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ADVANCED CHEMICAL TECHNOLOGIES: AN INNOVATIVE PROBLEM-BASED APPROACH TO TEACHING CHEMISTRY

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ADVANCED CHEMICAL TECHNOLOGIES:

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APPROACH TO TEACHING

CHEMISTRY

by

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ABSTRACT

ADVANCED CHEMICAL TECHNOLOGIES:

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APPROACH TO TEACHING

CHEMISTRY

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The University of Texas at Arlington, 2018

Faculty Mentor: Frank W. Foss Jr.

The Advanced Chemical Technologies (ACT) Program led by Dr. Kevin A. Schug and Dr. Frank W. Foss Jr. proposes an innovative approach to achieving a Bachelor of Science (B.S.) in Chemistry and Biochemistry for students at the University of Texas at Arlington (UTA). By quantifying the effects of the inclusion of research methods and problem/inquiry-based learning in the programs first semester General Chemistry laboratory through analysis of student test scores and survey responses, it can be concluded that the ACT program can be projected to achieve the goals of increased retention of students who major in Chemistry and Biochemistry by increasing comprehension and evolving student views on the nature of science through a community-based learning approach.

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CHAPTER 1

INTRODUCTION

1.1 Advanced Chemical Technologies (ACT) Overview

The goal of the ACT program is to create an engaging and experience-based four-year program designed for chemistry majors planning on achieving their Bachelor of Science (B.S.) at the University of Texas at Arlington (UTA). The program combines components of an inquiry-based educational model for experiential learning with a four-year degree plan with prescribed coursework, while removing the redundancies present in the current chemistry curriculum, such as to introduce technology earlier and tie that technology to its industrial and interdisciplinary applications. The ACT environment is designed to build a community of majors through problem-based approaches, peer-led teaching, and team-based learning allowing for science to be taught as an exploratory adventure leading to increased comprehension and enhanced student views on the nature of science.[1]

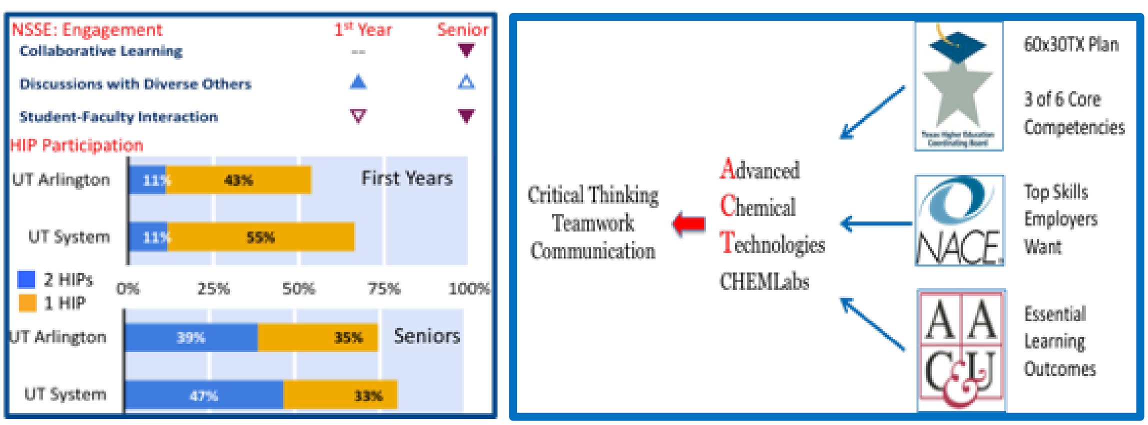

Figure 1.1: Motivation for the ACT Program in Chemistry[3]

The purpose of the ACT program is thus to improve retention of chemistry majors at UTA through to graduation and provide an educational edge to the UTA Chemistry department and its graduates by teaching skills employers are seeking and providing students with skills to become responsible independent researchers and free thinkers.[2] The goals of the ACT program are at the intersection of the goals of the Texas Higher Education Coordinating Board (THECB) Core Competencies, and the National Association of Colleges and Employers (NACE). The ACT program also addresses the need of undergraduates as indicated by their National Survey of Student Engagement (NSSE) scores by providing a community with peers and faculty as well as access to high impact practices (Figure 1.1).[3] The prescribed chemistry courses for the ACT Program to achieve a B.S. in Chemistry over a four-year degree plan are displayed in Table 1.1.

Table 1.1: ACT Program Prescribed Chemistry Courses at UTA

Year One	Fall Semester	General Chemistry 1	CHEM 1341 and 1181*
	Spring Semester	General Chemistry 2	CHEM 1342 and 1182*
Year Two	Fall Semester	Organic Chemistry 1	CHEM 2321 and 2341*
		Quantitative Chemistry	CHEM 2335 (with 2341*)
	Spring Semester	Organic Chemistry 2	CHEM 2322 and 2142*
Year Three	Fall Semester	Physical Chemistry 1	CHEM 3321 and 3181
		Biochemistry 1	CHEM 4311
	Spring Semester	Physical Chemistry 2	CHEM 3322 and 3182
		Inorganic Chemistry 1	CHEM 3317
Year Four	Fall Semester	Instrumental Analysis	CHEM 4461*
		Advanced Synthesis	CHEM 4346*
	Spring Semester	Chemistry Research	CHEM 4380*
		Seminar in Chemistry	CHEM 4101*

*New laboratory course design

1.1.1 Year One Overview – FACTs

Frontiers in Advanced Chemical Technologies (FACTs) incorporates presentations by chemistry department faculty and others, such as adjuncts and industry representatives, over current hot topics in chemistry research into the overall lab curriculum covered in the fall and spring General Chemistry lab components – CHEM 1181 and CHEM 1182.[2] These laboratory courses replace the current one-credit general chemistry laboratories (part of CHEM 1441 and 1442) with a controlled-inquiry (problem-based) approach. Though students in the ACT program take different labs than other CHEM majors, both cohorts attend the same general chemistry class. ACT classes (CHEM 1341 and 1342) were cross-listed with non-ACT classes (CHEM 1441 and 1442, respectively). The cross-listed lectures met in the same room at the same time, with other non-ACT program chemistry and biochemistry majors.

It is important to note that students enrolled in the ACT program, during its inaugural class, were B.S. Chemistry majors. Students enrolled in the cross-listed class, but non-ACT 1441 laboratory, were B.S. Biochemistry and B.S. Biological Chemistry majors. As first-year chemistry students, it is possible that these intended majors change overtime and the educational preparation for each major should be similar. In the fall of 2018, all CHEM B.S. majors (biochemistry, biological chemistry, and chemistry) will be enrolled in the new ACT program.

1.1.1.1 Fall General Chemistry Lab

The first semester of the ACT program consists of CHEM 1341 general chemistry lecture and CHEM 1181 lab. The lab component focuses on reinforcing general, analytical and synthetic chemistry concepts through problem/inquiry-based laboratory activities. The topics investigated are often taught during the second year of the B.S. in Chemistry Program; however, the ACT program introduces advanced techniques and development of research skills in the first semester through guided-inquiry. Students begin by designing their own CheMythBuster (CMB) experiment, where students work in groups on a research problem of their choosing.[2] One day of lab is dedicated to completing a module coined "Gen. Chem. in 3 Hours," where students quickly summarize four key labs used in the current General Chemistry and Quantitative Chemistry lab sessions: acid/base standardization and determination by titration, food dye extinction coefficients and mixtures with ultraviolet-visible spectroscopy, chemiluminescent oxidation of luminol investigating catalysis and stoichiometry, and exploration of a battery by electrochemistry. Students are also introduced to the use of technology in chemistry research through Synthesis and Analysis Projects (SAPs).

Three SAPs are completed in CHEM 1181. These were designed to follow the five E's of lesson planning—students engage, explore, explain, elaborate, and evaluate each new chemical process and technique they are exposed to in these SAPs. To illustrate this process, SAP 1 focuses on a green (more sustainable) chemical reaction and its characterization by analytical techniques including gas chromatography mass spectrophotometry (GC-MS). Students perform hands-on reactions and conduct analysis using cutting edge analytical equipment available through the Shimadzu Center for Advanced Analytical Chemistry. After performing more guided reactions, changing a single reaction variable, students must design their own experiment, test a hypothesis about the reaction system, and analyze the outcome of their reactions. Throughout the semester, students are expected to keep detailed notebooks of their research activities for assessment.

Additionally, student presentation and problem-solving skills are evaluated following each project through the presentation of a ten-minute scientific talk. Students also write a 250-word abstract over the significance of the reaction observed in SAP 1. In one case, the student-selected topic of this abstract was developed into a second CheMythBuster, which is proposed at the end of CHEM 1181 and performed at the beginning of CHEM 1182.

1.1.1.2 Spring General Chemistry Lab

The second semester of the ACT program consists of CHEM 1342 general chemistry lecture and CHEM 1182 lab. Students are increasingly exposed to technology including gas chromatography mass spectrophotometry (GC-MS), high pressure liquid chromatography (HPLC), differential scanning calorimetry / thermogravimetric analysis (DSC/TGA), infrared spectroscopy, computational modeling processes, and x-ray crystallography–analytical instrumentation. This is typically not addressed until Organic Chemistry (CHEM 2322) or instrumental analysis (CHEM 4461). Students embark on their exploration of these analytical methods and instrumentation through a combination of four consecutive SAPs, as well as through the exploration of their second round of CheMythBuster projects. Throughout the semester, students are evaluated on presentations, research papers, and a synopsis of their first-year projects posted on LinkedIn. Students also participate in guided research discussions, which replicate the weekly meetings experienced in many academic research laboratories. Finally, students develop a proposal for the following year’s Advanced Organic and Analytical Chemistry laboratory semesters, which combines synthesis and analysis methods learned throughout the semester.

1.1.2 Year Two Overview – IDEAs

Innovative Directions Early Assessments (IDEAs) incorporates presentation skills and mini-proposal writing of three potential concepts for their Capstone projects, which are presented to peers and an industry panel of representatives into the overall lab curriculum covered in the fall and spring Advanced Organic and Analytical Chemistry lab components.[2] These courses replace the current organic chemistry lab components with a semi-independent inquiry approach. Students continue to attend the same Organic Chemistry lectures (CHEM 2321 and CHEM 2322) and Quantitative Chemistry lecture (CHEM 2335) as other non-ACT program students. The organic lectures are dominated by pre-health students, incorporating a large diversity of majors, primarily from the College of Science. The Quantitative Chemistry lecture consists of primarily Biochemistry, Biological Chemistry, and Chemistry majors.

1.1.2.1 Fall Organic and Analytical Chemistry Lab

The first semester of the ACT program's second year consists of CHEM 2321 Organic Chemistry lecture, CHEM 2335 Quantitative Chemistry lecture, and a new and combined CHEM 2341 laboratory that combines the credit hours previously used for CHEM 2181 (organic) and CHEM 2381 (analytical) laboratories. These labs focus on year-long combinatorial synthesis and analysis research projects based on proposals submitted the prior spring semester coined "New Chemicals for New Solutions." These projects will focus on investigations in enzymology, medicinal chemistry (e.g. antimicrobial), and materials chemistry (e.g. polymers and surfaces). The goal for these research endeavors is to craft projects that are similar to those performed by participants in NSF-funded Research Experiences for Undergraduates, which are usually eight-week projects performed during the summer months at a host institution. The projects will be structured around hypotheses on structure and function relationships, where the structure of a molecule can be systematically modified to investigate a particular function. Students will present their current IDEAs projects at the end of this semester and make final decisions on work to be completed in the corresponding spring semester.

1.1.2.2 Spring Organic Chemistry Lab

The second semester of the ACT program's second year consists of CHEM 2322 organic chemistry lecture (and CHEM 2335, if not completed in the previous fall) and the ACT lab-CHEM 2142. Students continue their combinatorial synthesis and analysis research project from the fall semester and present their findings at ACES as a poster and oral presentation. Students will also complete a written report over their research and prepare an abbreviated Capstone proposal, ideally based on their IDEAs projects from the fall semester.

1.1.3 Year Three Overview – Connect

Connect: "Community of Learners" focuses on building formal ties between ACT students and the chemical community on and off campus. Progressing through the ACT program, students are engaged in informal discussion sessions on cross-cutting research themes, provide feedback and guidance to first and second year ACT students, and are guided to participate in undergraduate research and internships to facilitate a larger learning community. Due to the course load challenges during a student's third year (Physical Chemistry, Biophysical Chemistry, and Biochemistry), formal ACT laboratory activities are minimized. However, ACT students are required to choose one of the following courses alongside their prescribed chemistry courses: Readings in Chemistry (CHEM 4191/4192), Chem. Community Service Learning (CHEM 3131/3231/3331), or Independent Research (CHEM 4180/4380).

As a part of Connect: "Community of Learners," through their chosen course, students will focus on literature research for Capstone proposal refinement, service learning, and facilitating a feedback loop with first and second-year ACT students.[2] The prescribed chemistry courses for the ACT program's third-year fall and spring semesters is displayed in Table 1.1. Finally, students are expected to apply for external research experiences or internships outside of UTA for the upcoming summer. Many NSF-funded REU programs are available to UTA students at institutions across the country and overseas. The Chemistry and Biochemistry Department has created a number of ties to industry through our Internship requirement for graduate students, which will provide opportunities for undergraduate internships. In addition to providing hands-on experience to undergraduates beyond UTA, the mentoring of students through the application process for these programs will further develop student skills for applying to graduate programs and industrial positions as they approach graduation.

1.1.4 Year Four Overview – Capstone Communicate: Chemistry Seminar

Capstone Communicate: Chemistry Seminar focuses on the creation of an oral presentation, poster presentation, and a written thesis of the student's independent Capstone research. Capstone research will be completed by students in the fall, using the credit hours for Advanced Synthesis (CHEM 4346) and Instrumental Analysis (CHEM 4461) labs, twelve hours per week. The creation and presentation of communications (e.g. oral presentations, poster presentations, and a written thesis) will be completed by students in the spring through a chemistry research course (CHEM 4380).[2] Students are expected to graduate in the spring.

1.2 The Typical B.S. in Chemistry Overview

The typical four-year road map, designed for chemistry majors planning on achieving their B.S. in Chemistry at UTA, is instruction-based with labs that follow a prescribed system consisting of predesigned experiments. The prescribed chemistry courses for the typical B.S. in Chemistry over a four-year degree plan are displayed in Table 1.2.[4]

Table 1.2: B.S. in Chemistry Prescribed Chemistry Courses at UTA

<table>
<tr><td rowspan="2">Year One</td><td>Fall Semester</td><td>General Chemistry 1</td><td>CHEM 1441</td></tr>
<tr><td>Spring Semester</td><td>General Chemistry 2</td><td>CHEM 1442</td></tr>
<tr><td rowspan="3">Year Two</td><td>Fall Semester</td><td>Organic Chemistry 1</td><td>CHEM 2321 and 2181</td></tr>
<tr><td rowspan="2">Spring Semester</td><td>Organic Chemistry 2</td><td>CHEM 2322 and 2182</td></tr>
<tr><td>Quantitative Chemistry</td><td>CHEM 2335 and 2285</td></tr>
<tr><td rowspan="4">Year Three</td><td rowspan="2">Fall Semester</td><td>Physical Chemistry 1</td><td>CHEM 3321 and 3181</td></tr>
<tr><td>Inorganic Chemistry 1</td><td>CHEM 3317</td></tr>
<tr><td rowspan="2">Spring Semester</td><td>Physical Chemistry 2</td><td>CHEM 3322 and 3182</td></tr>
<tr><td>Inorganic Chemistry 2</td><td>CHEM 4318</td></tr>
<tr><td rowspan="5">Year Four</td><td rowspan="3">Fall Semester</td><td>Biochemistry 1</td><td>CHEM 4311</td></tr>
<tr><td>Chemistry Seminar</td><td>CHEM 4101</td></tr>
<tr><td>Instrumental Analysis</td><td>CHEM 4461</td></tr>
<tr><td rowspan="2">Spring Semester</td><td>Advanced Synthesis</td><td>CHEM 4346</td></tr>
<tr><td>Chemistry Research</td><td>CHEM 4180/4380</td></tr>
</table>

1.2.1 Year One Overview – General Chemistry

Fall and spring General Chemistry (CHEM 1441 and CHEM 1442) have lab components, which are designed by Dr. Jimmy Rogers to teach concepts in a prescribed hands-on manner that correlates to concepts as they are taught in his lectures. Each lab taught in CHEM 1441 begins with turning in a pre-lab worksheet and taking a short pre-lab quiz based on the concepts taught in the previous lab or in the pre-lab. Students then spend forty-five minutes in a worksheet session based on related concepts before taking a short worksheet quiz. Next, students perform a two-to-three hour-long experiment using the procedures detailed in their student lab manuals and write a post-lab report and discussion, which they turn in the day of the next lab session.[5] Each lab taught in CHEM 1442 follows a similar procedure with turning in a pre-lab worksheet and taking a short pre-lab quiz based on the concepts taught in the previous lab or in the pre-lab. Students do not complete a worksheet session in second-semester labs; instead, students then perform a three-to-four hour-long experiment using the procedures detailed in their student lab manuals and write a post-lab report and discussion, which they turn in the day of the next lab session[6]. An overview of experiment and worksheet topics over the course of both the fall and spring semesters are displayed in Table 1.3 and Table 1.4.[5,6]

Table 1.3: General Chemistry Fall Semester Worksheet and Experiment Topic Overview

Lab Session	Worksheet Topic	Experiment Topic
1	Significant Figures	Lab Check-In
2	Dimensional Analysis and Polyatomic Ions	UTA-701 – Mass and Volume Measurements
3	Reaction Stoichiometry	UTA-702 – Separation of a Three Component Mixture
4	Stoichiometry of Formulas and Equations	UTA-703 – Determining the Empirical Formula of a Copper Oxide
5	Molarity and Solution Stoichiometry	UTA-704 – Titration as an Analytical Method Determining the Acid Content in Vinegar
6	Solubility Rules, Precipitation, and Net Ionic Equations	UTA-705 – Qualitative Analysis: Identifying Simple Salts from their Properties and Reactions
7	Mole Fractions and Daltons Law of Partial Pressures	UTA-706 – The Ideal Gas Law and Gas Constant
8	Calorimetry	UTA-707 – Hess's Law and Calorimetry
9	N/A	UTA-708 – Synthesis of Tris-1,10-phenanthroline iron(II) chloride
10	Electron Configurations	UTA-709 – Spectrophotometric Determination of Purity and Concentration
11	Lewis Structures	UTA-710 – Atomic Emission Spectra of Gases: Evidence of Quantum Structure
12	VSPER Theory	UTA-711 – Chemiluminescence Optimization of a Chemical Reaction
13	N/A	Lab Check-Out

Table 1.4: General Chemistry Spring Semester Experiment Topic Overview

Lab Session	Experiment Topic
1	Lab Check-In
2	UTA 540 – Forensic Investigations with Chromatography
3	UTA 541 – Freezing Point Depression in *tert*-Butyl Alcohol
4	UTA 542 – Chemical Kinetics: Determining the Rate Law for a Chemical Reaction
5	UTA 543 – Synthesis of Green Crystals Trans-dichloro-bis-ethylenediamine cobalt(III) chloride
6	UTA 544 – Analysis of 'Green Crystals' for Cobalt Content
7	UTA 545 – Colorimetric Determination of the Equilibrium Constant for the Formation of a Complex Ion
8	UTA 546 – Buffer Solution Behavior
9	UTA 547 – Behavior of Strong and Weak Acids Upon Titration
10	UTA 548 – Enthalpy and Entropy of a Reaction
11	UTA 549 – Redox Titration
12	UTA 550 – Construction of Simple Batteries and Electrolysis
13	Lab Check Out

1.2.2 Year Two Overview – Organic Chemistry

Fall and Spring Organic Chemistry (CHEM 2321 and CHEM 2322) have lab components (CHEM 2181 and CHEM 2182), which are designed by Dr. Frank W. Foss Jr. and his colleagues to teach concepts and techniques in a prescribed hands-on manner that correlates to concepts as they are taught in lecture. Each lab taught in CHEM 2181 and CHEM 2182 begins with turning in a pre-lab worksheet and taking a short pre-lab quiz online based on the concepts taught in the previous lab or in the pre-lab. Students then perform a three-to-four hour-long experiment directly following the procedures detailed in their student lab manuals and write a post-lab report and discussion, which they turn in the day of the next lab session. These labs are completed in an identical manner, close to onethousand times per year at UTA, and countless times at various institutions around the world. An overview of experiment topics over the course of both the fall and spring semesters are displayed in Table 1.5 and Table 1.6.[7,8] The typical B.S. in Chemistry four-year plan also includes Quantitative Chemistry (CHEM 2335 and 2285), not shown.

Table 1.5: Organic Chemistry Fall Semester Experiment Topic Overview

Lab Session	Experiment Topic
1	Lab Check-In
2	THIN-LAYER-CHROMATOGRAPHY: Separation of Spinach Pigments
3	DETERMINATION OF MELTING POINTS
4	RECRYSTALLIZATION
5	DISTILLATION AND GAS CHROMOTOGRAPHY
6	SEPARATION OF A MIXTURE BYACID-BASE EXTRACTION
7	Practical I: RESOLUTION OF RACEMIC 1-PHENYLETHYLAMINE
8	Practical I: RESOLUTION OF RACEMIC 1-PHENYLETHYLAMINE
9	DEHYDRATION OF CYCLOHEXANOL – An Elimination Reaction
10	Practical II: S_N1 – SUBSTITUTION: Preparation and S_N1 Reactivity of 2-Bromobutane
11	Practical II: S_N1 – SUBSTITUTION: Preparation and S_N1 Reactivity of 2-Bromobutane
12	BROMINE ADDITION TO *trans*-CINNAMIC ACID: A Stereospecific Electrophilic Addition Reaction
13	Lab Check-Out

Table 1.6: Organic Chemistry Spring Semester Experiment Topic Overview

Lab Session	Experiment Topic
1	Lab Check-In
2	POLYMERIZATION – Synthesis of Polystyrene and Nylon 6,6
3	A GRIGNARD REACTION – Synthesis of 4-Chlorobenzhydrol
4	OXIDATION OF AN ALCOHOL – Synthesis of 4-Chlorobenzophenone
5	THE DIELS-ALDER REACTION – Cyclization of Anthracene and Maleic Anhydride
6	Practical I: ELECTROPHILIC AROMATIC SUBSTITUTION – Nitration of Methyl benzoate
7	Practical I: ELECTROPHILIC AROMATIC SUBSTITUTION – Nitration of Methyl Benzoate
8	ALDOL CONDENSATION – Reaction of Piperonal with Pinacolone
9	Practical II: HORNER-WADSWORTH-EMMONS REACTION – Synthesis of 3,4-Methylnedioxystilbene
10	Practical II: HORNER-WADSWORTH-EMMONS REACTION – Synthesis of 3,4-Methylnedioxystilbene
11	IDENTIFICATION OF UNKNOWN ORGANIC COMPOUNDS
12	Lab Check-Out

1.2.3 Year Three Overview – Physical Chemistry

Once students are in their third year, both the ACT program and the typical BS in Chemistry four-year plan students have more or less the same course schedule, consisting of Physical Chemistry (CHEM 3321 and 3181; CHEM 3322 and 3182), and Inorganic Chemistry 1 (CHEM 3317). The Typical B.S. in Chemistry four-year plan also includes Inorganic Chemistry 2 (CHEM 4318), which is not required by the ACT program; instead, students in the ACT program take Biochemistry 1 (CHEM 4311) a semester early.

1.2.4 Year Four Overview – Instrumental Analysis and Advanced Synthesis

In their fourth year, the typical B.S. in Chemistry four-year plan students take Biochemistry 1 (CHEM 4311), Chemistry Seminar (CHEM 4101), and Instrumental Analysis (CHEM 4461) in the fall semester. Students take Advanced Synthesis (CHEM

4346) and a Chemistry Research course (CHEM 4180/4380) in the spring prior to graduation. This course schedule differs from that of students in the ACT program in that the ACT program does not take Chemistry Seminar (CHEM 4101) or Biochemistry 1 (CHEM 4311) in the fall. Instead, ACT program students take modified versions of both Instrumental Analysis (CHEM 4461) and Advanced Synthesis (CHEM 4346) in their fall semester in order to focus on their Capstone research. The typical lab coursework for both Instrumental Analysis and Advanced Synthesis labs are described below.

1.2.4.1 Description of Instrumental Analysis Lab Coursework

The coursework for the Instrumental Analysis lab component consists of four problem-based projects using different lab instrumentation and communications styles. Students are placed in teams of two and assigned to one of four instruments, which teams rotate through over the course of the semester: Gas Chromatography Mass Spectrometry (GC-MS), High Pressure Liquid Chromatography (HPLC), Flame Atomic Absorption (FAA) / Ultraviolet-Visible Spectroscopy (UV- Vis) / Fluorescence Spectroscopy, and Differential Scanning Calorimetry (DSC) / Thermogravimetric Analysis (TGA). For each instrumentation assignment, students complete two prescribed pre-lab experiments over the course of two-days and write a two to three-page informal report. Students are then given two weeks to complete a problem-based research project. Following each rotation, the communications style of presentation for each project changes: an individually-prepared Journal of the American Chemical Society (JACS) formatted communication paper, an individually-prepared Standard Operating Procedure (SOP) Document, a jointly-prepared and presented poster presentation and, finally, a jointly-prepared JACS formatted communication paper.[9]

1.2.4.2 Description of Advanced Synthesis Lab Coursework

The coursework for the Advanced Synthesis Lab consists of five organic synthesis experiments and five inorganic synthesis experiments designed to teach the various methods of synthesis, isolation, and characterization of organic, inorganic, and organometallic compounds. The experiments and their descriptions, that are performed in this lab, can be found in Table 1.7.[10]

Table 1.7: Advanced Synthesis Experiments and Their Descriptions

Experiment	Experiment Description
Synthesis of a Flavone	Multistep synthesis of a classical heterocyclic system
Sonogashira Reaction	A palladium and copper co-catalyzed cross-coupling reaction using a microwave reactor
CSI@UTA	structural assignment of a reaction product using advanced analytic techniques
Organocatalytic Adol	Using proline as a catalyst
Synthesis of Quinolone	A thermal rearrangement of vinylogous amide
Reactions of a metal-metal bond	Cyclopentadienyl iron iodide
Coordination Compounds of a Chelating Compound	Preparation of tris(2,4-pentanedionato)cobalt(III): $Co(acac)_3$
Reactions on a Coordinated Ligand	Nitration of tris(2,4-pentanedionato)cobalt(III)
Synthesis of a fluorinated pyrazole	Synthesis of 3,5-bis(trifluoromethyl)pyrazole
Synthesis of a metal containing ring	Synthesis of silver(I) pyrazole complex using 3,5-$CF_3)_2P_2H$

CHAPTER 2

THE ADVANCED CHEMICAL TECHNOLOGIES (ACT) PROGRAM

2.1 Summary of Pilot Study Supplemental Material

A pilot study, which was conducted over the summer of 2017 comparing two CHEM 1442 lab sections, incorporated supplemental materials into the experimental group's coursework in the form of pre-lab preparation activities and post-lab elaboration assignments in order to influence students to think critically about the experiments being completed in lab. The effects of this "discovery learning" inquiry approach on the student's opinions of the course were recorded and analyzed, and many of the supplementary materials, which were deemed successful, were used for the ACT Program, including CHROMacademy modules.[11,12] The results are discussed in Chapter 3.

2.1.1 Pre-lab Module Assignments

The typical lab session for CHEM 1442 General Chemistry second semester begins with a pre-lab briefing led by the teaching assistant over the motivation behind the experiment being done in lab and detailing the procedure students will be following. In the experimental group, students were assigned a supplemental pre-lab module to complete, rather than attend a pre-lab briefing allowing more time for experimentation during the lab itself provided students read the lab manual procedures and complete the assigned module. The assigned modules are displayed beside their respective lab in Table 2.1.

Table 2.1: Supplemental Pre-lab Modules and Experiment Topics for Pilot Study

Experiment Topic	Pre-lab Module
UTA 540 – Forensic Investigations with Chromatography	CHROMacademy Module: GC-MS[11]
UTA 541 – Freezing Point Depression in *tert*-Butyl Alcohol	N/A – Lab Briefing
UTA 542 – Chemical Kinetics: Determining the Rate Law for a Chemical Reaction	CHROMacademy Module: UV-Vis[12]
UTA 545 – Colorimetric Determination of the Equilibrium Constant for the Formation of a Complex Ion	N/A –Lab Briefing
UTA 546 – Buffer Solution Behavior	KHAN ACADEMY: Buffer Capacity (Video)[13]
UTA 547 – Behavior of Strong and Weak Acids Upon Titration	KHAN ACADEMY: Titration (Questions)[14]
UTA 548 – Enthalpy and Entropy of a Reaction	N/A –Lab Briefing
UTA 549 – Redox Titration	Redox Reactions: Crash Course – Chemistry #10 (Video)[15]
UTA 550 – Construction of Simple Batteries and Electrolysis	N/A – Lab Briefing

2.1.2 Post-lab Problem-Based Elaboration Assignments

The typical lab session for CHEM 1442 General Chemistry second semester incorporates a discussion of results as a part of the post-lab report. In the experimental group, students were assigned an elaboration assignment to complete, rather than write a discussion, in order to force students to think more creatively, and apply the concepts learned in lab to real world situations. The elaboration assignments are described in Appendix A.

2.2 Summary of ACT Program Lab Activities

The first year of the ACT program, FACTs, consists of two inquiry-based student-designed CheMythBusters at the beginning of each semester and four Synthesis and Analysis Projects (SAPs) over the course of the year. These projects will prepare students for designing their own synthesis and analysis project to investigate during year two, IDEAs, an organic and analytical chemistry lab section.

2.2.1 Summary of CheMythBusters

2.2.1.1 First Semester CheMythBusters

At the beginning of ACT students' first semester, they are divided into groups of three or four to determine the experiment they will complete as an open-inquiry CheMythBuster. Once a CheMythBuster topic is assigned, students design their own experimental procedure and interpret their own data with the help of their GTA and peer-leaders (four or five teaching assistants are assigned to the ACT lab session and divide groups amongst themselves such that there is a TA assigned to each of the lab groups). Students are given 6 weeks to complete their project alongside lab activities. At the end of the six weeks, all groups present their findings in the form of a professional PowerPoint presentation with visual aids. Out of five groups, two groups of students investigated the "Ewok Log Smash Myth."[16] To test this myth, students devised a system for smashing logs defining important variables related to weight distribution, the stability of logs, and the distance the logs needed to fall. In both groups, students assigned themselves a specific variable as their focus, which was crucial to the success of their model. A second group investigated cooking popcorn using sunlight. Students investigated multiple approaches and found that the indirect heating of oil with sunlight was superior to attempts to directly heat the kernels with the light. Students developed various methods to capture light and transfer heat. The third group evaluated the flow of cold and warm air taking multiple temperature measurements using an insulated Styrofoam box, a Styrofoam divider, and two thermometers. Finally, the last group determined if a selection of different grape juices were made from real fruit or artificial ingredients. These students synthesized an organic molecule standard with the help of their GTA, Pawan Thapa, and used an analytical method to quantify the amount of this flavoring agent in each juice. Students found that natural juices contained lower amounts of the molecule than artificially flavored juices.

2.2.1.2 Second Semester CheMythBusters

Students based the second-semester CheMythBuster off of the results of their SAP assignments (Described in Section 2.2.3.1) or other topics that they came into contact with through their FACT presentations. Several students noted combustion as a significant oxidation reaction, while others focused on medicines and other topics, including the color stability and antioxidant content in cosmetics and the concentrations of diethylene glycol, ethylene glycol, and propanediol in adult and children's toothpaste. Students who focused on the color stability and antioxidant content in cosmetics, focused on the "Oompa-Loompa-Effect" in which cosmetic foundations can change color (sometimes to an orange tint) with prolonged exposure to oxygen in the air. Students tested the concentrations of vitamin E in foundations and analyzed its color-change when applied to washed or unwashed skin as a function of time in order to correlate color stability to the presence of antioxidants.

2.2.2 Summary of "Gen. Chem. in 3-Hours"

In their first semester, students summarize four key labs used in the current General Chemistry and Quantitative Chemistry lab sessions in one lab period: acid/base standardization and determination, food dye extinction coefficients and mixtures, chemiluminescent oxidation of luminol, and exploration of a battery.

2.2.2.1 Acid/Base Standardization and Determination

Students explore acid-equilibrium by standardizing a sodium hydroxide solution with potassium hydrogen phthalate (KHP) and titrating an acetic acid solution of unknown concentration using phenolphthalein indicator.

2.2.2.2 Food Dye Extinction Coefficients and Mixtures

Students explore extinction coefficients of different food dyes using a spectrophotometer. Students use serial dilutions to create a standardized curve. Students work in groups and are each assigned a different food dye. In part two of the experiment, students must determine the concentrations of different food dyes in an unknown mixture.

2.2.2.3 Chemiluminescent Oxidation of Luminol

Students explore chemiluminescence by experimenting with multiple variables (concentration of luminol, hydrogen peroxide, hydrochloric acid, sodium hydroxide, and Iron(II) metal catalyst) in order to determine the optimum conditions for the light emitting reaction.

2.2.2.4 Exploration of a Battery

Students create batteries with copper and zinc electrodes in solutions of equal and unequal molarities and record the difference in voltage of each battery. Students then explore electrolysis by witnessing the plating of an iron nail with zinc.

2.2.3 Summaries of Synthesis and Analysis Projects

Students are exposed to analytical methods in their first year, which are not typically introduced until much later in instrumental analysis: GC-MS, HPLC and DSC/TGA. Students complete SAP 1 in their first semester and use their discussions of the results to determine their open-inquiry CheMythBuster topic for the second semester.

Students complete SAPs 2-4 in the second semester with increasing independence and use their discussions of the results to determine the open-inquiry synthesis and analysis project, which will be the focus of their second-year research in the Advanced Organic and Analytical Chemistry Laboratories.

Students then develop a proposal for the following year, which combines synthesis and analysis methods learned throughout their first two semesters.

2.2.3.1 SAP 1 – Gas Chromatography Mass Spectrometry (GC-MS)

The oxidation of primary, secondary, and tertiary alcohols is a core organic chemistry concept. A lab procedure to demonstrate ketone formation, through gas chromatography mass spectrometry in the time frame of a four-hour long teaching lab, was designed for students to analyze isothermally using GC-MS, the conversion of benzhydrol to benzophenone, 4-chlorobenzhydrol to 4-chlorobenzophenone, and 1-phenyl ethanol to acetophenone[17]. For the analysis of triplicated reactions, the preparation and analysis of all three reactions can be achieved in a single lab session. Figure 2.1 illustrates the comparison of a standardized benzhydrol and benzophenone mixture to the oxidation of benzhydrol as prepared and analyzed by the students. Above is the standard chromatogram of benzhydrol and benzophenone at 225 °C, with a split ratio of 10 and a run time: 20 min. Below is the chromatogram of the oxidation of benzhydrol to benzophenone analyzed with the same specifications.

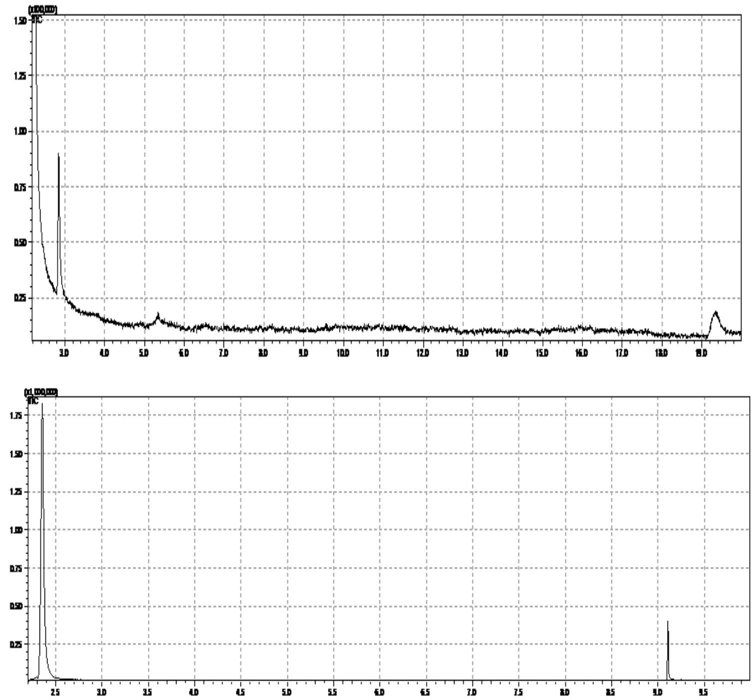

Figure 2.1: Comparison of a Standardized Benzhydrol and Benzophenone Mixture to the Oxidation of Benzhydrol as Prepared by the Students[17]

2.2.3.2 SAP 2 – High Pressure Liquid Chromatography (HPLC)

Amino acids are the building blocks for proteins, and therefore amino acids play an important biological role. They can also be useful chiral building blocks for the synthesis of other organic compounds. However, when utilizing amino acids, it is often important to consider protecting group strategies. A protecting group is introduced by chemical modification of a functional group to obtain the desired chemo-selectivity. It plays an important role in multistep organic synthesis and can later be removed for the desired final product. A standard operating procedure (SOP) was designed for L-phenylalanine, an amino acid with low water solubility that is UV active. Students are instructed to perform esterification of the amino acid to protect the amino group and acylation of the amino acid to protect the carboxylic acid group.[18] After reactions are completed, the derivatized amino acids are assessed using HPLC and MS. Figure 2.2

illustrates students' analysis of the aqueous mixture of L-phenylalanine esterifications in positive SIM mode and Figure 2.3 illustrates the analysis of the aqueous mixture of L-phenylalanine acylations in negative SIM mode.

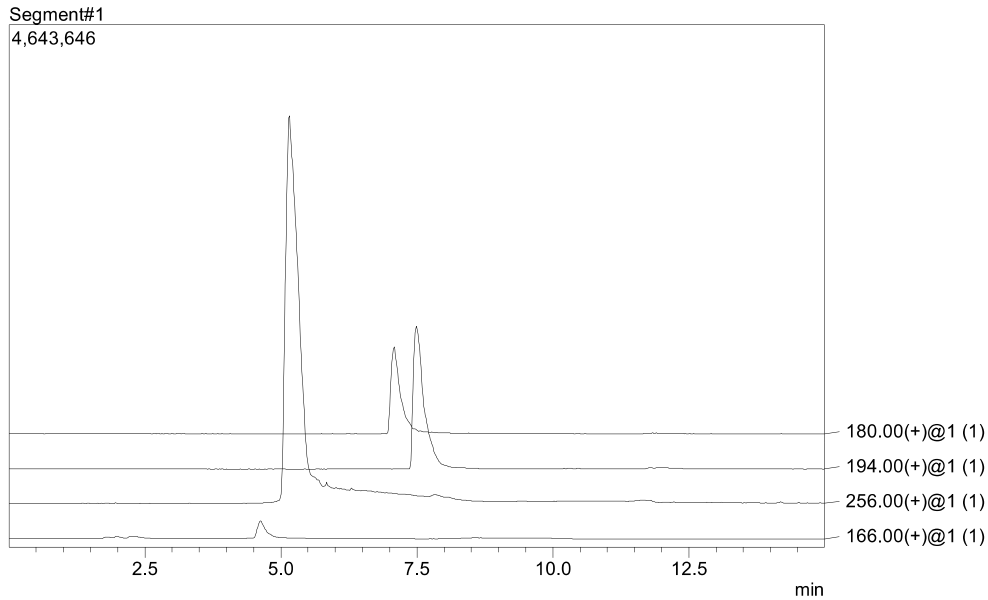

Figure 2.2: Chromatogram of Aqueous Mixture of L-phenylalanine Esterifications in Positive SIM Mode[18]

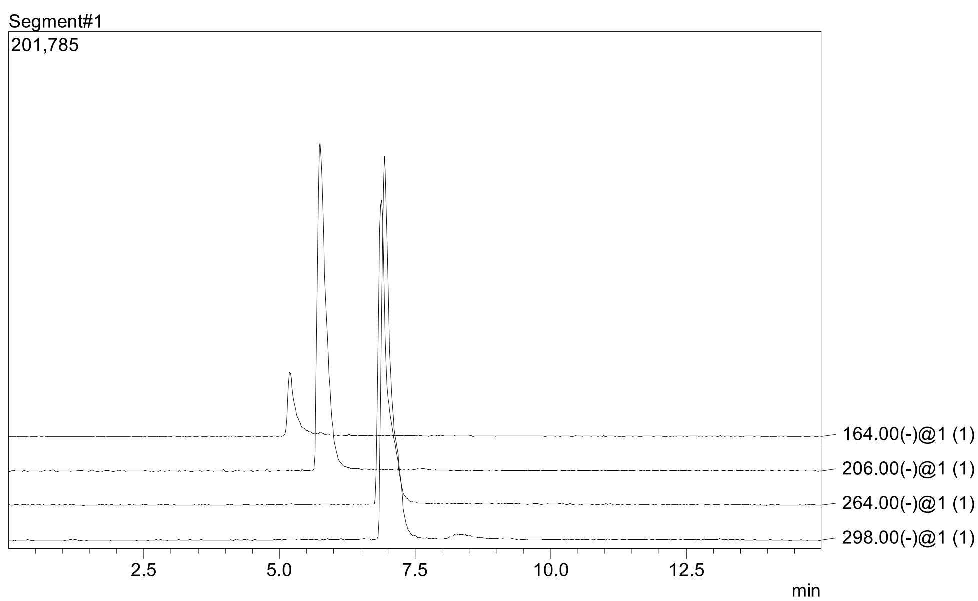

Figure 2.3: Chromatogram of Aqueous Mixture L-phenylalanine Acylations in Negative SIM Mode[18]

2.2.3.3 SAP 3 – Differential Scanning Calorimetry and Thermogravimetric Analysis (DSC/TGA)

Polymers are chain-like molecules made up of multiple monomers. Here, we synthesize two types of polymers: polyamides and polyesters. A procedure to determine the thermal properties of student-created polymers was designed using DSC/TGA.[19] While the experimental properties differed from the commercially available polymers, the overall trend remained the same. Figures 2.4 and 2.5 illustrate the DSC thermogram for a student-created polyester fiber with a melting temperature of 190.17 °C and a TGA thermogram for student-created Nylon 6,6 illustrating the stability of the polyamide fiber.

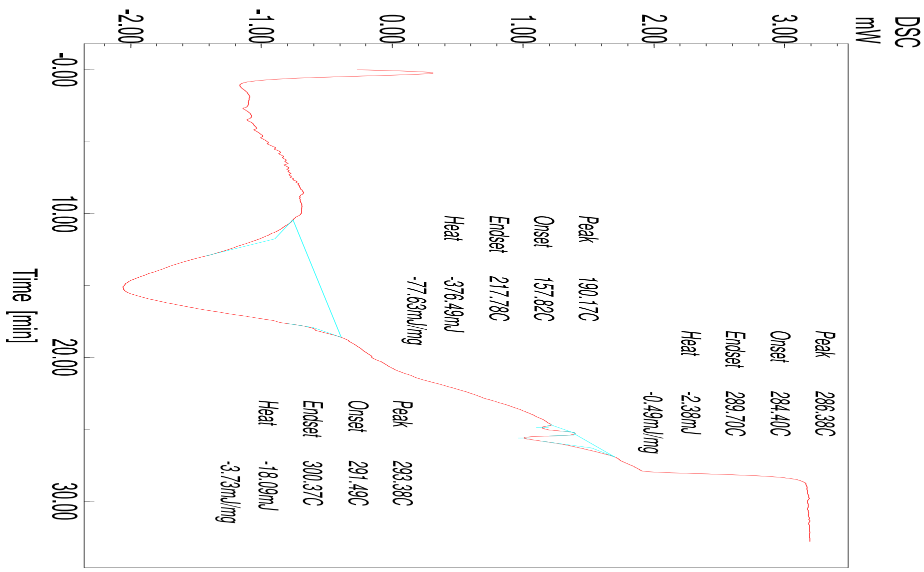

Figure 2.4: DSC Thermogram for Student Created Polyester Fiber[19]

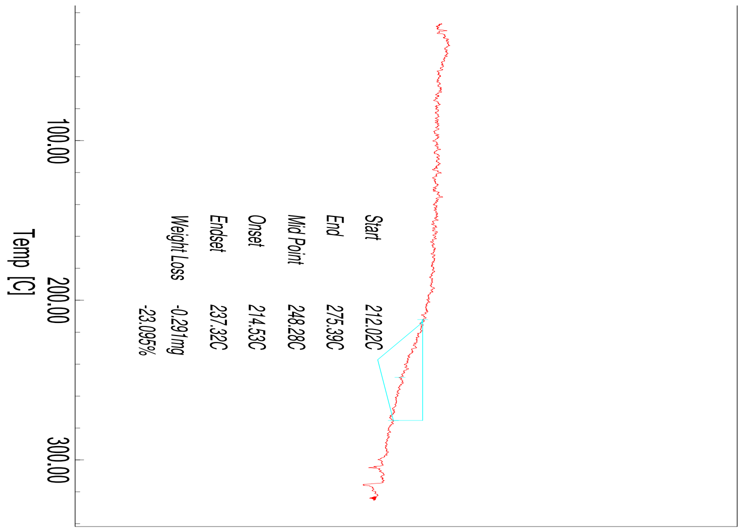

Figure 2.5: TGA Thermogram for Student Created Nylon 6,6[19]

2.2.3.4 SAP 4 – Computational Modeling

Intermolecular forces are an important topic taught in general chemistry, and through computational modeling, students can visualize the binding of small organic or inorganic molecules to their biological targets illustrating the importance of chemistry in drug discovery. Students investigate the possibility of HMP(P)K as a new antibacterial target; the design of Flavin mimics as LSD1 inhibitors, myoglobin binding of oxygen, and Transcriptase inhibitors for anti-HIV treatment. Students are also required to describe the significance of molecular docking.

CHAPTER 3

DATA ANALYSIS

3.1 Summary of Pilot Study

The summer of 2017 prior to the initialization of the ACT program, a pilot study was conducted comparing two General Chemistry second semester lab sessions such that the experimental lab session incorporated a more inquiry-based approach into the typical lab coursework in comparison to the control lab session. The responses of students from both lab sessions to the lab and its potential changes were compared.

3.1.1 Methodology

This study consisted of thirty-two university students enrolled in CHEM 1442 General Chemistry second semester eleven-week summer course at the University of Texas at Arlington in 2017. Students chose to attend one of two lab sections. The first lab section was used as a control group, while the second lab section was provided with experimental conditions. All participants signed a consent form in compliance with the Institutional Review Board (IRB) regulations prior to their participation in this study. Participants completed a pre-survey and a post-survey adapted from the Views on the Nature of Science Questionnaire as well as a short feedback survey over the lab itself. The control group, consisting of fourteen students, followed standard lab procedures; participants complete a pre-lab, attend a pre-lab briefing, complete the assigned experimental procedures detailed in the student lab manual, complete a post-lab report, and write a post-lab discussion.

The experimental group, consisting of eighteen students, followed an inquiry-based approach to the standard lab procedures. Participants complete a pre-lab, but they also use instructional videos to supplement standard lecture methods for introducing new laboratory techniques and experiments. Participants complete the assigned experimental procedures detailed in the student lab manual, and they complete a post-lab report. Additionally, participants complete three exercises, on separate occasions, that ask the student to propose a research protocol based on protocols learned in the laboratory. Students who did not wish to participate in the study were placed in the control lab section. No data was collected for students who did not consent to participate. All data collected was kept anonymous and confidential.

3.1.2 Summary of Student Feedback Responses

A two-tail t-test reveals significant differences in the responses of students, who participated in the control group versus the experimental group, in terms of their opinions on the pre-lab and post-lab assignments. The corresponding p-values for student responses are tabulated in Table 3.1. P-values correlate to percentage likelihood the two samples have the same average response. In the control group, students were given a pre-lab briefing explaining the experimental procedures outlined in the student lab manuals prior to beginning lab. In the experimental group, students were given supplementary material to complete at home prior to lab rather than a pre-lab briefing. Following lab, the students in the control group were expected to complete a discussion over the results of their lab experiment, while the students in the experimental group were expected to, on separate occasions, complete three exercises that ask the student to propose a research protocol based on protocols learned in the laboratory. Based on calculated p-values, students in the control group were 95% more likely to feel the pre-lab briefing helped them conduct their experiments, interested them in the topic of the particular lab, helped their understanding of the instrumentation used in lab, and was a necessary component of their learning experience. Students in the experimental group were less likely to agree with the same statements in regards to the supplementary materials provided to them prior to lab. Students in the control group were also 99% more likely to feel that their written post-lab discussions helped solidify the concepts covered in lab. Students in the experimental group were less likely to agree with the same statement in regards to their post-lab elaboration exercises. Finally, students in the control group were 96% more likely to feel that their scientific writing skills were improved by writing post-lab discussions. Students in the experimental group were less likely to agree with the same statement in regards to their post-lab elaboration exercises.

Table 3.1: Comparison of Midterm Feedback Surveys

	Average Response: 1 – Strongly Agree 5 – Strongly Disagree				
Prior to lab, I found the material presented to me:	Experimental (n=16)		Control (n=13)		T-Test
	Avg.	Std. Dev.	Avg.	Std. Dev.	P-value
Helped me conduct the experiment	2.7	1.1	1.5	1.4	0.0102
Made me more interested in the topic of the particular lab	2.8	1.2	1.7	1.4	0.0296
Helped me understand the instrumentation used in lab	2.6	1.1	1.5	1.3	0.0168
Was a necessary component of my learning experience	3.0	1.2	1.6	1.4	0.0053
After lab, I found the elaboration assignment or discussion assignment:	Experimental (n=16)		Control (n=13)		T-test
	Avg.	Std. Dev.	Avg.	Std. Dev.	P-value
Helped solidify the concepts covered in lab	2.6	1.1	1.5	1.3	0.0110
Improved my scientific writing skills	2.4	1.2	1.6	1.2	0.0609
Was very difficult to understand	3.2	1.6	2.9	1.2	0.6033

3.2 Summary of ACT Program Research Study

A research study was conducted in Fall of 2017 comparing the initialization of the ACT program General Chemistry first semester lab to a control group lab session that a typical student planning on achieving their B.S. in Chemistry would attend. The opinions and understandings of students in the ACT program, as well as exam scores and question responses, are compared to the control lab sessions.

3.2.1 Methodology

This study consisted of thirty-three university students enrolled in Dr. Rogers' CHEM 1341/1441, General Chemistry first semester fall course, at the University of Texas at Arlington in 2017. Ten participating students enrolled in CHEM 1341 as a part of the ACT lab group for chemistry majors, while the remaining twenty-three students enrolled in CHEM 1441 and attended either the chemistry majors' lab section or another lab section with non-majors. All non-ACT students who agreed to participate in the study were a part of the control group. All participants signed a consent form in compliance with IRB regulations prior to their participation in this study. Participants completed a pre-survey and a post-survey adapted from the Views on the Nature of Science Questionnaire as well as a survey over their background and demographics. Students were also asked to answer brief reflection questions concerning their conceptual understandings as they progressed through the lab. At the completion of the lab, students were asked to complete a student feedback survey. Participant responses on exams, exam averages, and final course grades were collected anonymously. No data was collected from students who did not consent to participate. All data collected was kept anonymous and confidential.

3.2.2 Summary of Student Performance on Exams

After analysis, Students in the ACT program had a higher percentage of students with a final grade of A, B or C and a lower percentage of students who had Dropped-Failed-Withdrew (DFW) from the course than the control group or the previous year's CHEM 1441 students; however, this difference is insignificant without a larger sample of ACT program students.

There were no significant differences between exam scores or final course grade between students in the control group and the ACT students. On their final exam, student responses to individual questions proved significantly different with a 96% likelihood between the control group and the ACT students when analyzed using a Chi-Square Test. Tables 3.2–3.6 summarize only the question topics, where student responses differed and provide the z-score. If a topic was covered in multiple questions, all questions of that topic are summarized in the table regardless of the significance of their associated p-value. A z-score greater than or equal to 1.28 corresponds to a greater than or equal to 90% probability that there is a significant difference between the two samples. A z-score greater than or equal to 1.64 corresponds to a greater than or equal to 95% probability that there is a significant difference between the two samples.

3.2.2.1 Summary of Student Performance on the First Exam

Prior to the first exam, students in the control group attended two lab sessions: Check-In and UTA-701 Mass and Volume Measurements. In each lab session, the control group was given a forty-five-minute worksheet session and subsequent quiz over significant figures, dimensional analysis, and polyatomic ions.' ACT students, in the experimental group, attended three lab sessions in which they covered topics: what is a good scientific question, the philosophy of science, the scientific method, and notebooks and note keeping. ACT students also began their first inquiry-based CheMythBuster.

The performance of the experimental group, compared to the control group, was significantly different for questions related to three topics covered on the first exam. There is a 90% chance that ACT students were more likely than the control group to correctly determine the number of subatomic particles in the isotopes of an element. There is also a 90% chance that ACT students were less likely than the control group to correctly use units and conversion factors in calculations, and there is a 95% chance that ACT students were less likely than the control group to correctly determine the names and formulas of anions and acids. This difference between the percentage of correct responses over these topics seems highly correlated to the control group completing labs and worksheet sessions over the topics prior to the first exam.

Table 3.2: Comparison of Student Responses on Exam 1 Questions

		Fraction of Students with the Correct Response		
#	Question Topic	Experimental (n=9)	Control (n=23)	Z-score
2	Determining the Number of Subatomic Particles in the Isotopes of an Element	<u>80.00%</u>	60.87%	1.2840
6	Determining the Number of Subatomic Particles in the Isotopes of an Element	<u>100.00%</u>	78.26%	1.3914
8	Units and Conversion Factors in Calculations	70.00%	<u>91.30%</u>	1.3736
10	Units and Conversion Factors in Calculations	70.00%	<u>91.30%</u>	1.3736
15	Units and Conversion Factors in Calculations	80.00%	<u>86.96%</u>	0.7219
16	Determining Names and Formulas of Anions and Acids	50.00%	<u>78.26%</u>	1.6570
19	Units and Conversion Factors in Calculations	80.00%	<u>91.30%</u>	0.9425

3.2.2.2 Summary of Student Performance on the Second Exam

Prior to the second exam, students in the control group attended three lab sessions: UTA-702: Separation of a Three-Component Mixture, UTA-703: Determining the Empirical Formula of a Copper Oxide, and UTA-704: Titration as an Analytical Method Determining the Acid Content in Vinegar. In each lab session, the control group was given a forty-five-minute worksheet session and subsequent quiz over reaction stoichiometry, the stoichiometry of formulas and equations, and molarity and solution stoichiometry. ACT students, in the experimental group, attended three lab sessions in which they covered topics of research methods and basic statistics. ACT students were also introduced to SAP 1 and they continued experimentation for their CheMythBuster projects. During the fifth lab session, ACT students completed an activity coined, "Gen. Chem. in 3-Hours," where they performed 4 basic outlines of experiments performed in chemistry courses at UTA: acid/base standardization and determination, food dye extinction coefficients and mixtures, chemiluminescent oxidation of luminol, and exploration of a battery.

The performance of the experimental group compared to the control group was significantly different for questions related to three topics covered on the second exam. There is a 90% chance that ACT students were more likely than the control group to correctly solve problems concerning the stoichiometry of precipitation reactions. There is a 95% chance that ACT students were more likely than the control group to correctly solve problems concerning Charles Law and the relationship between the temperature and the volume of a gas. There is also a 90% chance that the ACT students were less likely than the control group to correctly solve problems using the ideal gas law itself. This correlation, however, seems unrelated to the lab over ideal gas laws, UTA-706: The Ideal Gas Law and

Gas Constant, completed by the control group after the exam was administered. Additionally, the control group performed worse on the topic of precipitation reactions seemingly due to not having covered the topic in lab yet. Meanwhile, ACT students displayed a high percentage of correct responses to questions over the topic despite their lab sessions having no relation to the topic.

Table 3.3: Comparison of Student Responses on Exam 2 Questions

		Fraction of Students with the Correct Response		
#	Question Topic	Experimental (n=9)	Control (n=23)	Z-score
4	Stoichiometry of Precipitation Reactions	<u>100.00%</u>	86.96%	1.0224
8	The Relationship Between Volume and Temperature: Charles Law	<u>80.00%</u>	56.52%	1.4623
14	Stoichiometry of Precipitation Reactions	<u>60.00%</u>	26.09%	1.8912
18	The Ideal Gas Law	70.00%	<u>95.65%</u>	1.5507

3.2.2.3 Summary of Student Performance on the Third Exam

Prior to the third exam, students in the control group attended three lab sessions: UTA-705: Qualitative Analysis–Identifying Simple Salts from their Properties and Reactions, UTA-706: The Ideal Gas Law and Gas Constant, and UTA-707: Hess's Law and Calorimetry. In each lab session, the control group was given a forty-five-minute worksheet session and subsequent quiz over solubility rules, precipitation, net ionic equations; mole fractions and Dalton's law of partial pressures, and calorimetry. ACT students, in the experimental group, attended four lab sessions in which they covered the topic of how to make a scientific presentation and completed multiple lab modules, either in lab or as supplementary material prior to the lab session itself. ACT students also finalized their CheMythBuster projects, and they collected and analyzed data for SAP 1 and SAP 2 using GC-MS and HPLC.

The performance of the experimental group compared to the control group was significantly different for questions related to five topics covered on the third exam. There is a 90% chance that ACT students were more likely than the control group to correctly solve problems over the general principles of electron configurations, as well as correctly identify state functions. There is a 90% chance that the ACT students were less likely than the control group to correctly solve problems calculating the energy of an emitted or absorbed electron in a hydrogen atom, as well as correctly identify the aspects of the electromagnetic energy spectrum. There is a 95% chance that the ACT students were less likely than the control group to correctly solve calorimetry problems measuring the heat of a chemical or physical change. This difference in the percentage of correct responses on the topic of calorimetry may have a correlation to the worksheet session and lab, UTA-707: Hess's Law and Calorimetry, which the control group completed the week before the exam. Meanwhile, the control group seemingly struggled with the topic of electron configurations, which would not be covered in a worksheet session until after the third exam.

Table 3.4: Comparison of Student Responses on Exam 3 Questions

		Fraction of Students with the Correct Response		
#	Question Topic	Experimental (n=9)	Control (n=23)	Z-score
2	The Special Case of Energy Levels in the Hydrogen Atom: Calculating the Energy of an Emitted or Absorbed Electron	40.00%	<u>60.87%</u>	1.3558
13	General Principles of Electron Configurations	<u>80.00%</u>	60.87%	1.2840
14	Identifying State Functions	<u>90.00%</u>	69.57%	1.3379
15	Calorimetry: Measuring the Heat of a Chemical or Physical Change	60.00%	<u>91.30%</u>	1.7822
16	The Nature of Light: The Electromagnetic Energy Spectrum	70.00%	<u>95.65%</u>	1.5507
18	General Principles of Electron Configurations	<u>80.00%</u>	65.22%	1.0996
20	Calorimetry: Measuring the Heat of a Chemical or Physical Change	<u>70.00%</u>	56.52%	1.0420
21	The Nature of Light: The Electromagnetic Energy Spectrum	30.00%	<u>56.52%</u>	1.5861
23	General Principles of Electron Configurations	<u>70.00%</u>	52.17%	1.2296

3.2.2.4 Summary of Student Performance on the Fourth Exam

Prior to the fourth exam, students in the control group attended three lab sessions: UTA-708: Synthesis of Tris-1,10-phenanthroline iron(II) chloride, UTA-709: Spectrophotometric Determination of Purity and Concentration and UTA-710–Atomic Emission Spectra of Gases: Evidence of Quantum Structure. In two lab sessions, the control group was given a forty-five-minute worksheet session and subsequent quiz over electron configurations and Lewis structures. ACT students, in the experimental group, attended three lab sessions in which they completed multiple lab modules as supplementary material prior to the lab session itself. ACT students finalized SAP 2 and prepared presentations for both SAP 1 and SAP 2 while beginning their proposals for the next years research prior to the fourth exam.

The performance of the experimental group to the control group was significantly different for three topics on the fourth exam. There is a 90% chance that ACT students were more likely than the control group to correctly answer questions over Lewis structures for exceptions to the octet rule, despite the control group having attended a worksheet session prior. There is also a 90% chance that ACT students were less likely than the control group to correctly answer questions over periodic trends and the electronic structure of atoms or chemical bonding.

Table 3.5: Comparison of Student Responses on Exam 4 Questions

		Fraction of Students with the Correct Response		
#	Question Topic	Experimental (n=9)	Control (n=23)	Z-score
3	Periodic Trends and the Electronic Structure of Atoms: Ionization Energy	50.00%	<u>69.57%</u>	1.3020
9	Periodic Trends and the Electronic Structure of Atoms: Ionization Energy	<u>80.00%</u>	56.52%	1.4623
13	Periodic Trends and the Electronic Structure of Atoms: Electronegativity	80.00%	<u>100.00%</u>	1.3200
24	Chemical Bonding: Bond Length	70.00%	<u>95.65%</u>	1.5507
25	Lewis Structures for Exceptions to the Octet Rule	<u>90.00%</u>	69.57%	1.3379

3.2.2.5 Summary of Student Performance on the Final Exam

The performance of the experimental group compared to the control group was significantly different for questions related to a variety of topics covered on the final exam. There is a 90% chance that ACT students were more likely than the control group to correctly solve problems over using bond energies to calculate the enthalpy of a reaction, rearrangements of the ideal gas law (finding the density of a gas), general principles of electron configurations, the nature of light (the electromagnetic energy spectrum), calorimetry (measuring the heat of a chemical or physical change), and reactions that involve a limiting reactant. There is a 90% chance that the ACT students were less likely than the control group to correctly solve problems over the kinetic-molecular theory, converting between amount, mass and number of chemical identities, and Lewis structures for exceptions to the octet rule.

Table 3.6: Comparison of Student Responses on Final Exam Questions

		Fraction of Students with the Correct Response		
#	Question Topic	Experimental (n=9)	Control (n=23)	Z-score
6	Using Bond Energies to Calculate the Enthalpy of a Reaction	80.00%	52.17%	1.6392
12	Rearrangements of the Ideal Gas Law: The Density of a Gas	80.00%	60.87%	1.2840
15	General Principles of Electron Configurations	80.00%	52.17%	1.6392
16	The Nature of Light: The Electromagnetic Energy Spectrum	80.00%	52.17%	1.6392
23	General Principles of Electron Configurations	70.00%	43.48%	1.5861
25	Calorimetry: Measuring the Heat of a Chemical or Physical Change	80.00%	52.17%	1.6392
31	How the Kinetic-Molecular Theory Explains the Gas Laws	40.00%	60.87%	1.3558
32	Reactions that Involve a Limiting Reactant	80.00%	60.87%	1.2840
35	Reactions that Involve a Limiting Reactant	80.00%	65.22%	1.0996
36	Converting between amount, mass, and number of chemical identities	30.00%	52.17%	1.4092
50	Lewis Structures for Exceptions to the Octet Rule	40.00%	65.22%	1.5331

CHAPTER 4

CONCLUSIONS

Advanced Chemical Technologies (ACT) is a program that engages students in research through a problem-based approach that allows the student to direct themselves as they learn the scientific methods and instrumentation a chemist uses.

4.1 Students May Prefer Prescribed Coursework

Based on the mid-term feedback survey responses from the pilot study over the summer the control group for the CHEM 1442 lab was more likely to feel that the pre-lab briefing (compared to the supplemental materials provided to the experimental group) helped them conduct their experiments, interested them in the topic the particular lab, helped them understand the instrumentation used in lab, and was a necessary component of their learning experience. Students in the control group were also more likely to feel that their written post-lab discussions (compared to the post-lab elaboration assignments provided to the experimental group) helped solidify the concepts covered in lab and improved their scientific writing skills. With this in mind, it can be concluded that the more hands-off problem-based inquiry approach was not received as positively by the students as the tried-and-true method of teaching general chemistry that was already in place.

4.2 First Semester Students Benefit from Worksheet Sessions

When comparing the percentage of correct answers on exams between the ACT program experimental group and the control group, there are a few significant differences.

Prior to the first exam, the control group attended two worksheet sessions; the second worksheet session discussed dimensional analysis and polyatomic ions. Students in the ACT program did not complete a worksheet session, and a significantly lower percentage of ACT program students correctly answered questions over units and conversion factors in calculations, as well as questions over determining names and formulas of anions and acids on the first exam. Prior to the third exam, control group students completed a worksheet session over calorimetry, and a significantly higher percentage of students in the control group correctly answered questions over calorimetry. Finally, on the final exam, there was a significantly higher percentage of students in the control group who answered questions correctly over two topics: converting between amount, mass, and number of chemical identities and Lewis structures for exceptions to the octet rule. The control group covered a worksheet session over the former topic in the first few weeks of class. A worksheet session over Lewis structures was covered during the control group's final lab sessions. The significantly higher percentage of correct responses for these topics indicates that attending these worksheet sessions correlates to a higher comprehension of the topic.

4.3 Why ACT Program Students Might Excel in the First Semester

Not only did the ACT proposal win the President's Innovative Teaching Award to aid in the initial laboratory experience for CHEM Majors during the Summer of 2017, but the results of that restructuring reveal a promising projection. When comparing the percentage of correct answers on exams between the ACT program experimental group and the control group, there are a few significant differences. Although the experimental group had a significantly lower percentage of correct answers than the control group when looking at the first exam, by the final exam the experimental group had a significantly higher percentage of correct answers than the control group. Students in the experimental group had a significantly higher percentage of correct answers over topics with a mathematical or critical thinking component such as using bond energies to calculate the enthalpy of a reaction, rearrangements of the ideal gas law to find the density of a gas, and calorimetry. Students in the experimental group also had a significantly higher percentage of correct answers over the electromagnetic energy spectrum and general principles of electron configuration.

4.4 ACT Program Next Steps

In the upcoming school year, 2018-2019, pilot ACT students will embark on their second year, IDEAs*,* while a new cohort of freshman will begin their first year, FACTs. The goal is to have four new lab sections consisting of 16 students each. As a part of Collaborate UTA: Quality Enhancement Plan (QEP) that began development in the College of Liberal Arts in 2017, more broad and quantitative data will be gathered and analyzed in order assess the ACT program's effectiveness in enhancing teamwork skills through collaborative learning.[20]

Figure 4.1: Connecting the Maverick Advantage and Teamwork[20]

The ACT program will focus on collaboration between the students and faculty in order to support retention of STEM majors in gateway courses (e.g. General Chemistry). A few changes will be made to the CHEM 1181 and CHEM 1182 lab sections for the new ACT students. To supplement the need for worksheet sessions in lab (as in CHEM 1441), the ACT program will hold its own recitation sessions with peer-leaders to solidify content learned in lecture and tie that content into the research being conducted by the students. Furthermore, a professional learning community (PLC) will continue to be cultivated within the ACT program aimed at closing the gap through innovative approaches to learning and collaboration that increase the creativity, adaptability, and productivity of students by developing teamwork enhancing activities.

APPENDIX A

PILOT STUDY ELABORATION ASSIGNMENTS

UTA-540 – Forensic Investigations with Chromatography:

"Crime Scene Scenario
It looks like a love story gone wrong. An entire apartment up in flames. A strongly worded note, the handwriting unidentifiable. Lipstick stains on every shirt strewn about the rooms. Unfortunately, our homicide victim seemed to have a lot of angry girlfriends… 204 potential murder suspects. The forensics team has gathered the following evidence for testing:

- 5 different hair fibers… that could mean 5 serious suspects
- Lipstick stains from the shirts which all seem to be the same color and thus potentially the same brand?
- Charred wood from the armoire in the bedroom, where it is believed the fire was started, identifying the accelerant could be of help
- The note, maybe the ink used might give some clues

2 Write a basic procedure for analyzing either the wood from the armoire or the ink from the note. Be certain to be very specific on how one might prepare the samples in this scenario.

3 Look up procedures for either analyzing the hair fibers or the lipstick stains using chromatography. Cite your sources. If you find a YouTube video or other media include the link in your citation. Write a short summary of what you learn."

UTA-541 – Freezing Point Depression in *tert*-Butyl Alcohol:

"Discussion of Results. t-Butanol has a known freezing point. What is the percent error of your results in comparison? Write a short-pointed discussion on the accuracy of your results (~3 sentences).

Boiling Point Elevation. Describe what boiling point elevation is and compare it to freezing point depression. What equations are used, how are they similar? Different? How does the addition of a volatile solute affect the temperature at which something boils differently?

Problem: To calculate the molal boiling point constant of a solution, K_b, you must first be able to answer 3 questions: What is the boiling point of the pure solvent? What is the density of the solvent? What is the molar mass of the solute?

How does the addition of benzoic acid affect the boiling point of ethanol? If you added 2g benzoic acid to 100mL of ethanol and saw a temperature change of .250 degrees Celsius, what would you calculate the K_b, molal boiling point elevation constant, to be?"

UTA-542 – Chemical Kinetics: Determining the Rate Law for a Chemical Reaction:

> "Answer one of the following questions, and cite at least one source:
> A. What occurs on a molecular level to determine the rate law for brilliant blue with bleach?
> B. Describe how another reaction's rate law is/was determined using any instrumentation, UV-Vis or otherwise.
> C. UV-Vis can be used to identify unknown concentrations of mixtures. Thus, it can be used to evaluate the quality of water-soluble dyes. Explain how a dye company might use UV-Vis for quality control."

UTA-545 – Colorimetric Determination of the Equilibrium Constant for the Formation of a Complex Ion:

> "Discuss your results. In your discussion, the following questions must be answered: What is the reaction that occurred? At equilibrium does this reaction favor reactants or products? How do you know? At what wavelength was your absorbance? What is the literature value Kc? (Cite your source) What is your percent error? *Hint. Read abstracts from google scholar peer-reviewed papers, your discussion should have a similar format (i.e. hypothesis, relevant data, conclusive results, analysis)."*

UTA-547 – Behavior of Strong and Weak Acids Upon Titration:

> "Write a discussion over your lab experiment based on the notes from your discussion for UTA 545 Lab.
> Be certain to include the purpose of the experiment, indicate the reactions which took place during the experiment, and to compare your observed Ka value to the literature value. Citations should be in Chicago, MLA, or APA format."

UTA-548 – Enthalpy and Entropy of a Reaction:

> "First, explain the procedure you used to determine Ksp of borax.
> Second, cite the true Ksp of borax and calculate the percent error."

UTA-549 – Redox Titration:

> "Read the procedure for 'Vitamin C Determination by Iodine Titration and write a short theoretical discussion of the results that would be found in this experiment."

UTA-550 – Construction of Simple Batteries and Electrolysis:

> "Write a short bullet list of the procedure you followed for Part 1 or Part 2 of the experiment."

APPENDIX B

PILOT STUDY SURVEY RESPONSES

Participant	Helped me conduct the experiment	Made me more interested in the topic of the particular lab	Helped me understand the instrumentation used in lab	Was a necessary component of my learning experience	Helped solidify the concepts covered in lab	Improved my scientific writing skills	Was very difficult to understand
Experimental Group Responses							
1	2	2	2	3	3	2	4
2	2	1	3	1	2	1	4
3	2	2	1	2	1	1	1
4	2	1	2	1	2	1	5
5	1	2	1	2	2	3	2
6	4	3	4	3	4	4	2
7							
8	1	1	1	1	1	3	5
9	3	4	3	4	3	3	3
10	2	3	3	4	3	2	5
11	4	4	3	4	5	5	2
15	5	5	5	5	3	3	3
17							
18	4	3	4	4	4	3	3
19	1	4	1	2	4	3	3
24	3	3	2	4	1	1	3
26	5	5	4	5	1	2	2
Averages	*2.7*	*2.8*	*2.6*	*3.0*	*2.6*	*2.4*	*3.2*
Control Group Responses							
12	2	2	2	2	2	2	4
13							
14	1	2	1	1	1	1	2
16	1	1	1	1	1	1	3
20	1	1	1	1	1	1	5
21	1	1	1	1	1	1	1
22	2	3	2	2	2	2	3
23	1	1	1	1	1	1	1
25	5	5	5	5	5	5	1
28	1	1	1	1	1	1	4
29	1	1	1	1	1	1	5
30	1	2	2	3	1	1	4
31	1	1	1	1	1	3	4
27	1	1	1	1	1	1	1
Averages	*1.5*	*1.7*	*1.5*	*1.6*	*1.5*	*1.6*	*2.9*

APPENDIX C

FALL 2017 ACT SURVEY RESPONSES

#	In your own words, explain why citing external references might aid you in the (1) process of experimentation	and (2) drawing conclusions.	In your own words, describe what is statistical significance? What factors affect whether data gathered has statistical significance?	Science reflects social and political values, philosophical assumptions and intellectual norms of the culture in which it is practiced.	Science is universal transcending national and cultural boundaries and is not affected by the social and political values of the culture in which it is practiced.	Explain why you chose to agree with one of the statements above over the other. If you agree with neither statement explain why.
Experimental Group (ACT) Responses						
1	allows us to have better understandings of chemical processes and mechanisms for our own experimental purposes	allows us to synthesize more complex ideas, concepts, and understandings of our own experiment in relation to other's research and in terms of real world application.	method used to measure a variety of data in relation to a hypothesis, meaning that if the data does not support a hypothesis within a certain bound of confidence, it will be difficult to fail to reject the hypothesis	Science reflects social and political values, philosophical assumptions and intellectual norms of the culture in which it is practiced.		In the past many scientific discoveries were based on both cultural and political methods, such as advances in astrology during the space race. It can even be limited as some religions reject ideas of modern medicine or the concept of evolution. These however are minor cases and science can still expand on a national and international and independent of political and cultural factors.
2	gives us insight on what we are experimenting	allows us to compare conclusions to others	significant variable that rejects the null hypothesis. Comparing the expected and observed outcomes affects whether the data has statistical		Science is universal transcending national and cultural boundaries and is not affected by the social and political values of the culture in which it is practiced.	science is the study of nature, it is unrelated to the culture in which it is practiced, it is about the explanations on what we see.

			significance.			
3	providing background knowledge on a topic that could be completely foreign. If I am unsure how to proceed on an experiment, it will give me ideas	it can help me better analyze data and bring me to draw conclusions on it	refers to how much data is worth, in a sense. For example, if the same experiment has been repeated multiple times with similar results, and someone else tries to repeat it and gets the same result, then it is statistically significant.			both statements hold truths in them. Science is the study of the world around us and beyond, which already exists, however, the way it is studied and what is studied reflects our values.
4	can tell you if proposed experimental methods are reasonable and fair in regards to the possible outcomes	allow you to compare your data to other people's data and determine if there could be a significant amount of error in either of your experiments	whether or not your data actually genuinely contributes to your analysis and explanation of the data; correlation does not necessarily equal causation. Just because trends in your data seem to follow your conclusions, that doesn't mean your conclusion is necessarily true. there may be factors that you are not considering. I feel that	Science reflects social and political values, philosophical assumptions and intellectual norms of the culture in which it is practiced.		I agree with the first statement because, unfortunately, all government has some form of corruption, usually in the form of lobbying or individual candidates being supported by large corporations. If a candidate comes to power because of help of some large corporation, the candidate may feel obligated to pass legislation to benefit the corporation. For example, the current US administrated largely rejects climate change research results for the benefit of oil and energy companies. Another example,

			sample size is one of the biggest factors with regards to statistical significance			after WWI (or was it II?) milk sales dropped, so the government promoted dairy as a vital part of a healthy diet to help sustain dairy industry, even though people don't necessarily need dairy to be healthy, and most human adults have an intolerance to dairy, because humans aren't supposed to consume milk after infancy
5	will aid you in the process of experimentation because you want to show that the variation - is not your and it has been proven to some extent	drawing conclusions will give you a sort of expertise when you use your reference to show that you did not do it alone, show some gratitude for the sources you got	shows that it is proven to be true data is fact checked and is important. The sources used to show it is trusted. The repetition of this data and its importance		Science is universal transcending national and cultural boundaries and is not affected by the social and political values of the culture in which it is practiced.	science is universal and it doesn't change because of social or political values. Science laws never change in other countries, the significance of science…
6	You can compare your own research to the research presented by the external sources and then provide that in your own literature	you are also helping others (other scientists, researchers, students, etc.) have the chance to compare their research to yours.	realizing that the trends and data that you collect from your experiment is important and that they open our eyes to hidden patterns that we may not notice in our everyday lives… Anything	Science reflects social and political values, philosophical assumptions and intellectual norms of the culture in which it is practiced.		a large amount of what we know as science today was derived from philosophers like Aristotle and Socrates (Socratic method).

			that affects your data like errors and stuff.			
8	To see how other people set up the experiment or what materials they used	to compare data	statistics that are valuable to the experiment and conclusion		Science is universal transcending national and cultural boundaries and is not affected by the social and political values of the culture in which it is practiced.	scientific facts cannot change based on a person's culture or beliefs
9	You have a schematic to look at during your experimentation	having other conclusions gives you a comparison that reinforces your conclusions or bring about questions	the importance and validity of your information. Where you gathered your information as well as how	Science reflects social and political values, philosophical assumptions and intellectual norms of the culture in which it is practiced.		your environment greatly affects your actions as well as what your release into it.

APPENDIX D

FALL 2017 CONTROL SURVEY RESPONSES

#	In your own words, explain why citing external references might aid you in the (1) process of experimentation	and (2) drawing conclusions.	In your own words, describe what is statistical significance? What factors affect whether data gathered has statistical significance?	Science reflects social and political values, philosophical assumptions and intellectual norms of the culture in which it is practiced.	Science is universal transcending national and cultural boundaries and is not affected by the social and political values of the culture in which it is practiced.	Explain why you chose to agree with one of the statements above over the other. If you agree with neither statement explain why.
Control Group Responses						
11	might aid in the process of experimentation as a referral to check the work you are stating	aid by providing a reference as "proof" to what you are describing or stating	importance of showing demographics as a mean to provide assort of data to hat experiment is taking place. Factors affecting data having significance are populations, surveys, results.		Science is universal transcending national and cultural boundaries and is not affected by the social and political values of the culture in which it is practiced.	I agree with the second statement, as science should be constant as much as possible without cultural interference.
12	being able to read the experiments of outside sources might help me understand better in what direction to take my own experiment	would be beneficial in comparing my conclusions to outside sources	whether or not your results are consistent with known statistics. Errors in your experiment would affect the statistical significant of data.	Science reflects social and political values, philosophical assumptions and intellectual norms of the culture in which it is practiced.		I believe science has a huge influence over society
13	help keep you on track	make sure your data is as correct as possible	the ability of the data to give a set conclusion, factors such as bias affect statistical significance because if data isn't controlled it isn't significant enough to get a conclusion		Science is universal transcending national and cultural boundaries and is not affected by the social and political values of the culture in	science has nothing to do with social/political values but the way science is used can be affected by social and political groups

					which it is practiced.	
14	I am able to replicate the way it has been done before yielding similar results.	I am able to replicate the data and conclusions found in order to ensure that this study or experiment yields the same results	what is achieved when comparing two figures (one from a previous experiment and one from the one just obtained). Data includes human errors, different testing settings and procedure	Science reflects social and political values, philosophical assumptions and intellectual norms of the culture in which it is practiced.		I agree with the first statement more because science is always changing, what with the new studies always seeming to come out with data (I recently found out that power poses and smiling to feel happier have been statistically proven, they've never been replicated) science is looked at as fact ... but we are kidding ourselves if we don't think that sociocultural factors play an important role
15	shows what experiments were done prior to yours, shows past mistakes and ways to improve, can give you insight you may not have thought of	ties together previous research, can base some of your findings on that knowledge, compare differences, use info from past experiments	whether or not the data is sufficient enough to actually hold weight, sample size, errors, etc.			it depends on what facet of science. I feel one more separated from feelings and based on facts, while social sciences obviously have to deal w/ social aspects
16	it can show you different methods for doing the experiment, and also it can help	you can find information you didn't have	how accurate your results are	Science reflects social and political values, philosophica		science always reflects the social values of a culture. The practice that occur can

	you understand the reason	before and it adds to the credibility of your paper		l assumptions and intellectual norms of the culture in which it is practiced.		show what that society values and believes in.
17	allow you to observe the mistakes of others and not make them yourself	show you what your results should be and give you a goal to work towards	any set of data that falls within two standard deviations of the average		Science is universal transcending national and cultural boundaries and is not affected by the social and political values of the culture in which it is practiced.	science is universal, by following a set of rules not dependent upon culture or language one is able to draw the same conclusion as other individuals who have done the same experiment. Though science can be used to meet the needs of society, science itself exists independent and on its own
18	it will help you come up with different ways to conduct the experiment	it can help with comparing and contrastin g conclusion s	its why the statistics back up something so much that we can conclude that it is different. A factor that could affect it is if it's accurate	Science reflects social and political values, philosophica l assumptions and intellectual norms of the culture in which it is practiced.		In a way, I agree with both, but I agree with the first statement because, for example, there is still debate between science and religion if we should use stem cells or not
19	it will influence conclusion	it supports comment knowledg e	something that basically hold weight or leverage. Some factors include pull variety and basically just influence	Science reflects social and political values, philosophica l assumptions and intellectual		science always evolve and prioritize things as society evolve

				norms of the culture in which it is practiced.		
20	improves the extent of validness and to get a better understanding of what is experimenting and its true results	the source gives you an idea of what is expected, so from the sourced and end of experiment, you can draw conclusions of what happened, what was supposed to happen and improvements you can make to get the desired result	includes your analyzed data which allows to make conclusions of the experiment, this can be altered if there are not enough data points that can be true for all values of that variable	Science reflects social and political values, philosophical assumptions and intellectual norms of the culture in which it is practiced.		I agree with the first statement over the second statement. I truly believe that science is practiced by individuals in their own way. Their specific social and political values vary with their philosophical and the way science is practiced. Specific ways of experimenting can clash between people with different views, be it social or political. Though there are other factors that science reflects on, the first statement is truer than the second.
22	help us see how similar experiments were conducted and how we may be able to get the desired results	to be able to draw parallels between our results and the results of others to test the accuracy	whether or not an experiment or study is applicable to the population, bias and the conditions of the environment affect statistical significance		Science is universal transcending national and cultural boundaries and is not affected by the social and political values of the culture in which it is practiced.	science is based on fact and what we have found through experimentation - politics have nothing to do with it.
25	it may aid you in further	can draw better	when the data reflects that there	Science reflects		throughout history science

	understanding what it is you're doing in the experiment, rather than blindly following	conclusions based on	is a deviation large enough to imply that there is significance the difference of what we are testing. Whether the data is varied, where the data deviates from norm, these are possible factors that affect data significance	social and political values, philosophical assumptions and intellectual norms of the culture in which it is practiced.		is closely related to politics and social values, while science is usually right whether or not people believe it. Throughout history people have chosen what to believe, what is considered true based on their political and social belief, and the funding and development of science is also closely related to the politics and social aspects of a time period and the people
28	so, others can know what information you know and why you did the experiment in that specific way	you can compare your conclusion to the other studies you have referenced	a change that actually has an impact depending on what kind of data, factors that can cause statistical significance are having impurities, not following steps exactly the same was as before, small mistakes such as rushing	Science is universal transcending national and cultural boundaries and is not affected by the social and political values of the culture in which it is practiced.		science is a fact that has been proven and has nothing to do with a person's personal identity
29	help reader to know I've done proper research by listing sources that I got information. Also gives credit to other researchers	shows that I've done proper research and got more or new knowledge from these sources	quality or number that you would expect to find for an entire population. Factors that affect whether data gathered has statistical significance, values, error			I agree with both statement because science is study that get new information from each research, while social values or norms are what people

						first touched and realized and then learned from it. However, from these social norms or philosophical assumptions... science was born from the curiousness of human
30	it expands my knowledge	it speeds up conclusion processes	means you are sure that statistic is reliable. Resources such as experimental objects affect		Science is universal transcending national and cultural boundaries and is not affected by the social and political values of the culture in which it is practiced.	because science should rely solely on experiments and data and not what society or people believe as science
31	shows how to perform the experiment with a basic knowledge so that it can be modified for a real-life situation	other conclusions and experiments can guide your experiment and help support a same clause	when the data shows enough difference to support a hypothesis. The number of trials and accuracy of the experiment affect, where the data is statistically significant	Science reflects social and political values, philosophical assumptions and intellectual norms of the culture in which it is practiced.		why certain questions are asked or how these questions are answered are based on social and political views, where science proves things in our world, the curiosity to prove or disprove something comes from social views

APPENDIX E

FALL 2017 EXAM RESPONSES

Dr. Rogers General Chemistry First Semester Exam 1: Percent of Correct Responses				
Question Number	Experimental Group (ACT)	Control Group	Standard Error	Z-Score
1	70.00%	56.52%	0.13	1.0420
2	80.00%	60.87%	0.15	1.2840
3	90.00%	73.91%	0.14	1.1559
4	70.00%	69.57%	0.02	0.1745
5	80.00%	73.91%	0.09	0.6721
6	100.00%	78.26%	0.16	1.3914
7	80.00%	82.61%	0.06	0.4321
8	70.00%	91.30%	0.16	1.3736
9	60.00%	69.57%	0.11	0.8586
10	70.00%	91.30%	0.16	1.3736
11	100.00%	86.96%	0.13	1.0225
12	90.00%	73.91%	0.14	1.1559
13	60.00%	69.57%	0.11	0.8586
14	70.00%	78.26%	0.10	0.7922
15	80.00%	86.96%	0.10	0.7219
16	50.00%	78.26%	0.17	1.6570
17	70.00%	65.22%	0.08	0.5917
18	80.00%	78.26%	0.05	0.3512
19	80.00%	91.30%	0.12	0.9425
20	80.00%	86.96%	0.10	0.7219
Average	76.50%	77.17%	TTEST: P-value	
Standard Deviation	12.68%	10.16%	0.8539	

Dr. Rogers General Chemistry First Semester Exam 2: Percent of Correct Responses				
Question Number	Experimental Group (ACT)	Control Group	Standard Error	Z-Score
1	60.00%	69.57%	0.11	0.8586
2	90.00%	91.30%	0.04	0.3035
3	70.00%	82.61%	0.13	1.0028
4	100.00%	86.96%	0.13	1.0225
5	80.00%	82.61%	0.06	0.4321
6	30.00%	47.83%	0.14	1.2296
7	70.00%	73.91%	0.07	0.5328
8	80.00%	56.52%	0.16	1.4623
9	60.00%	56.52%	0.07	0.5012
10	80.00%	73.91%	0.09	0.6721
11	80.00%	91.30%	0.12	0.9425
12	90.00%	100.00%	0.11	0.8800
13	70.00%	65.22%	0.08	0.5917
14	60.00%	26.09%	0.18	1.8912
15	70.00%	65.22%	0.08	0.5917
16	90.00%	91.30%	0.04	0.3035
17	60.00%	73.91%	0.13	1.0613

18	70.00%	95.65%	0.17	1.5507
19	80.00%	86.96%	0.10	0.7219
20	80.00%	82.61%	0.06	0.4321
Average	73.50%	75.00%	TTEST: P-value	
Standard Deviation	15.31%	18.28%	0.7800	

Dr. Rogers General Chemistry First Semester Exam 3: Percent of Correct Responses

Question Number	Experimental Group (ACT)	Control Group	Standard Error	Z-Score
1	60.00%	52.17%	0.10	0.7693
2	40.00%	60.87%	0.15	1.3558
3	40.00%	52.17%	0.12	0.9829
4	30.00%	39.13%	0.11	0.8368
5	50.00%	60.87%	0.12	0.9219
6	90.00%	86.96%	0.07	0.4677
7	60.00%	65.22%	0.08	0.6194
8	100.00%	82.61%	0.14	1.2113
9	60.00%	69.57%	0.11	0.8586
10	70.00%	78.26%	0.10	0.7922
11	70.00%	73.91%	0.07	0.5328
12	50.00%	39.13%	0.12	0.9219
13	80.00%	60.87%	0.15	1.2840
14	90.00%	69.57%	0.15	1.3379
15	60.00%	91.30%	0.18	1.7822
16	70.00%	95.65%	0.17	1.5507
17	80.00%	73.91%	0.09	0.6721
18	80.00%	65.22%	0.13	1.0996
19	60.00%	65.22%	0.08	0.6194
20	70.00%	56.52%	0.13	1.0420
21	30.00%	56.52%	0.17	1.5861
22	90.00%	78.26%	0.12	0.9628
23	70.00%	52.17%	0.14	1.2296
24	70.00%	73.91%	0.07	0.5328
25	50.00%	60.87%	0.12	0.9219
Average	73.50%	75.00%	TTEST: P-value	
Standard Deviation	15.31%	18.28%	0.7813	

Dr. Rogers General Chemistry First Semester Exam 4: Percent of Correct Responses

Question Number	Experimental Group (ACT)	Control Group	STD.ERROR	Z-SCORE
1	90.00%	91.30%	0.04	0.3035
2	60.00%	60.87%	0.04	0.2473
3	50.00%	69.57%	0.15	1.3020
4	60.00%	78.26%	0.15	1.2478
5	70.00%	73.91%	0.07	0.5328
6	90.00%	91.30%	0.04	0.3035

7	90.00%	82.61%	0.10	0.7458
8	80.00%	69.57%	0.12	0.9011
9	80.00%	56.52%	0.16	1.4623
10	50.00%	56.52%	0.09	0.6973
11	60.00%	78.26%	0.15	1.2478
12	70.00%	65.22%	0.08	0.5917
13	80.00%	100.00%	0.15	1.3200
14	80.00%	78.26%	0.05	0.3512
15	60.00%	69.57%	0.11	0.8586
16	70.00%	65.22%	0.08	0.5917
17	50.00%	60.87%	0.12	0.9219
18	80.00%	82.61%	0.06	0.4321
19	80.00%	69.57%	0.12	0.9011
20	80.00%	86.96%	0.10	0.7219
21	80.00%	73.91%	0.09	0.6721
22	60.00%	65.22%	0.08	0.6194
23	70.00%	73.91%	0.07	0.5328
24	70.00%	95.65%	0.17	1.5507
25	90.00%	69.57%	0.15	1.3379
Average	64.80%	66.43%	TTEST: P-value	
Standard Deviation	12.91%	11.89%	0.5890	

Dr. Rogers General Chemistry First Semester Final Exam: Percent of Correct Responses

Question Number	Experimental Group (ACT)	Control Group	STD.ERROR	Z-SCORE
1	80.00%	69.57%	0.12	0.9011
2	70.00%	65.22%	0.08	0.5917
3	70.00%	65.22%	0.08	0.5917
4	80.00%	82.61%	0.06	0.4321
5	80.00%	78.26%	0.05	0.3512
6	80.00%	52.17%	0.17	1.6392
7	80.00%	65.22%	0.13	1.0996
8	40.00%	52.17%	0.12	0.9829
9	60.00%	52.17%	0.10	0.7693
10	70.00%	78.26%	0.10	0.7922
11	80.00%	69.57%	0.12	0.9011
12	80.00%	60.87%	0.15	1.2840
13	90.00%	82.61%	0.10	0.7458
14	60.00%	52.17%	0.10	0.7693
15	80.00%	52.17%	0.17	1.6392
16	80.00%	52.17%	0.17	1.6392
17	60.00%	60.87%	0.04	0.2473

18	70.00%	60.87%	0.11	0.8368
19	50.00%	47.83%	0.06	0.3936
20	70.00%	69.57%	0.02	0.1745
21	60.00%	65.22%	0.08	0.6194
22	40.00%	56.52%	0.14	1.1745
23	70.00%	43.48%	0.17	1.5861
24	60.00%	56.52%	0.07	0.5012
25	80.00%	52.17%	0.17	1.6392
26	80.00%	78.26%	0.05	0.3512
27	80.00%	69.57%	0.12	0.9011
28	40.00%	56.52%	0.14	1.1745
29	20.00%	17.39%	0.06	0.4321
30	70.00%	69.57%	0.02	0.1745
31	40.00%	60.87%	0.15	1.3558
32	80.00%	60.87%	0.15	1.2840
33	70.00%	65.22%	0.08	0.5917
34	80.00%	65.22%	0.13	1.0996
35	80.00%	65.22%	0.13	1.0996
36	30.00%	52.17%	0.16	1.4092
37	30.00%	43.48%	0.13	1.0420
38	50.00%	39.13%	0.12	0.9219
39	70.00%	52.17%	0.14	1.2296
40	60.00%	56.52%	0.07	0.5012
41	60.00%	43.48%	0.14	1.1745
42	70.00%	73.91%	0.07	0.5328
43	70.00%	56.52%	0.13	1.0420
44	70.00%	56.52%	0.13	1.0420
45	80.00%	69.57%	0.12	0.9011
46	80.00%	65.22%	0.13	1.0996
47	60.00%	52.17%	0.10	0.7693
48	70.00%	65.22%	0.08	0.5917
49	70.00%	56.52%	0.13	1.0420
50	40.00%	65.22%	0.16	1.5331
Average	65.80%	60.00%	TTEST: P-value	
Standard Deviation	16.30%	11.92%	0.0452	

APPENDIX F

SECTION COMPARISONS CHEM 1441 and CHEM 1341

	2162	2162	2178	2178
Semester	2016	2016	2017	2017
	Spring	Spring	Fall	Fall
Class	1441-001	1441-002	1341-001	1441-001
A	29	35	3	6
	20.28%	26.52%	30.00%	22.22%
B	45	39	3	8
	31.47%	29.55%	30.00%	29.63%
C	27	28	2	6
	18.88%	21.21%	20.00%	22.22%
D	13	12	0	2
	9.09%	9.09%	0.00%	7.41%
F	10	9	1	3
	6.99%	6.82%	10.00%	11.11%
W	19	8	1	2
	13.29%	6.06%	10.00%	7.41%
I		1		
		0.76%		
Total Students	143	132	10	27
Students who didn't drop	124	123	9	25
Total # ABC	101	103	8	20
%ABC	70.63%	78.03%	80.00%	74.07%
Total # DFW	42	29	2	7
% DFW	29.37%	21.97%	20.00%	25.93%
% DF, not counting W	18.55%	17.07%	11.11%	20.00%
Final Exam ***Avg.***	73.46	72.91	73.33	73.22
Lowest A	88.58	89.34	86.34	90.96
Highest B	88.45	88.22	81.54	87.40
Lowest B	79.33	79.31	74.62	79.39
Highest C	79.17	78.77	71.89	78.82
Lowest C	69.77	68.35	61.61	75.19
Highest D	67.57	67.62		68.22
Lowest D	60.50	58.20		64.97
Highest F	57.67	57.99	42.92	58.23

REFERENCES

1. Foss, F. W., O'Brien, A. M., & Schug, K. A. (2017). *IRB Protocol 2017-0853*. University of Texas at Arlington. Inclusion of Research Methods and Problem-/Inquiry-Based Learning in General Chemistry Laboratory 1, a Gateway STEM Course.
2. Schug, K. A., & Foss, F. W., Jr. (n.d.). Advanced Chemical Technologies (ACT) Yearly Plan.
3. Foss, F. W., (n. d.) 3. Course #2 and #3: ACT-Transforming Chemistry and Biochemistry Education at UTA.
4. B.S. in Chemistry Road Map. Undergraduate Catalog (2017-2018). University of Texas at Arlington.
5. Cleaver, B., University of Texas at Arlington. (2017). Chemistry 1441 Laboratory Syllabus.
6. Cleaver, B., University of Texas at Arlington. (2017). Chemistry 1442 Laboratory Syllabus.
7. Foss, F. W., University of Texas at Arlington. (2017). Organic Chemistry 1 Syllabus.
8. Foss, F.W., University of Texas at Arlington. (2017). Organic Chemistry 2 Syllabus.
9. Schug, K.A., University of Texas at Arlington. (2017). CHEM 4461/5461 Instrumental Analysis (Spring 2017) Lecture Course Syllabus.
10. Lovely, C., University of Texas at Arlington. (2017). Chemistry 4346 – Advanced Synthesis.

11. Crawford Science. (n.d.) Theory and Instrumentation to GC. Retrieved March 22, 2018, from https://www.chromacademy.com/
12. Crawford Science. Instrumentation of HPLC - Detectors. Retrieved March 22, 2018 from https://www.chromacademy.com/
13. Khan Academy. (2018). Buffer capacity. Retrieved March 22, 2018, from https://www.khanacademy.org/science/chemistry/acid-base-equilibrium/buffer-solutions/v/buffer-capacity
14. Khan Academy. (2018). Titration questions. Retrieved March 22, 2018, from https://www.khanacademy.org/test-prep/mcat/chemical-processes/titrations-and-solubility-equilibria/e/titration-questions
15. Crash Course. (2013, April 22). Redox Reactions: Crash Course Chemistry #10. Retrieved March 22, 2018, from https://www.youtube.com/watch?v=lQ6FBA1HM3s
16. Discovery Communications LLC. (2018). Ewok Log Smash - MythBusters | Discovery. Retrieved March 29, 2018, from https://www.discovery.com/tv-shows/mythbusters/videos/ewok-log-smash
17. O'Brien, A. M., Martin, M. S., Thapa, P., Schug, K. A., & Foss, F. W. (2017). Instrumentation Use in Teaching Undergraduate Chemistry: Method Design for the Oxidation of Alcohols into Ketones on the Gas Chromatograph Mass Spectrometer. Unpublished manuscript, University of Texas at Arlington.
18. Martin, M. S., & O'Brien, A. M. (2017). Procedure for Monitoring Derivatized Amino Acids Using LC-UV-MS (Standard Operating Procedure). Unpublished manuscript, University of Texas at Arlington.

19. Martin, M. S., O'Brien, A. M., Thapa, P., Foss, F. W., & Schug, K. A. (2017). Thermal Characterization of Polymers using Differential Scanning Calorimetry and Thermogravimetric Analysis. Unpublished manuscript, University of Texas at Arlington.

20. Collaborate UTA: Quality Enhancement Plan. (2017). *COLLABORATE UTA: Assessing and Enhancing Teamwork Through Professional Learning Communities*. University of Texas at Arlington.

BIOGRAPHICAL INFORMATION

Ariel O'Brien was born in Tucson, Arizona, but she grew up in Saginaw, Texas. In 2014, she received an Honors Distinction Scholarship from the Honors College to attend the University of Texas at Arlington, where she graduated with an Honors Bachelor of Arts in Chemistry in 2018. During her first three semesters, Ariel participated in the ASSURE research program for freshman biology and chemistry majors, discovering new drugs from marine species. Then, in summer 2015, Ariel participated in the Louis Stokes Alliance for Minority Participation (LSAMP), working under the supervision of Dr. Sven Kroener at the University of Texas at Dallas on "The effects of ACAMP on alcohol consumption and attentional set-shifting in a mouse model." In spring 2016, Ariel joined Dr. Morteza Khaledi's lab group, discovering "fluoroalcohol-induced coacervates for selective enrichment and extraction of hydrophobic proteins," work which eventually led to a publication in the *Journal of Chromatography B* in 2018. Finally, in 2017, Ariel joined the UTeach Program, where she received the National Science Foundation Robert E. Noyce Scholarship. Shortly thereafter, she began working with Dr. Frank Foss and Dr. Kevin Schug analyzing the effectiveness of the pilot Advanced Chemical Technologies (ACT) program: changing the way we teach general and organic chemistry labs. The results of her research are described herein.