internet, there is a chance that someone could access your online responses without permission. In some cases, this information could be used to identify you.

Participation in the study involves minimal time commitment. We expect that completion of the surveys (the only item not a component of your regular coursework) should take no more than a total of 145 minutes, spread throughout the term. That is, approximately, 10-15 minutes per week. There are no incentives for study participation.

Results will be used to improve future teaching methods and materials. Survey and other non-grade data are being collected purely for informational reasons, and will not be used in any type of student evaluation.

By consenting to participate, you agree to allow access to and use of your CBE 4764 grades, survey results, peer evaluations, and learning styles indicator results.

Again, participation is voluntary, refusal to participate will involve no penalty or loss of benefits and you may discontinue participation at any time without penalty or loss of
benefits. If you decline to participate in the study, we will not incorporate your information in the study. Your course grade and content will not be affected.

You should have two copies of this document. Please fill out the form below (next page) for one of them and return to the mailbox of Elif Miskioglu in KL 125A. By doing so, you are confirming that you have read this consent form. The second copy is for you to keep.

If you have questions or feel you were harmed as a result of study participation you may contact Elif Miskioglu at miskioglu.1@osu.edu.

For questions about your rights as a participant in this study or to discuss other study-related concerns or complaints with someone who is not part of the research team, you may contact Ms. Sandra Meadows in the Office of Responsible Research Practices at 1-800-678-6251.

Thank you for your time.

_____ I consent to participate

Signature_____________________________ Date________________
Printed Name_________________________ 

Investigator/Research Staff

I have explained the research to the participant or his/her representative before requesting the signature(s) above. There are no blanks in this document. A copy of this form has been given to the participant or his/her representative.

_________________________ _________________
Printed name of person obtaining consent Signature of person obtaining consent

AM/PM

Date and time
Directions for Taking Index of Learning Styles (ILS) Questionnaire

Go to:

http://www.engr.ncsu.edu/learningstyles/ilsweb.html and take the survey.

After hitting submit, make sure to create a record of your results to submit by either:

5) Dropbox on Carmen ("ILS Results")--“Print results” to a PDF to create a PDF file. If printing to PDF is unavailable, take a screen capture (ctrl + PrtScrn) and paste into a word document. Save with your first initial and last name (e.g. Joe Brown would be jbrown).

Do not copy/paste. This distorts the table of results generated.

6) Hard copy—print a hard copy and submit to the mailbox of Elif Miskioglu in KL 125A.
### Example Survey Used to Gather Student Self-Efficacy Data

Rate your degree of confidence to perform the following tasks:\(^1\)

<table>
<thead>
<tr>
<th></th>
<th>1</th>
<th>2</th>
<th>3</th>
<th>4</th>
<th>5</th>
</tr>
</thead>
<tbody>
<tr>
<td>cannot do at all</td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>might be able to do</td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>moderately can do</td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>considerably certain</td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>can do</td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>highly certain can do</td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
</tr>
</tbody>
</table>

- Conduct engineering design
- Identify a design need
- Research a design need
- Develop design solutions
- Select the best possible design
- Develop a simulation for a design
- Evaluate and test a design
- Communicate a design
- Redesign

Rate how motivated you would be to perform the following tasks:

<table>
<thead>
<tr>
<th></th>
<th>1</th>
<th>2</th>
<th>3</th>
<th>4</th>
<th>5</th>
</tr>
</thead>
<tbody>
<tr>
<td>not motivated</td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>slightly motivated</td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>moderately motivated</td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>considerably motivated</td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>highly motivated</td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
</tr>
</tbody>
</table>

- Conduct engineering design
- Identify a design need
- Research a design need
- Develop design solutions
- Select the best possible design
- Develop a simulation for a design
- Evaluate and test a design
- Communicate a design
- Redesign

---

\(^1\) Adapted from Carberry, et al. 2010. Journal of Engineering Education.
Rate how successful you would be in performing the following tasks:

<table>
<thead>
<tr>
<th></th>
<th>1</th>
<th>2</th>
<th>3</th>
<th>4</th>
<th>5</th>
</tr>
</thead>
<tbody>
<tr>
<td>cannot expect success at all</td>
<td>cannot expect much success</td>
<td>moderately expect success</td>
<td>considerably certain of success</td>
<td>highly certain of success</td>
<td></td>
</tr>
<tr>
<td>Conduct engineering design</td>
<td>1</td>
<td>2</td>
<td>3</td>
<td>4</td>
<td>5</td>
</tr>
<tr>
<td>Identify a design need</td>
<td>1</td>
<td>2</td>
<td>3</td>
<td>4</td>
<td>5</td>
</tr>
<tr>
<td>Research a design need</td>
<td>1</td>
<td>2</td>
<td>3</td>
<td>4</td>
<td>5</td>
</tr>
<tr>
<td>Develop design solutions</td>
<td>1</td>
<td>2</td>
<td>3</td>
<td>4</td>
<td>5</td>
</tr>
<tr>
<td>Select the best possible design</td>
<td>1</td>
<td>2</td>
<td>3</td>
<td>4</td>
<td>5</td>
</tr>
<tr>
<td>Develop a simulation for a design</td>
<td>1</td>
<td>2</td>
<td>3</td>
<td>4</td>
<td>5</td>
</tr>
<tr>
<td>Evaluate and test a design</td>
<td>1</td>
<td>2</td>
<td>3</td>
<td>4</td>
<td>5</td>
</tr>
<tr>
<td>Communicate a design</td>
<td>1</td>
<td>2</td>
<td>3</td>
<td>4</td>
<td>5</td>
</tr>
<tr>
<td>Redesign</td>
<td>1</td>
<td>2</td>
<td>3</td>
<td>4</td>
<td>5</td>
</tr>
</tbody>
</table>

Rate your degree of anxiety in performing the following tasks:

<table>
<thead>
<tr>
<th></th>
<th>1</th>
<th>2</th>
<th>3</th>
<th>4</th>
<th>5</th>
</tr>
</thead>
<tbody>
<tr>
<td>not anxious at all</td>
<td>not very anxious</td>
<td>moderately anxious</td>
<td>considerably anxious</td>
<td>highly anxious</td>
<td></td>
</tr>
<tr>
<td>Conduct engineering design</td>
<td>1</td>
<td>2</td>
<td>3</td>
<td>4</td>
<td>5</td>
</tr>
<tr>
<td>Identify a design need</td>
<td>1</td>
<td>2</td>
<td>3</td>
<td>4</td>
<td>5</td>
</tr>
<tr>
<td>Research a design need</td>
<td>1</td>
<td>2</td>
<td>3</td>
<td>4</td>
<td>5</td>
</tr>
<tr>
<td>Develop design solutions</td>
<td>1</td>
<td>2</td>
<td>3</td>
<td>4</td>
<td>5</td>
</tr>
<tr>
<td>Select the best possible design</td>
<td>1</td>
<td>2</td>
<td>3</td>
<td>4</td>
<td>5</td>
</tr>
<tr>
<td>Develop a simulation for a design</td>
<td>1</td>
<td>2</td>
<td>3</td>
<td>4</td>
<td>5</td>
</tr>
<tr>
<td>Evaluate and test a design</td>
<td>1</td>
<td>2</td>
<td>3</td>
<td>4</td>
<td>5</td>
</tr>
<tr>
<td>Communicate a design</td>
<td>1</td>
<td>2</td>
<td>3</td>
<td>4</td>
<td>5</td>
</tr>
<tr>
<td>Redesign</td>
<td>1</td>
<td>2</td>
<td>3</td>
<td>4</td>
<td>5</td>
</tr>
</tbody>
</table>
Rate your degree of confidence to perform the following tasks:

<table>
<thead>
<tr>
<th></th>
<th>1</th>
<th>2</th>
<th>3</th>
<th>4</th>
<th>5</th>
</tr>
</thead>
<tbody>
<tr>
<td>cannot do at all</td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>might be able to do</td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>moderately can do</td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>considerably certain can do</td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>highly certain can do</td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
</tr>
</tbody>
</table>

- Conduct [specific component, e.g., heat exchanger] design
- Develop [specific component, e.g., heat exchanger] design solutions
- Select the best possible [specific component, e.g., heat exchanger] design
- Develop a [specific component, e.g., heat exchanger] design simulation
- Evaluate and test a [specific component, e.g., heat exchanger] design
- Communicate a [specific component, e.g., heat exchanger] design
- Redesign a [specific component, e.g., heat exchanger]

Rate how motivated you would be to perform the following tasks:

<table>
<thead>
<tr>
<th></th>
<th>1</th>
<th>2</th>
<th>3</th>
<th>4</th>
<th>5</th>
</tr>
</thead>
<tbody>
<tr>
<td>not motivated</td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>slightly motivated</td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>moderately motivated</td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>considerably motivated</td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>highly motivated</td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
</tr>
</tbody>
</table>

- Conduct [specific component, e.g., heat exchanger] design
- Develop [specific component, e.g., heat exchanger] design solutions
- Select the best possible [specific component, e.g., heat exchanger] design
- Develop a [specific component, e.g., heat exchanger] design simulation
- Evaluate and test a [specific component, e.g., heat exchanger] design
- Communicate a [specific component, e.g., heat exchanger] design
- Redesign a [specific component, e.g., heat exchanger]
Rate how successful you would be in performing the following tasks:

<table>
<thead>
<tr>
<th></th>
<th>1</th>
<th>2</th>
<th>3</th>
<th>4</th>
<th>5</th>
</tr>
</thead>
<tbody>
<tr>
<td>conduct [component]</td>
<td>cannot expect success at all</td>
<td>cannot expect much success</td>
<td>moderately expect success</td>
<td>considerably certain of success</td>
<td>highly certain of success</td>
</tr>
<tr>
<td>develop [component]</td>
<td>1</td>
<td>2</td>
<td>3</td>
<td>4</td>
<td>5</td>
</tr>
<tr>
<td>select the best possible [component]</td>
<td>1</td>
<td>2</td>
<td>3</td>
<td>4</td>
<td>5</td>
</tr>
<tr>
<td>develop a [component]</td>
<td>simulation</td>
<td>1</td>
<td>2</td>
<td>3</td>
<td>4</td>
</tr>
<tr>
<td>evaluate and test a [component]</td>
<td>1</td>
<td>2</td>
<td>3</td>
<td>4</td>
<td>5</td>
</tr>
<tr>
<td>communicate a [component]</td>
<td>1</td>
<td>2</td>
<td>3</td>
<td>4</td>
<td>5</td>
</tr>
<tr>
<td>redesign [component]</td>
<td>1</td>
<td>2</td>
<td>3</td>
<td>4</td>
<td>5</td>
</tr>
</tbody>
</table>

Rate your degree of anxiety in performing the following tasks:

<table>
<thead>
<tr>
<th></th>
<th>1</th>
<th>2</th>
<th>3</th>
<th>4</th>
<th>5</th>
</tr>
</thead>
<tbody>
<tr>
<td>conduct [component]</td>
<td>not anxious at all</td>
<td>not very anxious</td>
<td>moderately anxious</td>
<td>considerably anxious</td>
<td>highly anxious</td>
</tr>
<tr>
<td>develop [component]</td>
<td>1</td>
<td>2</td>
<td>3</td>
<td>4</td>
<td>5</td>
</tr>
<tr>
<td>select the best possible [component]</td>
<td>1</td>
<td>2</td>
<td>3</td>
<td>4</td>
<td>5</td>
</tr>
<tr>
<td>develop a [component]</td>
<td>simulation</td>
<td>1</td>
<td>2</td>
<td>3</td>
<td>4</td>
</tr>
<tr>
<td>evaluate and test a [component]</td>
<td>1</td>
<td>2</td>
<td>3</td>
<td>4</td>
<td>5</td>
</tr>
<tr>
<td>communicate a [component]</td>
<td>1</td>
<td>2</td>
<td>3</td>
<td>4</td>
<td>5</td>
</tr>
<tr>
<td>redesign [component]</td>
<td>1</td>
<td>2</td>
<td>3</td>
<td>4</td>
<td>5</td>
</tr>
</tbody>
</table>

243
Please take a moment to evaluate your agreement with the following statements

1= Strongly Disagree 2= Disagree 3=Neutral 4=Agree 5= Strongly Agree

<table>
<thead>
<tr>
<th>Statement</th>
<th>1</th>
<th>2</th>
<th>3</th>
<th>4</th>
<th>5</th>
</tr>
</thead>
<tbody>
<tr>
<td>Design skills are important for chemical engineers</td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>I will use engineering design principles in my career</td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>I intend to pursue a career in chemical engineering</td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>I intend to pursue a career that deviates from chemical engineering</td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>It is important to know the theory (governing equations and principles)</td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>and apply it to the design</td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>I have been able to recall the theory I learned in previous courses and</td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>apply it to the design</td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>I have had difficulty recalling the appropriate theory from previous</td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>courses that is needed to proceed with the design</td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
</tr>
</tbody>
</table>
Example Surveys Used to Gather Team Dynamics Data

End of Term

Please take a moment to evaluate your group performance and dynamics.

1= Strongly Disagree 2= Disagree 3=Neutral 4=Agree 5= Strongly Agree

<table>
<thead>
<tr>
<th>Statement</th>
<th>1</th>
<th>2</th>
<th>3</th>
<th>4</th>
<th>5</th>
</tr>
</thead>
<tbody>
<tr>
<td>Group members worked well together.</td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>Group members all contributed to project.</td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>Group members were able to communicate clearly</td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>Group members all contributed to the final design</td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>Design benefitted from work as a team (i.e., tasks were performed at a higher quality or with greater ease than if working individually)</td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>Group members all contributed to writing report</td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>I would have preferred to complete the design project by myself.</td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>I would prefer to be completing the design project by myself.</td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>Group members did not listen to each others’ contributions.</td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>My group members helped me better understand the problem and solution.</td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>The burden of labor/tasks was divided unevenly among group members.</td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>I completed more than my share of the assignment.</td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>We divided tasks among group members.</td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>Most tasks were completed as a unit.</td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>Final design is high quality</td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>Final design was improved by contributions of all group members.</td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>I am confident in my group’s performance on this assignment.</td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>I am confident in my group’s sustained performance on upcoming protocols.</td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>I would be hesitant about working with this group in the future.</td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
</tr>
</tbody>
</table>

In a few words please describe:

What were your specific tasks/contributions to the group? Please list and elaborate as appropriate.

What was the primary group contribution that benefitted you?
In a few words please describe:

What have been your specific tasks/contributions to the group? Please list and elaborate as appropriate.

What is the primary group contribution that is benefitting you?
Appendix H  Compilation of Survey Responses and Team Scores from Combinatorial CBE 4764, Process Design and Development, Study

Figure H.1. Responses for Question 10 found on the general perceptions survey administered throughout the Spring 2015 term.
Figure H.2. Responses for Question 11 found on the general perceptions survey administered early in the Spring 2015 term.

Figure H.3. Responses for Question 12 found on the general perceptions survey administered early in the Spring 2015 term.

Figure H.4. Responses for Question 13 found on the general perceptions survey administered early and late in the Spring 2015 term.
Figure H.5. (left panel) Team scores for Final Report in ascending order. (right panel) Teams scores in order of descending standard deviation. Teams with reported dynamic problems are highlighted in gray.

<table>
<thead>
<tr>
<th>Team</th>
<th>Final Report</th>
<th>Standard Deviation</th>
</tr>
</thead>
<tbody>
<tr>
<td>G</td>
<td>80.0</td>
<td>0.0</td>
</tr>
<tr>
<td>S</td>
<td>84.4</td>
<td>11.8</td>
</tr>
<tr>
<td>Class Avg</td>
<td>85.9</td>
<td>21.5</td>
</tr>
<tr>
<td>T</td>
<td>85.9</td>
<td>10.8</td>
</tr>
<tr>
<td>U</td>
<td>89.1</td>
<td>8.6</td>
</tr>
<tr>
<td>D</td>
<td>91.4</td>
<td>2.8</td>
</tr>
<tr>
<td>E</td>
<td>93.3</td>
<td>1.2</td>
</tr>
<tr>
<td>H</td>
<td>93.3</td>
<td>9.3</td>
</tr>
<tr>
<td>J</td>
<td>95.0</td>
<td>0.0</td>
</tr>
<tr>
<td>V</td>
<td>96.9</td>
<td>2.3</td>
</tr>
<tr>
<td>Q</td>
<td>98.3</td>
<td>1.0</td>
</tr>
</tbody>
</table>

Figure H.6. (left panel) Team scores for Final Presentation in ascending order. (right panel) Teams scores in order of descending standard deviation. Teams with reported dynamic problems are highlighted in gray.

<table>
<thead>
<tr>
<th>Team</th>
<th>Final Presentation</th>
<th>Standard Deviation</th>
</tr>
</thead>
<tbody>
<tr>
<td>D</td>
<td>85.0</td>
<td>0.0</td>
</tr>
<tr>
<td>E</td>
<td>85.0</td>
<td>0.0</td>
</tr>
<tr>
<td>G</td>
<td>85.0</td>
<td>0.0</td>
</tr>
<tr>
<td>Class Avg</td>
<td>86.5</td>
<td>20.9</td>
</tr>
<tr>
<td>T</td>
<td>85.0</td>
<td>0.0</td>
</tr>
<tr>
<td>H</td>
<td>95.0</td>
<td>0.0</td>
</tr>
<tr>
<td>J</td>
<td>95.0</td>
<td>0.0</td>
</tr>
<tr>
<td>S</td>
<td>95.0</td>
<td>0.0</td>
</tr>
<tr>
<td>V</td>
<td>95.0</td>
<td>0.0</td>
</tr>
<tr>
<td>Q</td>
<td>100.0</td>
<td>0.0</td>
</tr>
<tr>
<td>U</td>
<td>100.0</td>
<td>0.0</td>
</tr>
</tbody>
</table>
Figure H.7. (left panel) Team scores for Project 3 (team-based) in ascending order. (right panel) Teams scores in order of descending standard deviation. Teams with reported dynamic problems are highlighted in gray.

<table>
<thead>
<tr>
<th>Team</th>
<th>Project 3</th>
<th>Standard Deviation</th>
</tr>
</thead>
<tbody>
<tr>
<td>T</td>
<td>80.0</td>
<td>3.6</td>
</tr>
<tr>
<td>G</td>
<td>81.6</td>
<td>0.9</td>
</tr>
<tr>
<td>Class Avg</td>
<td>82.9</td>
<td>20.1</td>
</tr>
<tr>
<td>D</td>
<td>83.4</td>
<td>1.8</td>
</tr>
<tr>
<td>S</td>
<td>87.5</td>
<td>6.2</td>
</tr>
<tr>
<td>E</td>
<td>87.6</td>
<td>1.4</td>
</tr>
<tr>
<td>H</td>
<td>90.0</td>
<td>6.1</td>
</tr>
<tr>
<td>V</td>
<td>91.4</td>
<td>1.7</td>
</tr>
<tr>
<td>U</td>
<td>92.0</td>
<td>3.4</td>
</tr>
<tr>
<td>J</td>
<td>92.9</td>
<td>1.0</td>
</tr>
<tr>
<td>Q</td>
<td>96.2</td>
<td>0.7</td>
</tr>
</tbody>
</table>

<table>
<thead>
<tr>
<th>Team</th>
<th>Project 3</th>
<th>Standard Deviation</th>
</tr>
</thead>
<tbody>
<tr>
<td>Class Avg</td>
<td>82.9</td>
<td>20.1</td>
</tr>
<tr>
<td>S</td>
<td>87.5</td>
<td>6.2</td>
</tr>
<tr>
<td>H</td>
<td>90.0</td>
<td>6.1</td>
</tr>
<tr>
<td>T</td>
<td>80.0</td>
<td>3.6</td>
</tr>
<tr>
<td>U</td>
<td>92.0</td>
<td>3.4</td>
</tr>
<tr>
<td>D</td>
<td>83.4</td>
<td>1.8</td>
</tr>
<tr>
<td>V</td>
<td>91.4</td>
<td>1.7</td>
</tr>
<tr>
<td>E</td>
<td>87.6</td>
<td>1.4</td>
</tr>
<tr>
<td>J</td>
<td>92.9</td>
<td>1.0</td>
</tr>
<tr>
<td>G</td>
<td>81.6</td>
<td>0.9</td>
</tr>
<tr>
<td>Q</td>
<td>96.2</td>
<td>0.7</td>
</tr>
</tbody>
</table>

Figure H.8. (left panel) Team scores for Final Grade in ascending order. (right panel) Teams scores in order of descending standard deviation. Teams with reported dynamic problems are highlighted in gray.

<table>
<thead>
<tr>
<th>Team</th>
<th>Final Grade</th>
<th>Standard Deviation</th>
</tr>
</thead>
<tbody>
<tr>
<td>T</td>
<td>82.8</td>
<td>10.4</td>
</tr>
<tr>
<td>Class Avg</td>
<td>86.5</td>
<td>14.8</td>
</tr>
<tr>
<td>G</td>
<td>87.1</td>
<td>3.2</td>
</tr>
<tr>
<td>H</td>
<td>87.3</td>
<td>11.0</td>
</tr>
<tr>
<td>S</td>
<td>87.5</td>
<td>4.5</td>
</tr>
<tr>
<td>D</td>
<td>89.8</td>
<td>1.2</td>
</tr>
<tr>
<td>U</td>
<td>90.4</td>
<td>4.8</td>
</tr>
<tr>
<td>E</td>
<td>90.4</td>
<td>2.6</td>
</tr>
<tr>
<td>J</td>
<td>92.6</td>
<td>0.9</td>
</tr>
<tr>
<td>V</td>
<td>93.4</td>
<td>1.4</td>
</tr>
<tr>
<td>Q</td>
<td>94.5</td>
<td>1.4</td>
</tr>
</tbody>
</table>

<table>
<thead>
<tr>
<th>Team</th>
<th>Final Grade</th>
<th>Standard Deviation</th>
</tr>
</thead>
<tbody>
<tr>
<td>Class Avg</td>
<td>86.5</td>
<td>14.8</td>
</tr>
<tr>
<td>H</td>
<td>87.3</td>
<td>11.0</td>
</tr>
<tr>
<td>T</td>
<td>82.8</td>
<td>10.4</td>
</tr>
<tr>
<td>U</td>
<td>90.4</td>
<td>4.8</td>
</tr>
<tr>
<td>S</td>
<td>87.5</td>
<td>4.5</td>
</tr>
<tr>
<td>G</td>
<td>87.1</td>
<td>3.2</td>
</tr>
<tr>
<td>E</td>
<td>90.4</td>
<td>2.6</td>
</tr>
<tr>
<td>Q</td>
<td>94.5</td>
<td>1.4</td>
</tr>
<tr>
<td>V</td>
<td>93.4</td>
<td>1.4</td>
</tr>
<tr>
<td>D</td>
<td>89.8</td>
<td>1.2</td>
</tr>
<tr>
<td>J</td>
<td>92.6</td>
<td>0.9</td>
</tr>
</tbody>
</table>
Figure H.9. Map of change in responses between Surveys 1 and 2 (bottom), and Surveys 2 and 3 (top). Responses to left of bolded vertical line are from students on teams reporting dynamics problems. Gray cells represent items where a decrease in self-efficacy, a negative change in perception, or an increase in anxiety was seen, whereas a white cell indicates either no change or a positive change.
Appendix I  Course Syllabus and Schedule for CBE 4194, Technical and Professional Communication for (Chemical) Engineers

Document #1: Course Syllabus – Spring 2015

Credits: 3.0  
Meeting times: Tuesday/Friday, 11:10 AM to 12:30 PM in CBEC 169

Instructor: Elif Eda Miskioglu  
E-mail: miskioglu.1@osu.edu  
Office hours: By appointment (CBEC 460)

Course Description: Developing good communication skills, both written and oral, is an important component of every student’s career development. We will cover several aspects of communication, including, but not limited to, oral and poster presentations as well as laboratory report/proposal writing, all of which are highly relevant to chemical engineers pursuing academic, industrial, or other career paths.

Course Goals: Upon completion of this course, students will...

- understand the importance of effective communication in all aspects of their work and life.
- view themselves as qualified to provide constructive feedback in communication, and understand the importance of the constructive component.
- understand the importance of identifying the significance of what they are communicating, both big and small picture and how they fit together.
- be comfortable in identifying the audience in their communication and appropriately address them (in content and choice of media, where choice is given).
- be confident in their ability to communicate in a written, oral, or mixed media fashion.
- be aware of their strengths and areas of improvement in communication, and understand that this is a life-long learning process of practice and development. Ideally, they will pursue opportunities to practice varying types of communication (especially those that are not prominent in their position) to keep their skills sharp.
Course Policies:
Attendance and Participation: This is an active and engaging class, and attendance is expected. Attendance and participation are an integral part of your grade (see section on grading), with points allotted per class period for each. You should notify the instructor of upcoming absences in advance or as soon as possible in the case of unforeseen circumstances.
Completion: Students must complete and turn in all assigned work to receive a passing grade.
Late Work: Any work handed in late will lose 10% of the possible points per day. Late work will receive a zero after three business days from the original due date.
Etiquette: A lot of this course will include active involvement and presentation from you. Thus, it is important to be courteous and attentive while your peers are presenting. Please remember to silence or turn off (vibrate is not silent!) your cell phones in class, refrain from eating (especially noisy items), and refrain from holding side conversations with your peers during class.

Grading:
Homework: 20%
Presentations: 30%
Review Paper: 15%
Pre-Proposal: 15%
Attendance: 10%
Participation: 10%

Grading Scale:
> 93 A
90-93 A-
87-90 B+
83-87 B
80-83 B-
77-80 C+
73-77 C
70-73 C-
67-70 D+
60-67 D
< 60 E

Academic Integrity: (from oaa.osu.edu/coam)
Academic integrity is essential to maintaining an environment that fosters excellence in teaching, research, and other educational and scholarly activities. Thus, The Ohio State University and the Committee on Academic Misconduct (COAM) expect that all students have read and understand the University’s Code of Student Conduct, and that all students will complete all academic and scholarly assignments with fairness
and honesty. Students must recognize that failure to follow the rules and guidelines established in the University’s Code of Student Conduct and this syllabus may constitute “Academic Misconduct.”

The Ohio State University’s Code of Student Conduct (Section 3335-23-04) defines academic misconduct as: “Any activity that tends to compromise the academic integrity of the University, or subvert the educational process.” Examples of academic misconduct include (but are not limited to) plagiarism, collusion (unauthorized collaboration), copying the work of another student, and possession of unauthorized materials during an examination. Ignorance of the University’s Code of Student Conduct is never considered an “excuse” for academic misconduct, so I recommend that you review the Code of Student Conduct and, specifically, the sections dealing with academic misconduct.

If I suspect that a student has committed academic misconduct in this course, I am obligated by University Rules to report my suspicions to the Committee on Academic Misconduct. If COAM determines that you have violated the University’s Code of Student Conduct (i.e., committed academic misconduct), the sanctions for the misconduct could include a failing grade in this course and suspension or dismissal from the University.

If you have any questions about the above policy or what constitutes academic misconduct in this course, please contact me.

Other sources of information on academic misconduct (integrity) to which you can refer include:
The Committee on Academic Misconduct web pages (oaa.osu.edu/coam/home.html)
Ten Suggestions for Preserving Academic Integrity
(oaa.osu.edu/coam/ten-suggestions.html)
Eight Cardinal Rules of Academic Integrity (www.northwestern.edu/uacc/8cards.html)

Disabilities:
Any student impacted by a documented disability who feels s/he may need an accommodation should first contact the Office for Disability Services at 614-292-3307 in room 150 of Pomerene Hall to coordinate reasonable accommodations. Please also contact me privately to discuss your specific needs, and I will work with the Office of Disability Services to accommodate as appropriate.
<table>
<thead>
<tr>
<th>Week</th>
<th>Date</th>
<th>Topic</th>
<th>Assignment</th>
</tr>
</thead>
<tbody>
<tr>
<td>1</td>
<td>January 13</td>
<td><em>Let’s get this party started</em>: Introduction/Expectations</td>
<td></td>
</tr>
<tr>
<td></td>
<td>January 16</td>
<td><em>You talking to me?</em> Audience Analysis</td>
<td></td>
</tr>
<tr>
<td>2</td>
<td>January 20</td>
<td><em>Tell Me About Yourself, Part 1</em>: The Paperwork &amp; Prep</td>
<td></td>
</tr>
<tr>
<td></td>
<td>January 23</td>
<td><em>Yes, I am talking to you</em>: Presentation 1</td>
<td>Reflection 1</td>
</tr>
<tr>
<td>3</td>
<td>January 27</td>
<td><em>What would you do with an extra 80 minutes?</em></td>
<td></td>
</tr>
<tr>
<td></td>
<td>January 30</td>
<td><em>The Art of Storytelling</em>: So What?</td>
<td>Resume/Ref. 2</td>
</tr>
<tr>
<td>4</td>
<td>February 3</td>
<td><em>Tell Me About Yourself, Part 2</em>: The Interview</td>
<td></td>
</tr>
<tr>
<td></td>
<td>February 6</td>
<td><em>An offer you can’t refuse</em>: Building a Convincing Case</td>
<td>Reflection 3</td>
</tr>
<tr>
<td>5</td>
<td>February 10</td>
<td><em>Lessons from the pizza guy</em>: Strategies for Delivery</td>
<td></td>
</tr>
<tr>
<td></td>
<td>February 13</td>
<td><em>Look Ma! No Hands</em>: Nonverbal Communication</td>
<td></td>
</tr>
<tr>
<td>6</td>
<td>February 17</td>
<td><em>With a little help from Dr. Scholl’s</em>: Poster Presentations</td>
<td>Reflection 4 &amp; Topic</td>
</tr>
<tr>
<td></td>
<td>February 20</td>
<td><em>Read, Reused, Referenced</em>: Citation Software/Plagiarism</td>
<td></td>
</tr>
<tr>
<td>7</td>
<td>February 24</td>
<td><em>Act fast! Limited time offer</em>: Introductions &amp; Pitches</td>
<td></td>
</tr>
<tr>
<td></td>
<td>February 27</td>
<td><em>A few of my favorite things</em>: Presentation 2</td>
<td></td>
</tr>
<tr>
<td>8</td>
<td>March 3</td>
<td><em>Make Me Pretty</em>: Formatting</td>
<td>Annotated Bib.</td>
</tr>
<tr>
<td></td>
<td>March 6</td>
<td><em>Practice Makes</em>: Writing Workshop</td>
<td></td>
</tr>
<tr>
<td>9</td>
<td>March 10</td>
<td><em>I’m…writing away</em>: Feedback loops</td>
<td>Outline</td>
</tr>
<tr>
<td></td>
<td>March 13</td>
<td><em>This is a talk, not a twinkie</em>: Eliminating fillers</td>
<td></td>
</tr>
<tr>
<td>N/A</td>
<td>March 16--20</td>
<td>Spring break</td>
<td></td>
</tr>
<tr>
<td></td>
<td>Date</td>
<td>Topic</td>
<td>Assignment</td>
</tr>
<tr>
<td>---</td>
<td>------------</td>
<td>------------------------------------------------------------------------</td>
<td>----------------------</td>
</tr>
<tr>
<td>10</td>
<td>March 24</td>
<td>Look into my eyes: Building rapport</td>
<td></td>
</tr>
<tr>
<td></td>
<td>March 27</td>
<td>Semi-colons are the spice of life: Editing</td>
<td>Paper Draft</td>
</tr>
<tr>
<td>11</td>
<td>March 31</td>
<td>Let us review Presentation 3</td>
<td>Review Paper</td>
</tr>
<tr>
<td></td>
<td>April 3</td>
<td>But I've been through it 100 times! Strategies for Revision</td>
<td></td>
</tr>
<tr>
<td>12</td>
<td>April 7</td>
<td>Good things come in small packages: The Abstract</td>
<td>Response/Revisions</td>
</tr>
<tr>
<td></td>
<td>April 10</td>
<td>Day c u l8tr: Communication for Daily Use</td>
<td></td>
</tr>
<tr>
<td>13</td>
<td>April 14</td>
<td>He said, she said: Real communication gone really wrong</td>
<td>Abstract</td>
</tr>
<tr>
<td></td>
<td>April 17</td>
<td>Ready? Set? Speak! Conversing with your audience</td>
<td>Reflection 5</td>
</tr>
<tr>
<td>14</td>
<td>April 21</td>
<td>Making long (Spring) term memories…Semester Review</td>
<td></td>
</tr>
<tr>
<td></td>
<td>April 24</td>
<td>Tell me how you feel: Course Debrief</td>
<td></td>
</tr>
<tr>
<td></td>
<td>April 28</td>
<td>Easy on the Red Bull and Insomnia Cookies!</td>
<td>Pre-proposal</td>
</tr>
<tr>
<td>15</td>
<td>May 4 (Mon.)</td>
<td>And they lived happily ever after… Final Presentations</td>
<td>10:00 –11:45 AM</td>
</tr>
</tbody>
</table>
Appendix J  Assignments Administered in CBE 4194, Technical and Professional Communication for (Chemical) Engineers

Assignment #1: Reflection 1 – Audience

Assigned: Friday, January 16, 2015
Due: in class on Friday, January 23, 2015

Read the article uploaded on Carmen labeled as Reflection1_Article. Write a brief (approximately 1/2 to 1 page single spaced, 1 inch margins, 11 point Arial font), informal response to the article, making sure to include the following points:

1) In a few sentences, summarize the topic of the article.
2) What “type” of article is it? (Research summary, persuasive/opinion, news, etc.)
3) Who is the audience for this article?
4) What content and language helped you understand the audience?
5) Are you part of the desired target audience?
   a) If so, did you find the article appropriately written?
   b) If not, how might the article be revised for you (define who you are as an audience)?

Use specific examples from the article to support your statements. Feel free to expand upon other aspects that are related to things we have discussed in class, but remember to stay brief (no longer than one page). This is meant to be a quick reflection done immediately after reading the article, rather than a formal paper. (Note: You are being evaluated on quality of ideas, not writing. However, do keep in mind that these are related. Your ideas cannot be evaluated if they cannot be identified and understood.)
Assignment #2: Reflection 2 – Resume

Assigned: Tuesday, January 20, 2015
Due: in class on Friday, January 30, 2015

Consider the resume you brought to class on January 20, and compare/contrast it to the one you will hand in on January 30. Write a brief (approximately 1/2 to 1 page single spaced, 1 inch margins, 11 point Arial font), informal analysis of your resume (before and after revisions), making sure to include the following points:

1) What is the purpose of your resume at this point in your career? How does that affect the content?
   2) Considering your original resume—what did your peer remember from it during the activity? Are these the things you want your peer to remember?
   3) What revisions have you made? Why?
   4) If you were to repeat the in-class activity, what do you think your peer would remember about your updated resume?

Use specific examples from your resumes to support your statements. Feel free to expand upon other aspects that are relevant and related to things we have discussed in class (identifying audience, significance), but remember to stay brief (no longer than one page). This is meant to be a quick reflection, rather than a formal paper. (Note: you are being evaluated on quality of ideas, not writing. However, do keep in mind that these are related. Your ideas cannot be evaluated if they cannot be identified and understood.)
Assignment #3: Reflection 3 – Significance

Assigned: Friday, January 30, 2015
Due: in class on Friday, February 6, 2015

Attend a talk on a STEM topic (departmental seminar, professional society event with a featured speaker, special lecture). Attending a class lecture does not count. Write a brief (approximately 1/2 to 1 page single spaced, 1 inch margins, 11 point Arial font), informal response to the talk, making sure to include the following points:

1) What is the significance of talk? What is the big picture? The small picture(s)?
2) Who is the speaker? What is his/her (specific) role in the topic?
3) Why did you choose this talk to attend?
4) How does the subject impact you?
5) Do you believe in the significance of the subject? Was the speaker convincing? Why or why not?
6) How could the presentation of the significance be improved?
7) Are you part of the speaker’s intended audience? Does this influence your evaluation of the significance or how the significance was presented?

Use specific examples from the talk to support your statements. Feel free to expand upon other aspects that are related to things we have discussed in class (identifying audience), but remember to stay brief (no longer than one page). This is meant to be a quick reflection done immediately after attending the talk, rather than a formal paper. (Note: you are being evaluated on quality of ideas, not writing. However, do keep in mind that these are related. Your ideas cannot be evaluated if they cannot be identified and understood.)

Potential Talks to Attend (this is not a comprehensive list; there are many other seminars on campus):

Physics Colloquium
Tuesday, February 3
4:00 PM in 1080 Physics Research Building
Speaker: Hamish Robertson (University of Washington), “Progress Toward Measuring the Mass of the Neutrino”

Molecular Life Sciences Seminar Schedule
Tuesday, February 3
4:00 PM in 170 Davis Heart & Lung Research Institute (473 W. 12th Ave)
Speaker: Tracy Johnson, PhD (UCLA) “RNA Processing, Chromatin Modification, and the Coordinated Control of Gene Expression”

Chemistry & Biochemistry Seminar
Tuesday, February 3
4:10 PM in 2015 McPherson
Speaker: Silas Cook, “The Search for Efficiency in Synthesis: From Natural Products to Catalysis”

CBE Departmental Seminar
Thursday, February 5
11:30 AM in CBEC 130
Speaker: Ishi Talmon, Wolfson Professor in Chemical Engineering, Russell Berrie Nanotechnology Institute, Technion—Israel Institute of Technology
Assignment #4: Reflection 4 – Significance and Delivery

Assigned: Tuesday, February 10, 2015
Due: in class on Tuesday, February 17, 2015

Watch the following TedTalk:

http://www.ted.com/talks/gregoire_courtine_the_paralyzed_rat_that_walked.html

Write a brief (approximately 1/2 to 1 page single spaced, 1 inch margins, 11 point Arial font), informal response to the talk, making sure to include the following points:

1) What is the significance of talk? What is the big picture? The small picture(s)?
2) Who is the speaker? What is his/her (specific) role in the topic?
3) Comment on the speaker’s delivery. How would you describe their “style”? Comment on things we discussed in class—content, organization, use of visual aids, physical skills…
4) How did the delivery of this talk differ from the talk you went to for Reflection 2?
5) Do you believe in the significance of the subject? Was the speaker convincing? Why or why not?
6) How could the presentation of the significance be improved?

Use specific examples from the talk to support your statements. Feel free to expand upon other aspects that are related to things we have discussed in class (identifying audience, nonverbal communication), but remember to stay brief (no longer than one page). This is meant to be a quick reflection done immediately after attending the talk, rather than a formal paper. (Note: you are being evaluated on quality of ideas, not writing. However, do keep in mind that these are related. Your ideas cannot be evaluated if they cannot be identified and understood.)
Assignment #5: Presentation 2
Assigned: February 17, 2015
Due: February 27, 2015

This presentation builds off the in-class activity on the solar hot dog cooker.

Scenario: You are an 8th grade STEM teacher in Iowa. You want your class to do a hands-on STEM project, but your school is low on funds. You need to apply for a grant to make this happen!

Your task: In your pairs, design a poster proposal for the STEM project of your choice (grade appropriate). Consider what we discussed in class about poster design.

Your Audience: Reviewers at Minds of Tomorrow, a K-12 grant funding program run through Iowa State University. They evaluate proposals from across the state and award two grants per semester. (You want to be one of those two!)

More information on Minds of Tomorrow:
Promo video 2009 (for sponsors): http://www.youtube.com/watch?v=VoUWIl4AuQs
Promo video 2011 (for volunteers): http://www.youtube.com/watch?v=JXtjSUjtOWs

Your presentation: Along with your poster, you should prepare a 5 minute presentation (with a 30 second to 1 minute hook) for those approaching.

February 27, 2015—Proposal Day!
Part 1: As a warm-up, you’ll be doing your 5 minute presentation to the class

Part 2: Poster Session. For the latter portion of class, reviewers will stop in to see your posters and provide feedback. Turn on the charm, your school needs this! You will have time to set up your poster after Part 1.

Poster Size: 36 by 48 inches or 48 by 36 inches

Printing Poster: You can print your poster at the library for about $10.
Assignment #6: Annotated Bibliography

Due: In-class on Tuesday, March 3, 2015

Review 3 literature sources related to your term project topic from peer-reviewed journals.

Instructions:
1. Do a search in the (scientific) database of your choice on your term project topic.
2. Compile a list of references that appear will be useful for your review paper. (minimum of 12 references)
3. Select three of the most relevant articles (one review article and two original research articles) to read and review. Write a summary report (review) using the “AnnotatedBib_ReviewTemplate” for each, containing:
   • Title of the article and journal name
   • The authors and affiliations (i.e., University, Company, or Laboratory) where this research was completed. (It may seem a little silly, but over time you will identify locations with particular types of research.)
   • Summarize the article including main ideas and key themes presented in the article (do NOT just re-word the abstract).
   • Note the relevance of this study. (Why is it important?)
   • Summarize the conclusions.
   • List possible future work either by suggesting extensions or listing questions you have about the results. This will help you form ideas for your pre-proposal.
   • Length: 1 page per article (single spaced, Arial 11 point font, 1 inch margins)

Be sure to define any unusual terms or acronyms (jargon) in either an introductory paragraph or as they occur in the text.

Submission Instructions:
• Submit to the Carmen dropbox a copy of the following:
   1. the list of references compiled
   2. each of the three selected articles that you reviewed
   3. your summaries of each article
• Name files: Bibliography, Article1, Review1, Article2, Review2, Article3, Review3

Bring to class on Tuesday, March 3rd hard copies of each review (item 3). Use the following template when organizing your articles:

Article Title:

Journal:
Authors:
Affiliations:
Summary: Main ideas and key facts
Significance: So what?
Relevance to my review paper: Why am I including this reference?
Conclusions: What were the key findings?
Possible Future Work: What can be done next to expand upon this work?
Assignment #7: Review Paper Outline

Due: Tuesday, March 10, in class

Prepare an outline for your review paper. An outline is, in essence, an organized summary of your paper.

Purpose:

A) To organize your paper and allow you to identify any missing components of your literature search.

B) To show the instructor that you have looked at literature and have a plan forward. You will receive feedback on your outline that may help in the development of your final paper.

Guidelines:

Use Arial 11-pt font. The format of your outline is of your own choosing, but a common format would be as follows:

I. Introduction
   a. Main point of introduction
      i. Relevant subpoint

At a minimum you should:

1. Identify main headings (introduction, background,....,etc.)
2. Outline the ideas/sources/topics of each heading

Complete sentences are not required, but complete thoughts are. Make sure a third-party reader (such as your instructor) can follow the thoughts!

Submission: Bring a hard-copy to class on Tuesday, March 10.
Assignment #8: Presentation 3 – Review Paper

Assigned: March 24, 2015
Due: In-class on Tuesday, March 31, 2015

Audience: American Institute of Chemical Engineers.

Purpose: To, in short, provide an oral presentation of your review paper. You should go through the necessary background for your audience,

Format: Individual presentation with PowerPoint slides.

Content: Your presentation must include (not necessarily in this order but in a logical order)
- Brief introduction of the topic/your talk
- Background information as appropriate
- Overview of current state of the area
- Significance

Time: You will have a total of 6 minutes for your presentation + questions/answers. Your presentation should be 5 minutes ± 20 seconds and the remaining time will be for questions and answers. You will be cut off at 6 minutes. Points will be deducted if you are unable to take any questions on account of being overtime.

Feedback: These presentations may be videotaped. You will later meet with the course instructor to review your presentation. There will also be a written peer-feedback component. Evaluation forms/rubric will be posted the class before the presentations. Make sure to print a copy and bring to class with you on presentation day.

Grading: You will receive two scores—one from the instructor and one from the class (students not presenting will score other students). Your final grade will be an average of the two scores.

Presentation Schedule: See next page. The order was determined using a random number generated. If you will be absent on your assigned day for any reason, please let me know ASAP and we will arrange to have you switch with someone.

Submission: Regardless of presentation date, you must submit your PPT to the dropbox on Carmen by 11:00 AM on Tuesday, March 31.
### Grading Rubric:

<table>
<thead>
<tr>
<th>Component</th>
<th>Excellent (10 PTS)</th>
<th>Good (8 PTS)</th>
<th>Needs Improvement (6 PTS)</th>
<th>Poor (4 PTS)</th>
<th>Points Earned</th>
</tr>
</thead>
<tbody>
<tr>
<td>Content</td>
<td>Content was complete (intro, background, significance, etc)</td>
<td>1 or 2 components seemed missing</td>
<td>Several components seemed missing</td>
<td>Content was not appropriate for assignment.</td>
<td></td>
</tr>
<tr>
<td>Organization</td>
<td>Logical flow of ideas from beginning to end.</td>
<td>Mostly logical flow, falters at 1 or 2 places.</td>
<td>Difficult to follow ideas in several areas.</td>
<td>Difficult to follow ideas throughout.</td>
<td></td>
</tr>
<tr>
<td>Visual Aids</td>
<td>Clear and appropriate visual aids.</td>
<td>Most visual aids clear and appropriate. Some mislabeled/too small.</td>
<td>Most visual aids need significant improvement (color, labeling, etc).</td>
<td>Visual aids unclear and or inappropriate throughout.</td>
<td></td>
</tr>
<tr>
<td>Eye Contact</td>
<td>Maintained good eye contact with entire audience throughout.</td>
<td>Maintained eye contact with majority of audience. Neglected one portion of the room or looked elsewhere at times.</td>
<td>Eye contact was shifty. Stared at floor, ceiling or other objects throughout.</td>
<td>Little or no eye contact was maintained.</td>
<td></td>
</tr>
<tr>
<td>Voice</td>
<td>Clear voice. Appropriate volume and pace.</td>
<td>Clear voice most of the time. Occasionally too soft/loud or fast/slow.</td>
<td>Too soft/loud or too fast/slow most of the time.</td>
<td>Too soft/loud or too fast/slow throughout.</td>
<td></td>
</tr>
<tr>
<td>Body Language</td>
<td>Body language was used appropriate throughout. (Stance, gestures)</td>
<td>Occasional weight shifting, stiff or over exaggerated gestures</td>
<td>Body language was distracting at times.</td>
<td>Body language was distracting or appeared uncomfortable throughout.</td>
<td></td>
</tr>
<tr>
<td>Attire</td>
<td>Business casual attire. No distracting pieces.</td>
<td>One aspect of attire was off (shirt untucked, sneakers, etc).</td>
<td>Multiple components of attire were off.</td>
<td>Inappropriate attire (casual wear)</td>
<td></td>
</tr>
<tr>
<td>Component</td>
<td>Excellent (10 PTS)</td>
<td>Good (8 PTS)</td>
<td>Needs Improvement (6 PTS)</td>
<td>Poor (4 PTS)</td>
<td>Points Earned</td>
</tr>
<tr>
<td>----------------</td>
<td>----------------------------------------------------------------------------------</td>
<td>------------------------------------------------------------------------------</td>
<td>--------------------------------------------------------------------------------------</td>
<td>--------------</td>
<td>--------------</td>
</tr>
<tr>
<td>Introduction</td>
<td>Engaging and clear presentation of topic</td>
<td>Fairly engaging and clear presentation of topic</td>
<td>Topic not entirely clear, but can be inferred. Somewhat engaging.</td>
<td>Topic unclear.</td>
<td></td>
</tr>
<tr>
<td>Content</td>
<td>Appropriate coverage of topic for audience, logical flow and transitions.</td>
<td>Topic was presented in a mostly logical manner, some connections unclear.</td>
<td>Content appeared to have gaps. Important connections were unclear.</td>
<td>Content was highly lacking.</td>
<td></td>
</tr>
<tr>
<td>Conclusion</td>
<td>Ended appropriately (not rushed) with satisfying concluding statements (not abrupt).</td>
<td>Ended slightly rushed with fairly satisfying concluding remarks.</td>
<td>Ended rushed with only slightly satisfying concluding remarks.</td>
<td>Ended abruptly/over time/without conclusion.</td>
<td></td>
</tr>
<tr>
<td>Impact &amp; Significance</td>
<td>Significance of the work is clear (big and small) and is thoroughly addressed</td>
<td>Significance of work (big and small) is addressed but could have been deeper</td>
<td>Significance of work not convincing (either big or small) is missing</td>
<td></td>
<td></td>
</tr>
<tr>
<td>Audience</td>
<td>Presentation was appropriate for audience. Presenter maintained appropriate persona throughout.</td>
<td>Mostly appropriate for audience. A few things were not suitable. Persona was maintained most of the time.</td>
<td>Somewhat inappropriate for audience, persona faltered, or audience was not entirely clear.</td>
<td>No indication of audience or content/person a was inappropriate for audience.</td>
<td></td>
</tr>
</tbody>
</table>
Assignment #9: Review Paper

Due: Tuesday, March 31, in-class

Scenario: You are writing a review article for an appropriate journal (Nature, Science, Nature Biotechnology, ACS Catalysis, Annual Review of …). You believe your topic is important and want to provide other professionals an overview of what is currently relevant in that area. You want to convey the importance of the topic while remaining unbiased in your presentation of the material, allowing your audience to form their own opinions on what the future holds for this topic.

Audience: Chemical engineers, or other STEM specialists as appropriate, who are interested in the topic you are reviewing.

Submission: Submit an electronic copy (Microsoft Word) to the Carmen dropbox before class on March 31, and bring a clean hard copy to class.

Specific Breakdown of Requirements for Review Paper

- Cover Page—This is your front page and should ONLY contain the following information:
  - A catchy and specific title (this has a big impact on reviewers)
  - Your name and affiliation directly under the title
  - Date of submission
- Abstract—This should be on its own page
  - Word Limit: 250 words
    - Anything beyond 250 words will not be read
  - Include key words after abstract “Key words: word 1, word 2, word 3”
  - Clear, concise summary of your review paper
  - Self-contained (no literature is cited)
  - No figures
  - No page number
- Table of Contents (1 page)
  - No page number
- Body (6 page limit)
  - Formatting
    - Page Limit: 6 pages, double-spaced, 1-inch margins, left aligned
      - Anything over the page limit will not be read; journals and funding agencies enforce strict length limits and so do I.
    - 11 pt Times Arial font
    - Page number (starting at 1) in lower right corner
    - Relevant headings and subheadings as appropriate
      - 14 pt, bold, Arial font for Heading 1
      - 12 pt, bold, italic, Arial font for Heading 2 (Subheading 1)
      - 12 pt, underline, Arial font for Heading 3 (Subheading 2)
    - Properly formatted and labeled tables and figures should be included in explaining important concepts. They will be counted in the page limit for this portion and is limited to 25% (maximum) of this section.
- References Cited (no page limit)
o No limit to number of references, 15 to 30 appropriate
o Formatting guidelines (adapted from http://www.nature.com/nature/authors/gta/#a5.4)
  • References are each numbered, ordered sequentially as they appear in the text
  • Authors should be listed surname first, followed by a comma and initials of given names.
  • Titles of all cited articles are required. Titles of articles cited in references should be in upright, not italic text; first word of the title capitalized, the title written exactly as it appears in the work, ending with a full stop. Book titles are italic with all main words capitalized. Journal titles are italic and abbreviated according to common usage. Volume numbers are bold. The publisher and city of publication are required for books cited. (Refer to published papers in Nature for details.)
  • References to web-only journals should give authors, article title and journal name as above, followed by URL in full - or DOI if known - and the year of publication in parentheses.
  • References to websites should give authors if known, title of cited page, URL in full, and year of posting in parentheses.
  • When cited in the text, reference numbers are superscript. They are not to be in brackets unless they are likely to be confused with a non-reference superscript number.
### Grading Rubric:

<table>
<thead>
<tr>
<th>General Component</th>
<th>Excellent</th>
<th>Good</th>
<th>Needs Improvement</th>
<th>Poor</th>
<th>Points Earned</th>
</tr>
</thead>
<tbody>
<tr>
<td>Cover Page (5 PTS)</td>
<td>Fulfills requirements of cover page as stated</td>
<td>1 missing or additional component</td>
<td>2 missing or additional components</td>
<td>&gt;2 missing or additional components</td>
<td></td>
</tr>
<tr>
<td>Abstract (5 PTS)</td>
<td>Clear, concise, and complete summary no longer than 250 words</td>
<td>Mostly clear, concise, but incomplete or slightly over 250 words</td>
<td>Slightly unclear or closer to 300 words</td>
<td>Unclear</td>
<td></td>
</tr>
<tr>
<td>Body (50 PTS) Thoroughly addresses all components</td>
<td>Thoroughly addresses most components</td>
<td>Some components missing</td>
<td>Incomplete or unclear body</td>
<td></td>
<td></td>
</tr>
<tr>
<td>References and Citations (5 PTS)</td>
<td>Properly formatted and complete references and in-text citations</td>
<td>Minor formatting errors</td>
<td>Did not follow proper formatting guidelines for references/citations</td>
<td>Missing references/citations, which would be interpreted as plagiarism</td>
<td></td>
</tr>
<tr>
<td>Formatting (10 PTS)</td>
<td>Follows formatting requirements</td>
<td>Follows most formatting requirements</td>
<td>Follows some formatting requirements</td>
<td>Does not follow many formatting requirements</td>
<td></td>
</tr>
<tr>
<td>Grammar (10 PTS)</td>
<td>Free (or nearly free) of grammatical errors</td>
<td>Only a few errors</td>
<td>Several errors (5 or more)</td>
<td>Many errors (greatly detracts from proposal)</td>
<td></td>
</tr>
<tr>
<td>Overall Clarity (10 PTS)</td>
<td>Writing is easy to follow (easy to understand) with a clear logic progression</td>
<td>Writing is easy to follow with some small gaps in logic progression or with some unclear statements</td>
<td>Writing has many gaps in logic progression and numerous unclear statements</td>
<td>Writing is difficult to follow; arguments and logic progression are unclear.</td>
<td></td>
</tr>
<tr>
<td>Body Components</td>
<td>Excellent</td>
<td>Good</td>
<td>Needs Improvement</td>
<td>Poor</td>
<td>Points Earned</td>
</tr>
<tr>
<td>-----------------------</td>
<td>------------------------------------------------</td>
<td>-------------------------------------------</td>
<td>------------------------------------------------------</td>
<td>-------------------------------------------</td>
<td>---------------</td>
</tr>
<tr>
<td>Introduction (10 PTS)</td>
<td>Sets up review paper and introduces subject to reader in a clear, concise manner</td>
<td>Well-written, but subject is somewhat unclear—is inferred but not clearly stated</td>
<td>General subject area is clear, but specific area unknown</td>
<td>Introduction lacking and subject is highly unclear</td>
<td></td>
</tr>
<tr>
<td>Background Information (25 PTS)</td>
<td>Demonstrates a thorough literature review and understanding of the relevant background with sound rationale</td>
<td>Thorough literature review with a good understanding of relevant background, but some background appears to be missing or the argument is unclear/biased in parts.</td>
<td>Literature review appears incomplete and argument is not entirely clear or biased in many areas.</td>
<td>Literature review is incomplete and/or presentation of argument/conclusions is entirely biased.</td>
<td></td>
</tr>
<tr>
<td>Significance (10 PTS)</td>
<td>Significance of the work is clear (big and small) and is thoroughly addressed</td>
<td>Significance of work (big and small) is addressed but could have been deeper</td>
<td>Significance of work not convincing (either big or small) is missing</td>
<td>Significance is either missing or unclear</td>
<td></td>
</tr>
<tr>
<td>Submission of Peer-Reviewed Version (5 PTS)</td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
</tr>
</tbody>
</table>
Assignment #10: Pre-proposal Abstract

Assigned: April 7, 2015

Due: April 14, 2015, in class

Your task:

While abstracts are generally written after you have finished your document, we are changing things up a bit. Like you did in-class, first develop an outline for your pre-proposal, then translate that into a paragraph-style abstract. Specifically:

1) Develop an outline for your pre-proposal—include major section headings and subheadings
   a. Submit your outline with your abstract. There are no specific formatting requirements for this part of the assignment. Electronic submission not required, just the hard copy will suffice.

2) From your outline, develop an abstract. Use full sentences.
   a. Arial, 11 point font
   b. No longer than 300 words
   c. Submit hard copy to instructor in class on Tuesday, April 14.
   d. Submit soft copy to Carmen dropbox

I do not expect this abstract to be the same as your final abstract, however, with your paper being due relatively soon it is a good point to make sure you are on track!
Assignment #11: Pre-proposal

*Due:* Tuesday, April 28, 11:10 AM

Agencies or companies looking to fund research and development will often ask for pre-proposals in order to screen a large batch of ideas and will then ask for fully developed proposals for the ideas they find interesting. For this assignment, you are asked to prepare a pre-proposal on your review paper topic, building off of the background you gathered there.

**Audience:** Depends. You have three options.

1) Submit to a research proposal review committee (*i.e.*, an NSF panel). This group will be scientists with expertise in the broad area of your proposal topic.

2) Submit to a review committee within a company. This group will consist of a senior operating engineer, a senior manager (also an engineer), a business manager, a research and development engineer, and an operator.

3) Submit to a group of venture capitalists. This audience will have a strong business background, and moderate technical background (higher than the average population, lower than an expert).

**Scenario:** Based on literature review (your review paper) you have come up with a new idea/suggestion/research proposal that you want to pitch to a funding agency/your company.

**Scope:** Do not forget to consider the time and money that your proposal will take. For audience (1), consider you are applying for a three-year grant that is $100,000 annually. For audience (2), you have no budget, per say, but rather an idea that you hope your company will agree to and your business manager will agree to fund. Likewise, for audience (3) you do not have an explicit budget, but rather an idea you hope will take hold! The economics do not have to be perfect, but should be addressed.

**Submission:** Submit an electronic copy (Microsoft Word) to the Carmen dropbox before class on April 28, and leave a hard copy in the instructor’s mailbox in 314 CBEC.

**Specific Breakdown of Requirements for Pre-Proposal:**

- **Cover Page**—This is your front page and should ONLY contain the following information:
  - Center align cover page
  - A catchy and specific title (this has a big impact on reviewers)
    - 26 point, Arial font, black
  - Your name and affiliation directly under the title
• 18 point, Arial font, black
  o Date of submission
    • 18 point, Arial font, black
  o Audience (“Submitted to:”)
    • 18 point, Arial font, black
    • Space away from other components of the title, place near bottom
• Abstract—This should be on its own page
  o 11 point Arial font, black
  o Single-spaced (not 1.15, which is Word’s default), 1-inch margins, left aligned
  o Word Limit: 250 words
    • Anything beyond 250 words will not be read
  o Include key words after abstract “Key words: word 1, word 2, word 3…”
  o Clear, concise summary of your project
  o Self-contained (no literature is cited)
  o No figures
  o No page number
• Table of Contents
  o No page number
  o Page numbers for all headings
  o Separate table for figures and tables on same page
• Project Description
  o Formatting
    • Page Limit: 5 pages, double-spaced, 1-inch margins, left aligned
      • Anything over the page limit will not be read; journals and funding agencies enforce strict length limits and so do I
    • 11 pt Arial font, black
    • Page number (starting at 1) in lower right corner
    • Relevant headings and subheadings as appropriate
      • 14 pt, bold, Arial font for Heading 1

274
- 12 pt, bold, italic, Arial font for Heading 2 (Subheading 1)
- 12 pt, underline, Arial font for Heading 3 (Subheading 2)

Main sections (as a minimum):

- **Introduction** (briefly explain the need for the research, research problem, or development) [5%]
- **Objectives** (may be linked to hypotheses/specific aims; should clearly explain what the proposed work is intended to accomplish) [5%]
- **Background and Rationale** (literature review) [30%]
- **Research/Implementation Plan** (including planned methods) [40%]
- **Expected Outcomes/Results** [10%]
- **Impact and Significance of the Proposed Work** [10%]

Properly formatted and labeled tables and figures should be included if/where appropriate. They will be counted in the five page limit for this portion, and should be limited to no more than 25% of this section.

- Table labels should be above the table.
- Figure labels should be below the figure.
- All labels should be in 9 pt Arial font, with the identifying “figure x” or “table x” in bold.

**References Cited**

- No limit to number of references, should have at least as many as your review paper
- Formatting guidelines (adapted from [http://www.nature.com/nature/authors/gta/#a5.4](http://www.nature.com/nature/authors/gta/#a5.4))
  - References are each numbered, ordered sequentially as they appear in the text
  - Authors should be listed surname first, followed by a comma and initials of given names.
  - *Titles of all cited articles are required.* Titles of articles cited in reference lists should be in upright, not italic text; the first word of the title is capitalized, the title written exactly as it appears in the work cited, ending with a full stop. Book titles are italic with all main words capitalized. Journal titles are italic and abbreviated according to common usage. Volume numbers are bold. The publisher and city of publication are...
required for books cited. *(Refer to published papers in Nature for details.)*

- References to web-only journals should give authors, article title and journal name as above, followed by URL in full - or DOI if known - and the year of publication in parentheses.

- References to websites should give authors if known, title of cited page, URL in full, and year of posting in parentheses.

When cited in the text, reference numbers are superscript. They are not to be in brackets unless they are likely to be confused with a non-reference superscript number.
Assignment #12: Reflection 5 – Argument

Assigned: Friday, April 10, 2015

Due: in class on Friday, April 17, 2015

Revisit your in-class argumentative essay on the following question:

What is more important, breadth of knowledge or depth of knowledge?

Write a brief (approximately 1/2 to 1 page single spaced, 1 inch margins, 11 point Arial font), informal response, building your argument from your previously written essay.

Use specific examples to support your statements. Remember, you are developing an argument. This is meant to be a persuasive piece, and while not formal, should present clear logic. (Note: You are being evaluated on quality of ideas, not writing. However, do keep in mind that these are related. Your ideas cannot be evaluated if they cannot be identified and understood.)
Assignment #13: Presentation 4 – Pre-proposal

Final Exam Period—Monday, May 4, 9:50 AM to 12:00 PM (official, 10:00 AM to 11:45 AM)

Audience: Depends. You have three options (same as written paper, audience should be consistent!).

4) Submit to a research proposal review committee (i.e., an NSF panel). This group will be scientists with expertise in the broad area of your proposal topic.

5) Submit to a review committee within a company. This group will consist of a senior operating engineer, a senior manager (also an engineer), a business manager, a research and development engineer, and an operator.

6) Submit to a group of venture capitalists. This audience will have a strong business background, and moderate technical background (higher than the average population, lower than an expert).

Purpose: To, in short, provide an oral presentation of your pre-proposal. You should go through the necessary background for your audience, and make sure that it is clear who your audience is!

Format: Individual presentation with visual aid/media of choice (that is supported by and appropriate for topic and space). Submit any electronic visual aids (PPT, etc) to the Carmen dropbox available before the final exam period.

Content: Your presentation must include (not necessarily in this order but in a logical order)

- Brief introduction of the pre-proposal
- Background information as appropriate
- Proposed Project
- Hypothesis/Aims
- Research/Implementation Plan
- Significance

Time: You will have a total of 6 minutes for your presentation + questions/answers. Your presentation should be 5 minutes ± 20 seconds and the remaining time will be for questions and answers. You will be cut off at 6 minutes. Points will be deducted if you are unable to take any questions on account of being overtime.

Feedback: These presentations will be videotaped. You will later be e-mailed your tape. There will also be a written peer-feedback component. Evaluation forms/rubric will be posted the week before the presentations. Make sure to print a copy and bring to class with you on presentation day.
**Grading:** You will receive at least two scores—one from the instructor and one from the class (students not presenting will score other students). Your final grade will be an average of the two scores. In the event that we do have outside “reviewers” also observing, the average reviewer score will also be incorporated into your final score.

There may be external reviewers present in the audience, in which case their scores will also be incorporated in your final grade.

<table>
<thead>
<tr>
<th>Presentation Order</th>
<th>Ideal Time*</th>
<th>Likely Time*</th>
</tr>
</thead>
<tbody>
<tr>
<td>1 Student 1</td>
<td>9:55 - 10:01</td>
<td>9:55 - 10:01</td>
</tr>
<tr>
<td>2 Student 2</td>
<td>10:01 - 10:07</td>
<td>10:02 - 10:08</td>
</tr>
<tr>
<td>3 Student 3</td>
<td>10:07 - 10:13</td>
<td>10:09 - 10:15</td>
</tr>
<tr>
<td>4 Student 4</td>
<td>10:13 - 10:19</td>
<td>10:16 - 10:22</td>
</tr>
<tr>
<td>5 Student 5</td>
<td>10:19 - 10:25</td>
<td>10:23 - 10:29</td>
</tr>
<tr>
<td>6 Student 6</td>
<td>10:25 - 10:31</td>
<td>10:30 - 10:36</td>
</tr>
<tr>
<td>7 Student 7</td>
<td>10:31 - 10:37</td>
<td>10:37 - 10:43</td>
</tr>
<tr>
<td>8 Student 8</td>
<td>10:37 - 10:43</td>
<td>10:44 - 10:50</td>
</tr>
<tr>
<td>9 Student 9</td>
<td>10:43 - 10:49</td>
<td>10:51 - 10:57</td>
</tr>
<tr>
<td>10 Student 10</td>
<td>10:49 - 10:55</td>
<td>10:58 - 11:04</td>
</tr>
<tr>
<td>11 Student 11</td>
<td>10:55 - 11:01</td>
<td>11:05 - 11:11</td>
</tr>
<tr>
<td>12 Student 12</td>
<td>11:01 - 11:07</td>
<td>11:12 - 11:18</td>
</tr>
<tr>
<td>13 Student 13</td>
<td>11:07 - 11:13</td>
<td>11:19 - 11:25</td>
</tr>
<tr>
<td>16 Student 16</td>
<td>11:25 - 11:31</td>
<td>11:40 - 11:46</td>
</tr>
<tr>
<td>17 Student 17</td>
<td>11:31 - 11:37</td>
<td>11:47 - 11:53</td>
</tr>
<tr>
<td>18 Student 18</td>
<td>11:37 - 11:43</td>
<td>11:54 - 12:00</td>
</tr>
</tbody>
</table>

*Ideal time assumes exactly 6 minutes per presentation and no turnover time between presentations. Thus, it is expected that the « actual time » will be different, and that we will end around noon, as shown in « likely time ».
Appendix K  Activities Used in CBE 4194, Technical and Professional Communication for (Chemical) Engineers

Activity 1: Non-Verbal Communication

How it works: Have students form two lines, facing each other. Arbitrarily designate each lines (line 1 and 2, a and b, cheddar and mozzarella, we’ll use line 1 and 2 from here out).

Give each student in line 1 a copy (slip of paper) of the first set of six directions.

Give each student in line 2 a copy of the second set of directions.

Round 1: Students in line 1 are the “speaker” and line 2 the “audience”. Give students in line 1 something to speak about, arbitrarily (their favorite food, what they did over the weekend, etc.). Students in line 2 (the audience) are to follow the first direction on their slip of paper. Have the speaker stop speaking when they notice the nonverbal communication cue. The round is over when the room becomes quiet, or several minutes have passed (discretion of TA/instructor).

Round 2: Repeat with switching roles, allowing students in line 1 to be the audience and demonstrate the nonverbal communication listed first on their slips.

Round 3 & subsequent rounds: repeat

Debrief Questions:

What was this experience like?

Were you able to notice the cues?

How did providing the cues feel? Was it easy? Natural?

Why would we do this activity? (demonstrate the power of nonverbal communication, and the difficulty of “faking it” on cue. Takes practice and awareness!)

1. Show interest in the person on your right (or wall, or window)
2. Become defensive.
3. Show agreement.
4. Show discomfort with what you are hearing.
5. Hold back something to say.
6. Show you are open to hearing their ideas.
1. Show you are closed (unwilling) to hear their ideas
2. Show engagement in the topic/what they are saying
3. Demonstrate that you are becoming impatient
4. Show sympathy or empathy towards or speaker
5. Show that you are looking to leave the conversation
6. Express confusion.

1. Show interest in the person on your right (or wall, or window)
2. Become defensive.
3. Show agreement.
4. Show discomfort with what you are hearing.
5. Hold back something to say.
6. Show you are open to hearing their ideas.

1. Show you are closed (unwilling) to hear their ideas
2. Show engagement in the topic/what they are saying
3. Demonstrate that you are becoming impatient
4. Show sympathy or empathy towards or speaker
5. Show that you are looking to leave the conversation
6. Express confusion.
Activity 2: Presentation Skills – Don’t Look!

Purpose: To challenge students to only glance at the slides they are using, rather than stare. In this case, they will have never seen the slide before, so the inclination to look at it will be greater.

Before Class: Have students submit three Columbus/camps related topics (people, places, etc) that they consider themselves knowledgeable about. Prepare one slide per student/per topic (so three sets of slides) before class. Add an “up next: Student Name” to the bottom of each slide to signify who the next slide belongs to, so they know when their turn is. Students are not to see the slides before class, nor know what they are for.

How it works:

Student listed as “up next” will go to the front of the room. They have 15 seconds from when they hit the next button to advance to their slide to begin speaking. Once those 15 seconds are up, they are not to look at the slide again.

Round 1: Students have one minute total to speak about their slide, while TA/instructor marks how many times they look at it.

Round 2: Same, but students are cut off the first time they look at their slide. Also, students are told how many times they looked at the slide in Round 1.

Round 3: Same, with students being told how long they made it in Round 2 before looking at the slide and challenging them to do better.

Note: Success in any round (making it a full minute without looking back at the slide) is a “pass” and exempts student from subsequent rounds.

Post-activity debrief:

How did you feel during this activity?

Why would we do this activity? (see purpose)

Why create slides that you’ve never seen? (To create an extreme situation where you are most inclined to look at the slides. If you can succeed not looking at slides you’ve never seen, you can succeed at not looking at any slides! Plus, how many times are you in seminar and clearly the speaker has never seen their slides? It’s not good.)
Activity 3: Presentation Skills – Avoiding Fillers

Purpose: To have students become more aware of the number of times they “uh” and “um” while speaking.

Before class: Have students submit three topics they consider themselves knowledgeable about. (Don’t tell them why you are collecting this information!)

How it works:

Round 1 Rules: Students have two minutes to speak about one of their three topics (chosen by TA/instructor) while the instructor counts “uhs” and “umms”. Each student is cut off at two minutes. The TA will call the student’s name, tell them their topic, and provide them 30 seconds to gather their thoughts before beginning.

Round 2 Rules: Students will be called upon and given their topic (with the 30 seconds of thinking time) in the same fashion as before. They will also receive the added information of how many fillers they used in their previous two minute talk. This time, they will be cut off at their first “uh” or “uhm”, or at two minutes, whichever comes first. Time of their first “uh” or “uhm” is to be recorded.

Round 3 Rules: Same as round two, with the challenge of making it further than in the previous round (i.e., students cut off at 30 seconds because of an “um” are challenged to make longer than 30 seconds). Time of first filler in previous round is stated before student begins. Time of first filler is again recorded, and student is told how they did when cut off.

Note: Successful completion of a round (defined as making it to two minutes without a single “uh” or “um”) exempts student from next round. This information is shared after the first round.

Post-Activity Debrief:

How was the experience?

What are the cause of “uh” and “umm”? (nerves, fillers for thinking)

So why would I ask for three topics you consider yourself knowledgeable about? (to make sure you are comfortable with the topic and hopefully eliminate one variable that may add to uhs/ums)

Why make it impromptu? (Fillers increase when we are uncertain of what to say next. Impromptu speeches are the epitome of uncertainty, so this exercise is intended to make you aware of what your habits/tendencies are when you are speaking “off the cuff” and incorporate this awareness into your presentation preparation. These speeches should be a “worst case” scenario for fillers, as you were not prepared at all.)
Activity 4: Presentation Skills – Eye Contact

Purpose: Make eye contact with your audience, not the wall/floor/window/door/projector/etc. Forcing students to make eye contact with each audience member allows them to gain a better understanding of the true breadth of the room.

Before Class: Ask students to submit three topics they consider themselves knowledgeable about. (Can specify a category if you want).

How it works:

Round 1: Each student will be called upon to give an impromptu speech. They have two minutes to speak, during which their challenge is to make eye contact with every single audience member. When their time is up, a poll of the audience will show their success rate, to be recorded for round 2.

Round 2: Much the same, however, this time the speaker will continue until they have (naturally) made eye contact with every audience member. A signal will be assigned for each audience member to do (raise arm, touch nose, etc) when eye contact has been achieved.

Debrief questions:

Did anything surprise you?

Was it easy to make eye contact with everyone?

What parts of the room were most difficult?

Why would we do this activity?
Activity 5: Presentation Skills – Shoulders Square!

*Purpose:* To increase student awareness of how they angle their body while presenting. Most speakers tend to angle to the projector.

*Before Class:* Compile a slideshow of slides from students’ previous presentation.

*How it works:*

Each student has one minute to present their slide. When they see their slide up, they come to the front of the room, and begin. The challenge is to keep their shoulders angled square to the back wall of the room. That is, to not angle their body towards one side of the room or the other.

*Post-activity debrief:*

How was the experience? Did you feel comfortable/natural?

Why would we do this activity? (see purpose. Avoid talking to slides.)