Comparison of Student Success using "Atoms First" Versus "Traditional" Curricula

Christina Sweeney Hillesheim

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Comparison of student success using “atoms first” versus “traditional” curricula

By
Christina S. Hillesheim

A Dissertation
Submitted to the Faculty of
Mississippi State University
in Partial Fulfillment of the Requirements
for the Degree of Doctor of Philosophy
in Curriculum and Instruction
in the Department of Curriculum, Instruction, and Special Education

Mississippi State, Mississippi
August 2016
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Christina S. Hillesheim

2016
Comparison of student success using “atoms first” versus “traditional” curricula

By

Christina S. Hillesheim

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The purpose of this study was to investigate the difference between the “atoms first” and the “traditional” curricula. Specifically focusing on which curriculum better aligns to curricular expectations, leads to higher student success when students are grouped together, and when students are differentiated based on several factors. The main difference between the two approaches being the sequence of topics presented in the first semester general chemistry course. This study involves more than 9,500 general chemistry I and II students over 7 semesters with about half of them being taught using the “atoms first” approach. Student success was measured using the American Chemical Society’s (ACS) final examination scores and the final letter grades. Alignment to curricular expectations was determined via a qualitative review of textbooks written for each of the approaches. This showed that the “atoms first” approach better aligns to research supported best practices. An analysis of covariance (ANCOVA) was performed to determine if there is a significant difference between the “atoms first” and the “traditional” curricula. The “traditional” approach was found to lead to higher student achievement for both measures of student success in both chemistry I and II courses.
Lastly, multiple linear, multinomial logistic, and binary logistic regressions were run using all of the subgroups – gender, race/ethnicity, major, ACT composite, math ACT, overall GPA, and classroom size – as predictor variables to determine if any significant interactions between the curricular methods and the different subgroups existed. Results found that the relationship between gender, GPA, and classroom size groupings significantly impact student achievement in general chemistry. Specifically, the “traditional” approach lead to higher student success compared to the “atoms first” approach for males, females, below average GPA students, above average GPA students, and students in large classroom settings. However, there are several factors – final examination content, new teacher impact, teacher’s view of science, and withdrawal rate and timing – that need to be taken into account when implementing these findings. Overall, the results of this study provides a cautionary reminder of the many impacts affecting curriculum implementation and the importance of professional development and training during a curriculum transitional period.
DEDICATION

This dissertation is dedicated to the very supportive people that have blessed my life. To my mother, Yvonne, you have made all of this possible. You always encouraged me to figure out the answers to my questions. I cannot thank you enough for the guidance, patience, and love that you have bestowed upon me my entire life.

To my husband, Patrick, thank you for encouraging me to go back to graduate school to earn my doctoral degree. You always kept a smile on my face through the ups and downs of this journey and for reminding me of the big picture.

But most importantly, thank you to God for giving me the abilities, knowledge, and stubbornness to finish this journey. This was only possible because of your love, support, and constant reminder that this is the path you want me to follow.
ACKNOWLEDGEMENTS

I would like to acknowledge my research advisor, Dr. Ryan Walker, for his guidance and mentorship. Dr. Walker, you were always there to encourage and support me when I needed it. You guided me on the path of blending the science world with the education world. I also want to thank you for fueling my passion for informal science education and for supporting all my diverse interests.

I would also like to thank Henry Valle, Gabe Posadas, and J.J. Keith who have always made themselves available for academic discussion and supported me throughout the analysis and writing process.

Lastly, I would like to thank Dr. Parisi, Dr. Moser, Dr. Ivy, Dr. Frank, and Dr. Sepehrifar for being part of my doctoral committee and for their input.
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There are two predominant approaches in teaching general chemistry in a collegiate setting known as the “traditional” approach and the “atoms first” approach. These two approaches have various similarities and differences. The differences include the order of topics covered, the inclusion of nature and history of science, and their relation to a corresponding laboratory course; whereas, the similarities are the specific topics themselves that are covered and the depth of these topics.

The “atoms first” content arrangement was developed by several publishers in an attempt to address the fragmented presentation of material found by the Task Force on General Chemistry Curriculum (Lloyd & Spencer, 1994). A survey was conducted of 114 colleges and universities with the conclusion being that the general chemistry curricula attempts to cover too many topics. Trying to cover a profuse amount of material leaves the student with surface-level comprehension or even incorrect interpretations of material (Lloyd & Spencer, 1994; Talanquer & Pollard, 2010). Thus, the “atoms first” curriculum was created to combat this fragmented and disjointed fashion of content presentation.

The “atoms first” approach differs from the “traditional” approach in that “atoms first” focuses on developing an understanding of chemistry based on the properties and interaction of atoms and molecules, whereas the “traditional” approach starts with macroscopic observations and deducing atomic properties from them (Esterling &
Bartles, 2013). The students are exposed to the structure of an atom prior to progressing to bonding or phase changes. The primary difference between the two approaches is the order in which the topics are presented in a textbook. Table 1 shows a comparison of the chapters from a “traditional” textbook and an “atoms first” textbook for the first semester of general chemistry (Burdge, 2014; Burdge & Overby, 2012). The topics covered are the same for the two approaches; however, the order of the topics are very different (as seen in Table 2). As for the second semester of general chemistry, the topics covered do not change between the two approaches. Table 3 shows that there is a little difference in the ordering of topics for second semester general chemistry, but that depends on the author of the textbook. The differences that do occur are very minor and do not appear to be two different approaches.
Table 1

*First semester chapter titles for the “atoms first” and the “traditional” approaches*

<table>
<thead>
<tr>
<th>Chapter</th>
<th>“Atoms First” Approach</th>
<th>AF Code</th>
<th>“Traditional” Approach</th>
<th>Trad Code</th>
</tr>
</thead>
<tbody>
<tr>
<td>1</td>
<td>Chemistry: The Science of Change</td>
<td>A</td>
<td>Chemistry: The Central Science</td>
<td>A</td>
</tr>
<tr>
<td>2</td>
<td>Atoms and the Periodic Table</td>
<td>B.1</td>
<td>Atoms, Molecules, and Ions</td>
<td>B.1</td>
</tr>
<tr>
<td></td>
<td></td>
<td>B.2</td>
<td></td>
<td>E</td>
</tr>
<tr>
<td>3</td>
<td>Quantum Theory and the Electronic Structure of Atoms</td>
<td>C</td>
<td>Stoichiometry: Ratios of Combination</td>
<td>B.2</td>
</tr>
<tr>
<td></td>
<td></td>
<td></td>
<td></td>
<td>H</td>
</tr>
<tr>
<td>4</td>
<td>Periodic Trends of the Elements</td>
<td>D</td>
<td>Reactions in Aqueous Solutions</td>
<td>I</td>
</tr>
<tr>
<td>5</td>
<td>Ionic and Covalent Compounds</td>
<td>E</td>
<td>Thermochemistry</td>
<td>J</td>
</tr>
<tr>
<td>6</td>
<td>Representing Molecules</td>
<td>F</td>
<td>Quantum Theory and the Electronic Structure of Atoms</td>
<td>C</td>
</tr>
<tr>
<td>7</td>
<td>Molecular Geometry and Bonding Theories</td>
<td>G</td>
<td>Electronic Configuration and the Periodic Table</td>
<td>D</td>
</tr>
<tr>
<td>8</td>
<td>Chemical Reactions</td>
<td>H</td>
<td>Chemical Bonding I: Basic Concepts</td>
<td>F</td>
</tr>
<tr>
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<td>I</td>
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<td>G</td>
</tr>
<tr>
<td>10</td>
<td>Energy Changes in Chemical Reactions</td>
<td>J</td>
<td>Gases</td>
<td>K</td>
</tr>
<tr>
<td>11</td>
<td>Gases</td>
<td>K</td>
<td>Intermolecular Forces and the Physical Properties of Liquids and Solids</td>
<td>L</td>
</tr>
</tbody>
</table>

(Burde, 2014; Burdge & Overby, 2012)
Table 2

First semester chapter topic comparisons labels

<table>
<thead>
<tr>
<th>Topic Label</th>
<th>Topic Title</th>
</tr>
</thead>
<tbody>
<tr>
<td>A</td>
<td>Classification and Properties of Matter, &amp; Scientific Measurement</td>
</tr>
<tr>
<td>B.1</td>
<td>Atomic Structure, Atomic Number, Isotopes, &amp; Average Atomic Mass</td>
</tr>
<tr>
<td>B.2</td>
<td>Mole and Molar Mass</td>
</tr>
<tr>
<td>C</td>
<td>Wave Properties of Matter, Atomic Orbitals, &amp; Electron Configuration</td>
</tr>
<tr>
<td>D</td>
<td>Development of Periodic Table, Effective Nuclear Charge, &amp; Trends</td>
</tr>
<tr>
<td>E</td>
<td>Ions and Ionic Compounds – Formulas and Naming</td>
</tr>
<tr>
<td>F</td>
<td>Lewis Structures, Resonance, &amp; Octet Rule Exceptions</td>
</tr>
<tr>
<td>G</td>
<td>Geometry, Polarity, Hybridization, &amp; Orbital Theory</td>
</tr>
<tr>
<td>H</td>
<td>Chemical Equations, Combustion Analysis, &amp; Limiting Reactants</td>
</tr>
<tr>
<td>I</td>
<td>Precipitation, Acid-Base, &amp; Oxidation-Reduction Reactions</td>
</tr>
<tr>
<td>J</td>
<td>Enthalpy, Calorimetry, &amp; Hess’s Law</td>
</tr>
<tr>
<td>K</td>
<td>Properties, Kinetic Molecular Theory, Ideal Gas Law, &amp; Gas Mixtures</td>
</tr>
<tr>
<td>L</td>
<td><em>Chapter at end of the traditional approach, but usually not covered</em></td>
</tr>
</tbody>
</table>

(Burdge, 2014; Burdge & Overby, 2012)
Table 3

Second semester chapter titles for the “atoms first” and the “traditional” approaches

<table>
<thead>
<tr>
<th>Chapter</th>
<th>“Atoms First” Approach</th>
<th>AF Code</th>
<th>“Traditional” Approach</th>
<th>Trad Code</th>
</tr>
</thead>
<tbody>
<tr>
<td>12</td>
<td>Intermolecular Forces and the Physical Properties of Liquids and Solids</td>
<td>A</td>
<td>Modern Materials</td>
<td>N</td>
</tr>
<tr>
<td>13</td>
<td>Physical Properties of Solutions</td>
<td>B</td>
<td>Physical Properties of Solutions</td>
<td>B</td>
</tr>
<tr>
<td>14</td>
<td>Chemical Kinetics</td>
<td>C</td>
<td>Chemical Kinetics</td>
<td>C</td>
</tr>
<tr>
<td>15</td>
<td>Chemical Equilibrium</td>
<td>D</td>
<td>Chemical Equilibrium</td>
<td>D</td>
</tr>
<tr>
<td>16</td>
<td>Acids and Bases</td>
<td>E</td>
<td>Acids and Bases</td>
<td>E</td>
</tr>
<tr>
<td>17</td>
<td>Acid-Base Equilibria and Solubility Equilibria</td>
<td>F</td>
<td>Acid-Base Equilibria and Solubility Equilibria</td>
<td>F</td>
</tr>
<tr>
<td>18</td>
<td>Entropy, Free Energy, and Equilibrium</td>
<td>G</td>
<td>Entropy, Free Energy, and Equilibrium</td>
<td>G</td>
</tr>
<tr>
<td>19</td>
<td>Electrochemistry</td>
<td>H</td>
<td>Electrochemistry</td>
<td>H</td>
</tr>
<tr>
<td>20</td>
<td>Nuclear Chemistry</td>
<td>I</td>
<td>Nuclear Chemistry</td>
<td>I</td>
</tr>
<tr>
<td>21</td>
<td>Metallurgy and the Chemistry of Metals</td>
<td>J</td>
<td>Environmental Chemistry</td>
<td>O</td>
</tr>
<tr>
<td>22</td>
<td>Coordination Chemistry</td>
<td>K</td>
<td>Coordination Chemistry</td>
<td>K</td>
</tr>
<tr>
<td>23</td>
<td>Nonmetallic Elements and Their Compounds</td>
<td>L</td>
<td>Metallurgy and the Chemistry of Metals</td>
<td>J</td>
</tr>
<tr>
<td>24</td>
<td>Organic Chemistry</td>
<td>M</td>
<td>Nonmetallic Elements and Their Compounds</td>
<td>L</td>
</tr>
<tr>
<td>25</td>
<td>Modern Materials</td>
<td>N</td>
<td>Organic Chemistry</td>
<td>M</td>
</tr>
</tbody>
</table>

(Burdge, 2014; Burdge & Overby, 2012)

According to Esterling and Bartles (2013), the “atoms first” approach has many proposed benefits such as introducing concepts in an order that is simpler for students to understand, whereas the “traditional” approach uses terms before explaining them in detail. Zumdahl and Zumdahl (2012) stated that the “atoms first” approach:
... should encourage the student to focus on conceptual learning early in the course, rather than rely on memorization and a “plug and chug” method of problem solving that even the best students can fall back on when confronted with familiar material. The “atoms first” organization provides an excellent opportunity for students to utilize the tools of critical thinkers: to ask questions, to apply rules and models and to evaluate outcomes. (p. ix)

This novel approach to the order of content or logical progression scaffolds information in a way to allow for learning with understanding. Teaching the content in this way could inadvertently support a more student centered learning environment. Furthermore, the “atoms first” approach moves away from focusing on the historical evolution of chemistry which often uses noncontemporary wording and is of little interest to students who have a modern atoms-based perception of science (Esterling & Bartles, 2013). An example of this disconnect can be illustrated by the use of laboratory terms which are no longer used because of recent advances in technology, equipment, and techniques.

Although the content presented in the lecture of the “atoms first” curriculum appears to be more student centered, this does not directly transfer to the laboratory setting. Since the “atoms first” curriculum focuses initially on fundamental atomic properties, the concurrent labs are unable to implement true hands-on experiments until later in the semester. Here, hands-on means that the students are actively engaged in scientific experiments that require chemicals and specific instruments and techniques. Thus, the “traditional” approach is better suited for courses that have a concurrent lab, since the “atoms first” approach allows for only a few directly related lab experiments at the beginning of the course (Esterling & Bartels, 2013; Zumdahl & Zumdahl, 2012). This
lack of hands-on activities in the beginning of the semester decreases the relevance of the laboratory experience reducing any activities/explorations/inquires to cookbook procedures that fail to reinforce the content delivered in the lecture. The beginning semester labs, if applied appropriately in the “atoms first” approach, are either theoretical or mathematics focused. For example, the students take mass and dimension related measurements of a zinc cylinder and then have to perform several mathematical calculations to determine the size of a zinc atom. The students are learning how to make basic measurements and use a digital scale, but the focus of the experiment is the mathematical calculations needed to convert from mass to the atom size. In comparison, an early lab in the “traditional” curriculum would be determining the limiting reagent of a reaction using stoichiometry via various chemical reactions. However, this lab is later in the “atoms first” approach given that this topic is not covered until later in the ordering of topics. Schools that are moving to the “atoms first” curriculum do several things to help counter the problems with concurrent labs, such as start lab sessions two weeks after schools has started instead of the typical one week delay, modify the “traditional” lab experiments to be more “atoms first” focused, or introduce new experiments that are more theoretical in nature. Mississippi State University, for example, has used all three techniques in implementing the “atoms first” curriculum into the concurrent laboratories.

Esterling and Bartels (2013) investigated the effects of an “atoms first” approach at the University of California in Riverside (UCR). The study examined the efficacy of the “atoms first” approach by contrasting students’ quarterly letter grades to the “traditional” approach. The work produced mixed results which showed that neither approach was more effective overall. The effectiveness depended on the on/off sequence
status of the course and how long the curriculum had been taught by the instructor. On/off sequence of a course refers to if a student takes the course during the usual semester. For example, students that are “on” sequence take general chemistry I during the fall and general chemistry II during the spring semester. Students that are “off” sequence take general chemistry I during the spring semester followed by the general chemistry II course. The researchers found that initially a lower fraction of students obtain passing grades in the first and second quarters of the general chemistry series. This effect is more than reversed for first-quarter students after one year of instruction experience with the “atoms first” curriculum, yet the decline is not reversed with the second quarter students. The authors suggest a deficiency in mathematical preparedness for the lack of increase for second quarter students. This preliminary work, however, did not examine students from a similar population as those at Mississippi State University, did not use an unbiased final comparison factor, and was limited in the variety of factors studied. More details of the Esterling and Bartles (2013) study and the differences between the two studies will be mentioned below.

This research will give insight into which of these two teaching approaches improves student success and understanding in a college general chemistry course. The results would impact chemistry education by providing quantitative data contrasting the advantages and disadvantages of each teaching approach. This could change the difficult and usually subjective decision of which approach to adopt into an objective and more scientific decision based on data. Overall, this study will give insight into a minimally explored research area in which only one previous study has been conducted. Additionally, this study will greatly impact the chemistry teaching community by
identifying the superior approach for teaching chemistry at the undergraduate level. By improving the delivery of chemistry content, students will understand chemistry and feel more confident in pursuing chemistry or science as a career, thus increasing and improving the scientific community. An increase in student understanding and motivation may lead to improved long term retention. The increase in long term retention of the material could impact student performance in later chemistry courses or other related science courses by allowing the students to make connections among various chemistry concepts and between chemistry and other science concepts.

**Statement of the Problem**

Without a detailed understanding of how these two approaches influence both chemistry teaching and student learning, experts in the field will continue to make curricular decisions based on their experience as a learner and instructor instead of using research supported best practices. Additionally, the lack of understanding and the compounding factors such as student demographics and poor mathematical preparedness bring to light the need for chemistry curricular research. It should be clear that the field of chemistry education needs to better understand how these factors interact with both the “traditional” and the “atoms first” approaches in order to improve students’ ability to learn chemistry in a meaningful way.

**Purpose of the Study**

The purpose of this study is to investigate the difference in student success between the “atoms first” and the “traditional” curricula. We will develop an understanding of how the ordering of the content could influence teaching methods
during the delivery of the chemistry approaches. And finally we will investigate if there is a difference in student success using the two curricular formats for other variables such as small versus large classroom setting, chemistry majors versus non-majors, gender, ethnicity/race, composite ACT score, math ACT subscore, and grade point average (GPA).

**Research Questions**

The goal of this proposal is to answer the following questions:

1. Does the “atoms first” curriculum better align to the curricular expectations established by research supported best practices?

2. Does the “atoms first” curriculum lead to higher student success compared to the “traditional” curriculum for all students when all other sub-factors are considered as covariates?

3. Does the “atoms first” curriculum lead to higher student success compared to the “traditional” curriculum when students are differentiated into each of the sub-factors? The sub-factors analyzed in this study are classroom setting size (large versus small), major (chemistry majors versus non-majors), gender, ethnicity/race, composite ACT score, math ACT subscore, and GPA.

**Statement of Hypothesis**

Esterling and Bartels’ (2013) preliminary work is limited to students from a distinct population significantly different than Mississippi State University. There are many differences, both geographical and demographical, between California and
Mississippi. California is the 3rd largest state in area and 1st in population, whereas Mississippi is 32nd in area and 31st in population. This difference in population is also seen in the location of the university, where Riverside is more urban than Starkville. Additionally, the states and corresponding cities are different in socioeconomic status, where the average household income for Riverside, CA is approximately double that for Starkville, MS. Additionally, this preliminary work did not use an unbiased final comparison factor such as standardized exam and did not investigate other important variables such as classroom size, major, gender, ethnicity/race, ACT, and GPA.

In the literature, there are no articles that investigate these subgroups for the two curricula being investigated in this research study. The several articles discussed in the literature review show the effect of these different subgroups on student achievement. This research will test the hypothesis that the “atoms first” approach is more effective in improving student success and understanding in a college general chemistry course. It will also test to determine if the “atoms first” approach is more successful for other categorical variables such as small versus large class room setting, chemistry majors versus non-majors, gender, ethnicity/race, composite ACT score, math ACT subscore, and GPA.

This study will not only determine if the “atoms first” curriculum is better for each subgroup, but the study will also provide more evidence regarding the effects of the subgroups on student achievement. This research will fill in the multiple identified gaps in the literature: 1) the effect on student achievement for the two curricula for all students combined; 2) research on the two general chemistry curricula and the various subgroups;
and 3) research focused specifically on college level general chemistry courses for those specific subgroups.

**Overview of Methodology**

The research will be a multiple year study where the classes will be taught using the “atoms first” approach and then analyzed against the data from previous years of teaching using the “traditional” approach. This is a basic, causal-comparative research study design in which the two groups will differ in only the curricular method and will be compared based on their final exam score and their final letter grade. SPSS 23 will be used to perform an analysis of covariance (ANCOVA) to determine if there is a significant difference between the “atoms first” and the “traditional” general chemistry curricula. Additionally, a multiple linear and logistic regression will be run using all of the subgroups (classroom size, major, gender/ethnicity, ACT, and GPA) as possible predictor variables to determine if there are any significant interactions between the curricular methods and the different subgroups (predictor variables).

**Assumptions**

There are a few assumptions that must be made to conduct this analysis. Making direct comparisons between semesters for a given instructor was not possible for all instructors, as instructors typically do not repeat a class sufficiently frequently. However, the comparison was made for those instructors that did repeat a course. Overall though, it was assumed that all instructors teach each curriculum equally well, and that there are no differences in instructional style across instructors relevant to student performance. This is similar to the no versions of treatment assumption required for causal comparison.
Secondly, it was assumed that all instructors assign letter grades in similar fashion, and that they all assign letter grades with equal rigor in the new and in the old curricula. Either assumption cannot be tested with the data available. However, the use of the final exam score, a standardized examination produced and verified by the American Chemical Society (ACS), and analyzing success in the subsequent class, general chemistry II, helps to limit these concerns.

**Limitations on Generalizability**

One possible limitation in interpreting the results of the study is the effect of changing from an existing curriculum to a new curriculum. Esterling and Bartels (2013) found that the change in curriculum caused an apparently lower student success rate in the first year, followed by significant improvement in the second year for both general chemistry courses. A second possible limitation is the lack of reliability information for the ACS final examination. This could mean that the exam is not providing reliable information for each of the sections per semester and for each of the semesters and years being analyzed and compared. This possible unreliability could mean that the difference in exam scores could be due to the exam itself and not the curricular method chosen.

**Delimitations**

This is a basic, causal-comparative research study design in which the two groups will differ in only the curricular method and will be compared based on their final exam score and their final letter grade. There is no manipulation involved in this research study. It was not possible to have one teacher teach a section using one approach and a second class using the other approach. A second limit is time in that it would be more beneficial
to study the two approaches over a longer span of time. This would give more time for
the instructors to get acquainted with the new “atoms first” approach.

**Definitions**

- **Composite ACT score** = measured on a scale from 1 to 36 with 1-point
  increments.

- **Ethnicity/Race** = Mississippi State University uses U.S. Census categories.
  Additionally, students self-report this information.

- **Grade point average** = measured on a continuous scale from 0 to 4.00.

- **Math ACT sub-score** = measured on a scale from 1 to 18 with 1-point
  increments.

- **Small versus large classroom setting** = In the college class setting and for
  this study small classes are defined as those containing approximately 70
  students and large classes contain 200 or more students.
CHAPTER II
LITERATURE REVIEW

This project will expand on the work of Esterling and Bartels’ (2013) to investigate the influence of the “atoms first” curriculum on student achievement. The research will control for the following factors: small versus large class room setting, chemistry majors versus non-majors, gender, ethnicity/race, composite ACT score, math ACT subscore, and GPA. These variables have been shown in previous studies to be of a significant impact on achievement (Carmichael, Bauer, Sevenair, Hunter, & Grambrell, 1986; Nordstrom, 1990; Rauschenberger & Sweeder, 2010; Steiner & Sullivan, 1984; Wright, Cotner, & Winkel, 2009; Wyss, Tai, & Sadler, 2007). By isolating these components of the study, the researcher will be able to identify the effects of the two curricula under investigation without the known effects of these components.

The theoretical framework for this project includes the essential elements of effective science instruction, sequential and spiraling learning theory, and curricular considerations. These topics provide a justification for science curricular research in showing the significance of curricular choice on science education and how differences in curriculum structure can impact student achievement and understanding. Following the theoretical framework, the researcher provides a detailed review of related research to frame the context of the project variables selected in regards to student achievement in an undergraduate general chemistry course.
Theoretical Framework

Essential Elements of Effective Science Instruction

There are three essential elements of effective science instruction: history/nature of science, content knowledge, and inquiry. A science educator will need to possess a mastery of all three areas to ensure that they are properly preparing their students for success in a scientific field. If embedded into the curriculum students will develop an understanding of these components through experiential learning, developing ownership of content, and the ability to perceive themselves as a scientist. This section describes the theoretical rational of each component through a detailed literature review followed by a summary of how the components should be represented in the curriculum.

History of Science (HOS) / Nature of Science (NOS). The phrase “history of science” (HOS) and “philosophy of science” (POS) have been used to describe the interplay of disciplines that inform science education about the character of science itself (Bacon, 1620). The “nature of science” (NOS), however, is a more encompassing phrase to describe the scientific enterprise for science education. The nature of science is a fertile, hybrid arena which blends aspects of various social studies of science including the history, sociology, and philosophy of science combined with research from the cognitive sciences such as psychology into a rich description of what science is, how it works, how scientists operate as a social group and how society itself both directs and reacts to scientific endeavors (McComas, Clough, & Almazroa, 1998).

For science educators the phrase “nature of science,” is used to describe the intersection of issues addressed by the philosophy, history, sociology, and psychology of science as they apply to and potentially impact science teaching and learning. As such,
the nature of science is a fundamental domain for guiding science educators in accurately portraying science to students.

The social studies of science should be included in science instruction training and professional development programs must specifically address misconceptions that both students and teachers hold regarding the nature of science. Driver et al., (1996) have suggested five additional arguments supporting the inclusion of the nature of science as a goal of science instruction. The arguments include the utilitarian view that “an understanding of the nature of science is necessary if people are to make sense of science and manage the technological objects and processes they encounter ...” (p. 16). People must understand the nature of science “to make sense of socio-scientific issues and participate in the decision-making process” (p. 18). This understanding will allow citizens to become active members of our democratic society. Additionally, people need to understand the nature of science “in order to appreciate science as a major element of contemporary culture” (p. 19). The fourth rationale is moral, to understand the “… norms of the scientific community, embodying moral commitments which are of general value,” (p. 19). Driver’s final justification for including the nature of science in science instruction is that it “supports successful learning of science content” (p. 20).

Metacognitive knowledge can support conceptual understanding in science. Progress in learning ideas about a topic is closely related to a student’s view of science and of how to best learn science. Students who value the scientific perspective and see science learning as something to which they can contribute are more successful at learning science content (Shapiro, 1989, 1994).
It is also important for teachers to have a firm understanding of the nature of science because teachers represent the most important variable in the classroom learning equation. Teachers have a large effect on what students understand and how they learn in the classroom. Even well designed NOS instructional packages that are at odds with the philosophical orientations of teachers may not be effective. Duschl (1987) writes that in spite of attempts to “teacher proof” schooling through the enforcement of strict curriculum guidelines and teaching models, teachers will continue to make the most critical decisions in the education of students. Regarding NOS instruction, Hodson (1988) argues that “the most important factors determining attitudes toward science are teaching style (Evans & Baker, 1977; Rubba, Horner & Smith, 1981) and the teacher’s own image of science” (Jungwirth, 1971). What this suggests for nature of science instruction is sobering given science teachers’ dismal understanding of the nature of science (Hodson, 1988). Hence, bolstering teachers’ understanding of NOS is clearly a prerequisite for effective science teaching.

**Content Knowledge.** Two events are impacting science teacher education: the release of the *Next Generation of Science Standards* (NGSS; Achieve, 2012) and the national focus on teacher quality (Darling-Hammond, Amerin-Beardsley, Haertel, & Rothstein, 2011). These two events are also important at the college level in that instructors need to adequately prepare students that are training to become science educators. These future teachers need to be taught science content at an appropriate depth and in a manner that increases their ability to later teach it to their students. Additionally, these two events necessitate science teachers to have sound content knowledge since they are required to meet these standards and are evaluated by student achievement scores.
Unfortunately, it is not clear what counts as sound science content knowledge, nor is there agreement about what constitutes content knowledge that can lead to sound instructional practice (Luft, Hill, Nixon, Campbell, & Dubois, 2015).

Teacher’s knowledge can be divided into three broad categories: pedagogical, curricular, and subject matter. The content of science for science teachers should focus on a discipline, and consist of domains and knowledge statements. According to Gardner (1972), disciplines are specialized areas of study that “span the alphabet from aerodynamics to zoology (p. 26),” while domains consist of the objects that are studied or explored, such as living things or elements. Knowledge, or as it is often referred to as subject-matter knowledge, is defined as what is produced by the discipline such as a “set of assertions or verifiable truth claims” (p. 27). Content knowledge interplays with the nature of science. Shulman (1986) writes:

Teachers must not only be capable of defining for students the accepted truths in a domain. They must also be able to explain why a particular proposition is deemed warranted, why it is worth knowing and how it related to other propositions, both within the discipline and without, both in theory and in practice. (p. 9)

Thus, content knowledge is an essential component of science instruction and must be constructed by the student through the guidance of a knowledgeable teacher.

Early studies of science teacher knowledge often involved an analysis of the college/university coursework taken by a teacher. Monk (1994) published one of the most important studies in this area. In his study, he found a significant and positive relationship between the number of courses teachers took in science and their students’ achievement in science. Yet, in a unique twist, he also found that a teacher with a background in
physical sciences had a larger impact on student performance in life science courses than in physical science courses (Monk, 1994). Even with this finding, it is generally accepted among policy makers and science teacher educators that science teachers need a sufficient background in the subject they will be teaching (Luft et al., 2015).

More recently, science education researchers have focused on the unique knowledge that teachers hold, which allows them to transform content knowledge into learning (Van Driel & Berry, 2010). This knowledge, pedagogical content knowledge (PCK), was initially described by Shulman (1986, 1987). PCK requires that teachers draw upon their content knowledge and adjust their teaching methods to meet the needs of their students. The initial work in science education in the area of PCK has been primarily descriptive in that most studies discuss science teachers’ PCK and how PCK changes in the midst of interventions, programs, or courses (Abell, 2007; Kind, 2009; Van Driel & Berry, 2010).

It is generally accepted that the science knowledge including PCK of a teacher is essential to his/her instruction. This is due to the premise that without content knowledge, a science teacher would have little to teach (Luft et al., 2015). The chemistry professors in the study bring to the table a robust depth of content knowledge to the subject area. With doctoral degrees in chemistry, they have a tremendous depth of knowledge, but this does not ensure that they have PCK or have had the significant opportunities to develop PCK for an introductory chemistry course. Requiring professors to rethink the scope and sequence of their course topics promotes metacognition and will help them develop PCK.

**Inquiry.** The focus of NOS is not about the natural world in the way that science itself is, but on how scientific knowledge is constructed (McComas at al., 1998). More
than 60% of the American populace effectively has no knowledge of how science works. These data come from the National Science Board as part of its Science and Engineering Indicators study used to determine the state of interest in and awareness of fundamental issues in the sciences and technology (McComas et al., 1998). This is mainly due to the fact that science teachers and science curricula seem rigidly bound to a tradition of communicating the facts or end products of science while generally neglecting how this knowledge was constructed. Thus, inquiry teaching is once again advocated as a central element in science teaching (American Association for the Advancement of Science [AAAS], 1989, 1993; National Research Council [NRC], 1990, 1995), where scientific inquiry is described as those processes used to generate and test scientific knowledge (Meichtry, 1998). This requirement makes it vital for science teachers to know and understand the basic processes and philosophies of science.

The National Science Education Standards (National Research Council, 1996) defines scientific inquiry as:

... the diverse ways in which scientists study the natural world and propose explanations based on the evidence derived from their work. Scientific inquiry also refers to the activities through which students develop knowledge and understanding of scientific ideas, as well as an understanding of how scientists study the natural world. (p. 23)

Scientific inquiry is a powerful way of understanding science content. Students learn how to ask questions and use evidence to answer them. In the process of learning the strategies of scientific inquiry, students learn to conduct an investigation and collect evidence from
a variety of sources, develop and explanation from the data, and communicate and defend their conclusions.

An understanding of the processes and nature of science and an ability to do scientific inquiry is a requirement for effective science teaching (Matson & Parsons, 1998). All those engaged in science teaching and learning must be able to carry out research projects by asking pertinent questions, construct hypotheses, predict outcomes, design experiments, analyze data, and reach conclusions. In brief, science teachers must be able to do science. Experiencing the processes of science by itself, however, is not sufficient. A teacher of science must also bring to the classroom the attitude and world view of scientists. To achieve this, a basic understanding of the philosophies of science is necessary. With a basic science content background and the ability to carry-out the process of science, science teachers can teach science as a conceptually oriented, hands-on/minds-on, problem solving, critical thinking activity which will promote science literacy among students (Matson & Parsons, 1998).

Understanding how science operates is imperative for evaluating the strengths and limitations of science, as well as the value of different types of scientific knowledge. For instance, science teachers or students may understand the atomic model, Boyle’s law, and quantum theory, but may not understand what model, law, and theory mean in the discipline of science. Furthermore, those who comprehend the durable, yet revisionary, nature of scientific knowledge will not be confused by changing science concepts or the disappearance of particular scientific ideas learned earlier. Additionally, it was found by Connelly, Wahlstrom, Finegold, and Elbaz (1977) that individuals who understand how science works will be less cynical about the scientific process. Because science is often
incorrectly perceived as primarily a body of literal truths, entire fields of knowledge are sometimes questioned when single facts are revised. The notion of tentativeness is turned into a strength rather than a weakness when science is perceived as a process of improving our understanding of the natural world (McComas et al., 1998).

One of the primary ways students understand how science works is through laboratory activities. These activities, however, should not be “cookbook” or verification type laboratory activities which portray science as a rhetoric of conclusions. These labs should involve active engagement of the students in science content and the nature of science concepts. Clough and Clark (1994) have suggested placing students in small research teams that are responsible for developing experiments to investigate a particular question posed by the instructor. Students must make important decisions concerning the experimental set-up, collection of relevant data, its interpretation, and judgements regarding the veracity of their work. Having students determine the meaning of results conveys a very different picture of science and the scientific process than typical cookbook/verification labs where students follow recipes to predetermined results. In this new lab setting, students are forced to think about the science content and how content and process are intricately tied together. Additionally, the nature of science is embedded into these lab experiments in that students reflect on what they learned, how they felt, the criteria used to make observations, and the final interpretations made during the experimental process.

Unfortunately, current college coursework requires professors to cover so much content that there is little room to teach this inquiry process. In fact in your typical college laboratory, students are expected to have already developed the skills before
entering. Unfortunately, this is not the case and very few college students enter into introductory level coursework with the ability to do inquiry. Thus, this is a vital aspect of the science curriculum that is not being taught.

**Essential Elements - Curriculum Comparison**

As mentioned in the Introduction Section, the “atoms first” and the “traditional” approaches are very similar in content covered, but order the topics covered differently. To lay a foundation regarding the expectations of results for this research study, a preliminary analysis of the approaches based on the following criterion is needed: inclusion of the HOS, NOS, content depth and overview, and inclusion of inquiry and a “scientific method”. The analysis presented herein is a generalized overview of both the “traditional” and “atoms first” curricula. The specifics of the curricula may vary amongst different authors within each approach.

The first comparison criterion is the HOS and the NOS. In Chapter 2, “Atoms and the Periodic Table”, found in the “atoms first” approach, the text goes through chronologically the discovery of the subatomic particles and then moves into the different atomic models that were proposed and the experiments that were used to determine our current understanding of the atomic structure. This leads into the determining of elements and the creation of the periodic table. The goal of this chapter is to use history to lay the foundation of the atom and the concept that everything builds off of it. Whereas, in the “traditional” approach the structure of the atom is mentioned, but it is glossed over very quickly with very little detail regarding the experiments used and the various models proposed. Additionally, the creation of the periodic table is not mentioned until later in Chapter 7, “Electronic Configuration and the Periodic Table.” The “traditional” approach
provides the material but not in a chronological format nor does it explain how the scientists came to understand this content.

Also important to the NOS is the usage of the terms law and theory. In both of the approaches, the terms are briefly introduced in the first chapter of the text. Neither approach, however, does a thorough job of explaining the difference between a theory and a law. The “atoms first” approach makes a marginally better attempt in this area in that there is mention as to how a theory is formed, but this is still not entirely accurate.

The second comparison criterion is that of content depth and overview. It was previously discussed that both approaches cover the same material, but the biggest difference is that the first 11 chapters are in a different order. The content is ordered differently, but the total number of pages devoted to these first 11 chapters is approximately the same for the two approaches. Thus, neither chapter is spending more time on this first half of content. Another difference deals with the focus of the material more specifically the depth given to the various topics. As mentioned the “atoms first” approach provides a more in-depth coverage of the history of the atom and its development. Besides the addition of the nature and history of science topics, the other concepts and topics are given approximately the same amount of space in each of the two approaches.

The last comparison criterion is that of inquiry and the scientific method. A representation of a scientific method is always mentioned in the “atoms first” approach; whereas, the “traditional” approach depends on the author. For those “traditional” approach texts that do include a scientific method, it is very brief and not described in a flexible concept, but rather as a more step by step procedure. The “atoms first” approach
contains a description of the scientific method in the majority of text. The method is
detailed and usually accompanied by an example of how the method works in a real-
world setting. This is an attempt to become closer to the actual definition and application
of the scientific method. There are still a lot of inaccuracies in how the scientific method
is presented in this approach, however. It is still visually shown as a flowchart of steps
and the application of the method does not mention the trials and errors, the length of
time it can take, and the thought process of the scientist. Overall, the “atoms first”
approach appears to be making a stronger move to an accurate description of the
scientific method.

The scientific method is seen in the texts, but inquiry is mainly seen in the set-up
and design of the chemistry laboratory. It has been mentioned previously that the
“traditional” approach is better suited for courses that have a concurrent lab. Since the
“atoms first” approach spends a significant amount of time at the beginning of the course
detailing the history of the atom and the periodic table, this leaves little room for
concurrent labs that are directly related. In the majority of the “atoms first” laboratories
the students have to do theoretical or mathematics focused labs instead of hands-on
reaction based experiments. These hands-on reaction based experiments come at the end
of the semester once the material has been presented. Whereas in the “traditional”
approach the students are introduced to the material earlier in lecture and thus can do
these hands-on experiments much sooner. Thus it appears that the “traditional” approach
provides more opportunities for inquiry based laboratory experiments. However, this is
dependent on how the laboratory activities are developed. The mathematical activities in
the “atoms first” approach may help the students develop their ability to do inquiry and
later maximize their outcomes during the hands-on reaction based portions of the lab. Additionally, some of these hands-on activities used in the “traditional” approach are cookbook or verification labs, which do not allow students the opportunity to develop a thorough understanding of the inquiry process. Overall if inquiry labs are used, the “traditional” approach provides students with more hands-on reaction based experimental time compared to the “atoms first” approach. Just having the additional time, however, does not necessarily mean it is inquiry focused instead of recipe type experiments. The nature of the laboratory will be very specific to the institution.

**Sequential Learning**

It is usually difficult for science students to learn complex systems. These complex system have multiple “levels”. There are three distinct levels of a system, which include an experiential macro level, an abstract macro level, and a micro level (see Table 4). An experiential macro level is an observable and concrete representation of the macro-level relationships (Li, 2013). Structurally and functionally analogous to the experiential level, the abstract macro level is a formal representation of the macro-level relationships (Li, 2013). These two macro levels are emergent from micro-level dynamics. The micro level of a chemical system is always abstract. However, students are able to observe and analyze the micro-level dynamics which are otherwise invisible with the help of various visualizing tools such as graphical simulations. Often students can understand gas properties at their experiential macro level (e.g., an aerosol can filled with gas will explode when the temperature is too high) and usually can follow phenomenon focused on the micro level. However, it is often difficult for students to
understand that something happening at a macro level is caused by something happening at a micro level.

Table 4

Levels in a system

<table>
<thead>
<tr>
<th></th>
<th>Experiential</th>
<th>Abstract</th>
</tr>
</thead>
<tbody>
<tr>
<td><strong>Macro</strong></td>
<td>Observable macro-level phenomena</td>
<td>Formal representations of macro-level relationships</td>
</tr>
<tr>
<td><strong>Micro</strong></td>
<td>----------------------------------</td>
<td>-----------------------------------------------</td>
</tr>
<tr>
<td></td>
<td></td>
<td>Micro-level dynamics</td>
</tr>
</tbody>
</table>

(Li, 2013)

Thus, there has been much debate on how to sequence learning activities while teaching complex systems. Some studies state that it is better to utilize an experiential macro-abstract macro-micro or, in simpler terms, a “top-down” sequencing method. The “top-down” sequencing method starts with a concrete experiential phenomenon, breaks it into easier to understand parts, and then explains how the “whole” is caused by the parts” (Li, 2013). For example, at the beginning of a lesson on the respiratory system, students are asked to think about an experiential phenomena such as “as an individual runs they may breathe more rapidly and demonstrate an increased heart rate” (Liu & Hmelo-Silver, 2009, p. 1025). Then, students can further learn how different organs and their substructures work together to help us breathe by asking additional “why” and “how” questions, such as “why do we breathe?” and “how does oxygen get into the body?” (Liu & Hmelo-Silver, 2009). But other studies argue that it is better to take a micro-abstract macro-experiential macro or, in simpler terms, a “bottom-up” sequencing method (Li, 2013). The “bottom-up” sequencing method allows students to experience how simple, small effects can cause something dramatic at a macro level. For example, Frederiksen,
White, and Gutwill (1999) found that providing explanations of current flow in terms of the behavior of electrically charged particles ("electrons" at the micro-level) helps students to understand the concept of voltage and enables them to apply it in reasoning about electrical circuits (macro-level) using the circuit laws.

These studies yield different results mainly due to the fact that the two methods serve different purposes. Research shows that the “top-down” sequencing method is often used to teach biological and life systems with many levels and ascending complexity from a macro to a micro level (Li, 2013). This sequencing method not only grounds abstract system concepts in everyday experience, but also provides a conceptual structure for knowledge integration. However, the “bottom-up” sequencing method is often used to teach systems with abstract causal structures, such as physics and chemistry (Li, 2013). Students can experience the process of how micro-level dynamics cause macro-level patterns to emerge, which is why this sequencing method is so effective for these topics.

**Sequencing Methods for the “Traditional” and “Atoms First” Approaches**

These two curricular approaches will be described in detail regarding their type of sequential approach being “top-down” or “bottom-up” and the advantages of their sequencing method in teaching complex systems to science students.

**Traditional approach.** The “traditional” approach to teaching chemistry follows an experiential macro-abstract macro-micro sequencing method. This method starts from the experiential macro-level function of a system and is labeled as a “top-down” approach. This sequencing method follows the “from concrete to abstract” principle and provides a desirable conceptual structure for knowledge integration (Li, 2013).
This sequencing method is effective in tackling two difficulties in learning complex systems. The first difficulty is that it is challenging for students to integrate and mentally reorganize a large amount of system knowledge. The second difficulty is that it is challenging for students to conceptually understand abstract system levels.

The experiential macro-abstract macro-micro sequencing method provides a good conceptual structure for students to integrate and organize system knowledge. For example, in Liu & Hmelo-Silver’s study (2009), they compared the “function-oriented” (top-down) and the “structure-oriented” (bottom-up) approaches in learning the human respiratory system in an instructional hypermedia environment. The results indicated that participants using the function-centered hypermedia or “top-down” approach, which starts from the experiential macro-level function, developed deeper understanding than those using the structure-centered version or “bottom-up” approach, which starts from complex micro-level system knowledge.

Secondly, this “top-down” sequencing method is function-oriented. Students can use “how” and “why” questions about various system functions to help integrate detailed structural and behavioral knowledge regarding the human respiratory system (Liu & Hmelo-Silver, 2009). The macro level of this particular system, which facilitates knowledge integration, is concrete and experiential. The function of the larger system is more accessible to students as compared to the lower-level subsystems and the molecular-level mechanisms; it is also more intuitive and easier for the students to integrate information around the macro-level system function (Li, 2013).

Thirdly, starting from an experiential macro-level “whole”, known as the “top-down” approach, makes science more accessible to students. “Making science accessible”
as a knowledge integration guideline requires that concrete levels of a topic come before abstract ones (Linn, 2006); source models containing familiar representations before derived models with less familiar ones (Frederiksen et al., 1999). This sequencing method could be very effective when the dynamics at the micro level are much more complex or abstract than the macro-level phenomena.

The experiential macro-abstract macro-micro sequencing method allows students to relate abstract concepts to concrete phenomena when the mechanism and micro-level dynamics of a system are abstract. Guisasola, Almudi, Ceberio, and Zubimendi (2009) demonstrated the effectiveness of this sequencing method in teaching the model of magnetic field. Students were taught either the standard/normal approach which included learning the macroscopic theories of magnetic fields and then applying the knowledge in solving magnetic field problems or the new approach in which students became familiar with various magnetic phenomena at the beginning. Students who were taught using the new approach produced better performance in both the magnetic field problems and general physics problems than their peers who learned the “magnetic field” system through the standard/normal approach.

Lastly, this sequencing method also has advantages from the motivational perspective. It is more motivating to explain a science problem around concrete phenomena and probe into the underlying mechanism of real scientific problems, which is more of an inquiry-based method, than to utilize the traditional “equation-to-application” approach, in which one learns an equation and then uses it to solve a science problem (Li, 2013). For example, higher motivation was found in students who learned
the magnetic field system under the experiential macro-abstract macro-micro approach compared to those under the “equation-to-application” approach (Guisasola et al., 2009).

**Atoms first approach.** The “atoms first” approach follows a micro-abstract macro-experiential macro sequencing method. This method starts from micro-level dynamics and is labeled the “bottom-up” approach. Students experience how small effects and simple interaction can cause something to emerge at a macro level (Li, 2013). In other words, this sequencing method is aligned with the deep causal structure of a system. In chemistry, changes at the molecular level cause changes at the macro level. For example, any single molecule is moving randomly and bumps into its container wall. When temperature is increased, these molecules move faster and bump into the walls more frequently. Thus, these micro-level dynamics are the cause for an increase in pressure.

This sequencing method is effective in tackling two difficulties in learning complex systems (Li, 2013). The first difficulty is that it is challenging for students to learn the implicit and abstract causal structures of a complex system. The second difficulty is that it is challenging for students to conceptually understand abstract system levels. As previously mentioned, this sequencing method takes a “bottom-up” approach. The “bottom-up” approach has been applied in modeling complex systems in various disciplines, including chemistry (Levy & Wilensky, 2006), ecology (Grimm, 1999), and economics (LeBaron, 2000). Wilensky and Stroup (2002) showed that starting from micro-level dynamics and moving to macro-level patterns is particularly effective in teaching complex dynamic systems.
Starting from the micro-level elements may be more accessible in that the micro-level behaviors of these systems may be less complicated than the large macro systems. There may be less complicated structural formation and less diversified interactivity at the micro level, as well as fewer levels (Li, 2013). The difficulty is less overwhelming from a knowledge integration perspective. Some macro-level concepts can also be more abstract than the micro-level concepts. For example, “gas pressure” as a phenomenon is more abstract than “gas molecules” (Li, 2013). Similarly, current flow or “electron movement”, a micro-level concept, is much easier to understand than “voltage,” which is a macro-level concept (Frederiksen et al., 1999).

Many systems have abstract and implicit causal structures. This could prove to be more of a learning difficulty than knowledge integration. Understanding the non-linear and decentralized causal processes, which are often counterintuitive and abstract, are considered to be the most difficult part of learning these systems (Chi, 2005; Jacobson, 2001). It is very difficult for students to construct a system in which all of the micro-level elements behave following a set of simple local rules which cause some macro-level patterns to arise. Additionally, there is no central higher-level power that controls these micro-level elements (Chi, 2012).

The micro-abstract macro-experiential macro sequencing method supports conceptual understanding of implicit causal structures, because it allows students to experience how micro-level behaviors cause macro-level phenomena. For example, in the Connected Chemistry Curriculum, developed at the Center for Connected Learning and Computer-Based Modeling at Northwestern University, students manipulate and observe chemical “entities” at the molecular level as well as the resulting aggregate patterns. In
the Gas Laws and Kinetic Molecular Theory activity, the students manipulated and articulated the micro-level behaviors (gas particles collide with each other and with the walls) of the system and then gradually expanded to the macro-level phenomena (the pressure of a gas in a container). Researchers claimed that this “from-the-molecule-up” approach helped students to conceptually understand the implicit linkages between the micro and macro levels of gas phenomena (Levy & Wilensky, 2006). Similarly, in learning some everyday complex systems such as traffic jams and bird flocking, taking a “bottom-up” approach, for example, by first manipulating the micro-level elements such as the movements of individual cars, is often most effective (Wilensky & Stroup, 2002). To bridge this “bottom-up” process, an “aggregate model” or “a smaller scale mid-level aggregation or group” can be used as a conceptual linkage or scaffold (Frederiksen et al., 1999; Levy & Wilensky, 2008). Using conceptual linkages among models which represent physical phenomena at increasing levels of abstraction, students can understand complex dynamic systems.

The micro-abstract macro-experiential macro sequencing method is more likely to represent a system problem, because it follows the causal process across system levels (Li, 2013). The problem structuredness (well versus ill), domain specificity (abstractness), and complexity, as well as what kind of problem schemas or structural knowledge students have, may all predict success in problem-solving (Jonassen, 2000). Levy and Wilensky (2004) compared “bottom-up” and “top-down” sequencing methods in learning complex systems such as equilibrium and stochasm, finding that the “top-down” approach produced a less robust understanding than the “bottom-up” approach.
The congruency between the sequencing method and the system causal structure might help students construct a better mental model (Levy & Wilensky, 2004).

From the motivational perspective, the “bottom-up” approach could also create “surprise” moments triggering deep thinking and further investigation. For example, after manipulating and observing the simple actions of vehicles, students participating in one study were very surprised to observe a traffic jam emerge and the continuous changing of the macro-level patterns (Wilensky & Resnick, 1999).

**Spiraling Curriculum**

The spiral curriculum is predicated on cognitive theory advanced by Jerome Bruner (1960), who wrote, “We begin with the hypothesis that any subject can be taught in some intellectually honest form to any child at any stage of development” (p. 33). In other words, even the most complex material, if properly structured and presented, can be understood by very young children.

Bruner (1960) hypothesized that human cognition occurred in three relatively discreet stages: enactive, iconic, and symbolic. Enactive is the actual manipulating and interacting with objects. Iconic is manipulating images of the objects or phenomena. Lastly, symbolic is the manipulation of representations of the actual objects or phenomena. For example in chemistry, the enactive stage would be working in a lab with specific chemicals, the iconic stage would be handling molecular modeling kits, and the symbolic stage would be drawing out the molecular reaction mechanism.

The key features of the spiral curriculum include: revisiting a topic, theme or subject several times throughout the course; the complexity of the topic or theme increases with each revisit; and new learning has a relationship with old learning and is
put in context with the old information (Bruner, 1960). The benefits ascribed to the spiral curriculum by its advocates include: the reinforcement and solidification of information each time the student revisits the subject matter; the logical progression from simplistic ideas to complicated ideas; and students receive encouragement to apply the early knowledge to later course objectives (Bruner, 1960).

Although there is no clear empirical evidence of the overall effects of the spiral curriculum on student learning, features of that curriculum have been linked to improved learning outcomes. In addition, the spiral curriculum incorporates many research-based approaches from cognitive science that have been linked, individually, to improved student performance as well.

The multidimensional nature of chemistry contributes to the difficulties faced by those learning it, in particular for novice learners. It is recommended to begin with one dimension of chemistry, e.g., macroscopic, before moving onto another dimension, e.g., microscopic or vice versa (Dwyer & Childs, 2014). Rather than introducing all the information at once, spiraling curriculum can facilitate the learners’ understanding of each aspect of chemistry by slowly building up concepts. Dwyer and Childs (2014) developed the Organic Chemistry in Action! (OCIA!) program using spiral curriculum. The goal of the program was to improve learners’ attitude towards, interest in, and understanding of organic chemistry. This intervention program was trialed and evaluated and the findings showed a positive influence on learners’ attitudes toward, interest in, and understanding of organic chemistry (Dwyer & Childs, 2015). The students in the focus group appreciated the spiral curriculum and referred to it as ‘useful revision’ of topics and ‘easy to build up new ideas’.
Bunce, VandenPlas, and Soulis (2011) provide one example in chemistry in which features of spiral curriculum were linked to an increase in student performance in general chemistry. It was found that students enrolled in courses in which the continued spiral use of chemistry concepts was not evident, frequent quizzing opportunities were not provided, and a final exam was not given experience a significant decrease in achievement during the first 48 hours following a test and remained constant for at least 2 weeks. However, a significant decrease in achievement from the original testing to delayed quizzing occasions over a 17-day period was seen for students enrolled in courses in which the spiral use of chemistry concepts was more explicit and regular quizzing opportunities and comprehensive final exams were given (Bunce, VandenPlas, & Soulis, 2011).

Aspects of the spiraling curriculum can be found in both chemistry approaches. However, the “atoms first” approach utilizes the spiraling curriculum concept in its overall format. This is due to the textbook structuring of the approach in that it starts at the micro level of the atom and builds to the macro level of reactions. Several concepts covered in the later chapters of the “atoms first” approach are easier to understand when knowledge of the micro-level interactions are understood and their corresponding macro-level effects.

**Chemistry Curriculum Development**

Curricula should match the needs of learners, their aspirations, and requirements. A very important aspect of this will be the aim to develop responsible citizenship and a population which can make informed decisions based on a sound understanding of the
chemical issues involved. For those students majoring in chemistry, an important aspect will be the need to develop the skills required for a wide range of career opportunities.

Evidence from empirical research suggests a set of clear guidelines that should be used to inform future curriculum planning. Mbajiorgu and Reid (2006) detail that chemistry curriculum should have the following guidelines as evidenced in the literature.

1. *Meet needs of all learners* – Meet the needs of the majority of school pupils (who will never become chemists or even scientists), and most students who will undertake chemistry degrees but never become bench chemists. Thus, the curriculum must seek to educate through chemistry as well as in chemistry.

2. *Relate to life* – Should relate tightly to applications in life.

3. *Reveal chemistry’s role in society* – Reflect attempts to answer questions like: What are the questions that chemistry asks? How does chemistry obtain its answers? How does this chemistry relate to life?

4. *Have a low content base* – Not be too “content-laden”, so that there is adequate time to pursue misconceptions, to aim at a deep understanding of ideas rather than content coverage, and to develop the appreciation of chemistry as a major influence on lifestyle and social progress.
5. *Be within information processing capacity* – Be careful in introducing sub-micro and symbolic ideas together too soon or too rapidly; avoid developing topics with high information demand before the underpinning ideas are adequately established to avoid overload and confusion. Introduce sub-micro, symbolic, or macro ideas one at a time gradually increasing to two groups at the same time once understanding is established.

6. *Take account of language and communication* – Be set in language which is accessible and offer learners opportunities to express chemical ideas verbally and in writing.

7. *Aim at conceptual understanding* – Be couched in terms of aims which seek to develop conceptual understanding rather than recall of information, being aware of likely alternative conceptions and misconceptions.

8. *Offer genuine problem solving experience* – Offer experiences of more open-ended problems (along with algorithmic exercises), with emphasis on the use of group work to solve “real-life” problems in chemistry.

9. *Use lab work appropriately* – Involve laboratory work with very clear aims; these should emphasize the role of lab work in making chemistry real as well as developing (or challenging) ideas rather than any focus on practical hands-on skills; lab work should offer opportunities for genuine problem solving.
10. *Involve appropriate assessment* – Involve assessment which is integrated into the curriculum and reflects curricular purpose, is formative as well as summative and aims to give credit for understanding rather than recall, for thinking rather than memorization.

These guidelines will help to develop a chemistry curriculum that meets the needs of learners and societal demands. A curriculum which is a sound reflection of the nature and methods of chemistry as a discipline, with its important place in a modern society. At the undergraduate non-chemistry major level, the outcome of this curriculum is an informed population that has also developed informed attitudes relating to the study of chemistry and its practical implications for society. At the graduate level, however, the outcome of this curriculum is to equip students with those skills which will enable them to make a contribution to society within and beyond chemistry. These skills should be seen in cognitive terms (like conceptual understanding, logical and critical thought, creativity, objectivity) as well as generic terms (like team working, written and verbal communication of chemical ideas).

**Curriculum Development Factors - Curriculum Comparison**

As mentioned in the Introduction Section, the “atoms first” and the “traditional” approaches are very similar in content covered, but order the topics covered differently. To lay a foundation regarding the expectations of results for this research study, a preliminary analysis of the approaches based on the ten curriculum development factors mentioned above was performed. The analysis presented here in is a generalized overview of the two approaches and specifics among different authors within the same approach may occur.
Some of the curriculum development factors have already been covered in the HOS, NOS, content, and inquiry curriculum comparison sections. Factor 4 – have a low content base – is discussed in the content section above. This section, however, could be improved on in both of the approaches by allowing students more time for each topic. The focus should be more in depth with fewer topics then on many topics at a shallow level. Factor 6 – take account of language and communication – is accomplished through the inquiry based laboratory activities. Like already mentioned this could be improved by having students write formal lab reports early in the semester instead of cookie cutter lab reports. Additionally, early labs in the “atoms first” curriculum could include activities focused on improving chemical communication and language. Factor 9 – use lab work appropriately – has also already been covered. By creating labs that are inquiry based, hands-on real world experiments that involve formal written reports, then several curriculum factors will be achieved.

Factor 1 focuses on meeting the needs of all learners especially those not planning on being chemists or even scientists. This factor is the primary focus of the “atoms first” approach. This approach arranges the content in a way that creates a more cohesive and ordered curriculum. By examining the atom, the student is able to slowly build up to more challenging concepts. This gives the student time to learn the vocabulary and slowly introduces the mathematical formulas. This is also related to factor 5 – be within information processing capacity – in that the “atoms first” approach slowly guides students through the atom and slowly introduces them to the vocabulary and mathematics. By focusing on students that are not science concentrations, you are also helping students to ease into the topics.
Factor 2 – relate to life – is meet in both approaches depending on the specific author. Authors have a wide range of examples they can use in writing the text. Some chose cross-disciplinary examples involving biology or medicine, whereas some will use examples that relate more to everyday life. This factor depends more on who wrote the text than the specific curricular approach.

Factor 3 – reveal chemistry’s role in society – is not answered in either of the two approaches’ textbooks. It is not a focus in any of the general chemistry textbooks. The area of society and science is not something that is discussed at all in the field of chemistry and thus would not be in either approach. Some textbooks try to relate to society, but they do not go as far as discussing chemistry’s role in society. This is one of the major gaps in chemistry instruction in general.

Lastly, some of the factors are contained in the texts of the two approaches but depend more on the instructor of the course. Factor 7 – aim at conceptual understanding – and Factor 8 – offer genuine problem solving experience – are dependent on the specific course instructor. Factor 7 depends on what the teacher focused on during the lecture period and what the teacher deems as important to test. The tests should focus more on concepts and understanding rather than memorization. Factor 8 depends on what assignments the teacher assigns to the students. The specific texts may have real-world examples, but they may or may not be assigned to the students. The best way to accomplish this factor is through the laboratory setting. The instructor, however, would have to design the lab to focus on real-world problems instead of theory checking experiments. Factor 10 – involve appropriate assessment – is also dependent on the instructor in that he/she is the one that develops the assessments and determines the goals.
of each. One change that would involve all of the instructors would be moving away from standardized final examinations to more appropriate assessments that involve more testing options besides multiple choice questions. Thus, these factors are not dependent on the specific curricular approaches, but rather on the instructor teaching the course.

Previous Research

This section will describe the need to address other factors that influence student learning. Controlling these variables will allow the researcher to determine the effects of the two approaches alone. This will give insight into the simple effects of the approaches and any possible interactions between the controlled variables and the curricular approach.

Esterling and Bartels’ Research

The research done by Esterling and Bartels (2013) spanned five years, involved more than 8,000 students in general chemistry, used a three-quarter series, and was conducted at the UCR located in Riverside, CA. The “atoms first” curriculum after the one year transition produced higher student success. These results were determined using statistical procedures at an alpha level of 0.05; however, the results of the findings were only given in graphs and the test statistics and descriptive statistics were not provided. They investigated the effect of the “atoms first” curriculum on student success in introductory chemistry classes by teaching two-fifths of the students the “atoms first” curriculum. UCR has approximately 20,000 undergraduate students with a total enrollment in general chemistry classes of 10% of its undergraduate student body (1,500-2,000 students). The authors only provided the exact number of students (1,722) for those
students in the second quarter of chemistry for one academic year. The students were divided into two groups: those on-sequence (started in the Fall/Winter) and those off-sequence (started in the Winter/Spring). The success of the approaches was measured by comparing the number of students who passed the course, which was defined as a C- or better, or meeting at least 50% of the course requirements (Esterling & Bartles, 2013). The results showed that in the first and second quarters of the general chemistry series a lower fraction of students obtained passing grades. The opposite was seen for first-quarter students after the faculty had one year of experience lecturing with the “atoms first” curriculum. The second quarter results remained the same as the first year.

This preliminary work is limited to students from a distinct population much different than that at Mississippi State University. There are many differences, both geographical and demographical, between California and Mississippi. California is the 3rd largest state in area and 1st in population, whereas Mississippi is 32nd in area and 31st in population. This difference in population is also seen in the location of the university, where Riverside is more urban than Starkville. Additionally, the states and corresponding cities are different in socioeconomic status, where the average household income for Riverside, CA is approximately double that for Starkville, MS (U.S. Census Bureau, 2014).

This preliminary work did not use an unbiased final comparison factor such as a standardized exam and did not investigate other important variables such as classroom size, major, gender, ethnicity/race, ACT, and GPA. This project will differ in that the ACS final examination and the final letter grade will be used as the measures of success instead of the fraction of students who passed the course. The ACS final examination is a
standardized exam that all the instructors use. This standardized exam is not written by the instructors, but instead by the ACS, thus removing the possible effects of instructor bias.

**Small versus Large Class Room Setting**

There are a number of studies that provide evidence that class size has an effect on student achievement. The majority of these studies, however, focus on students at the elementary level. The largest of these studies was conducted via the Tennessee Student Teacher Achievement Ratio (STAR) project, which involved more than 6,000 kindergarten students (Achilles, 1999). Research by Nye and Hedges (2001) reported cumulative positive effects in mathematics at the elementary level for smaller classes, which were still observed six years later even when students returned to larger classes. Mishel and Rothstein (2002) provided the following summary, “students in small classes performed significantly better than those in regular classes or regular classes with aides in kindergarten and … the achievement advantage of small classes remained constant through the third grade” (p. 55).

Even fewer studies have investigated the effect of class size on higher grade levels. Research by Finn, Gerber, Achilles, and Boyd-Zaharias (2005) found that students from the STAR study who attended small classes for three or more years in elementary school were more likely to graduate from high school, with a stronger effect among students who were eligible for free lunch (students with low socioeconomic status). These findings are consistent with research showing that the immediate academic impact of small classes is greater for minority students and low-socioeconomic status students (Finn & Achilles, 1990; Krueger & Whitmore, 2001). The question of why these effects
are realized remains largely unanswered. Wyss et al. (2007) focused on the influence of high school science class size on students’ achievement in introductory college science courses. The analysis indicated that only students reporting class sizes of 10 or fewer performed significantly different from their peers who reported high school class sizes of 21-25 students. Hence, incremental reductions in class size are likely to have a significant impact on later student achievement (Wyss et al., 2007). These results were for biology, chemistry, and physics courses and the median class size category was 21-25 students. Therefore, the results are not completely comparable to the college class setting where small classes are around 70 students and large classes have 200 or more students.

Chemistry Majors versus Non-Major Students

Research done by Basu-Dutt, Slappey, and Bartley (2010) focused on making chemistry relevant to the engineering major. The authors noted that engineering students struggle simultaneously with the challenges faced by other first-and second-year students (increased independence, responsibility, and level of rigor), as well as the significant additional challenge of assimilating content from multiple, simultaneous science and mathematics courses. It is believed that students struggle with three distinct, but interrelated challenges: (a) an overwhelming volume of content for novice students, (b) the need to make connections among disparate disciplines, and (c) the difficulty of recognizing that the content is relevant to their chosen discipline and their future careers (Seymour, 2002). The first two challenges are faced for both the major students and the non-major students; however, the third challenge is specific to non-chemistry majors. Consequently, non-major students have the difficulty of finding the motivation to succeed
in these classes if they are unable to make the connections of relevance to their specific fields.

Previous work done by Chittleborough, Treagust, and Mocerino (2005) examined the learning strategies of first-year non-major chemistry students who commonly have limited chemical and mathematical backgrounds that influence their approach to learning chemistry. Nearly all students identified multiple learning strategies. The authors found that teaching and assessment strategies direct students’ choice of learning strategies. The learning strategies that the students used were partially determined by the type of teaching method or focus. Thus, if the teaching and assessments were a rote-learning approach then the students used different learning strategies compared to those used when a conceptual-learning approach was taught and tested. This has an impact on the present study in that the curricular method implemented will directly impact the learning strategies used by the students.

Research done by Rauschenberger and Sweeder (2010) focused on the variables affecting success in a biochemistry course. Being a biochemistry major had a positive impact of similar magnitude as gender with respect to biochemistry performance. Students were found to have a higher GPA by 0.15-0.20 cumulative points in Biochemistry I, but there was no direct impact in Biochemistry II. The models do not provide reasons for the differences, but the researchers suggest that this improved performance could be a reflection of the students’ presumed greater interest in biochemistry and potential diligence to overcome course content challenges.
Gender

Previous work done by Shibley, Milakofsky, Bender, and Patterson (2003) investigated if the gender differences in Piagetian cognitive functioning found in 1981 are still evident in more recent society by using students from 1998. The authors compared the students in the 1981 study to those in a 1998 study who were enrolled in an introductory chemistry course taken by students who are not in science or engineering programs. The results found the gender difference in the conversation problem area to disappear; however, differences in imagery and classification emerged among men and women from 1981 to 1998. The overall cognitive developmental abilities were not statistically different between men and women; however, there was a decline in male performance and an increase in female performance. For females, course grades are significantly correlated with cognitive development, SAT-math, and SAT-verbal scores. Conversely for males, the only significant correlations are the SAT-math with cognitive development and course grades (Shibley et al., 2003). Therefore, this overall lack of significant gender difference may not necessarily be evidence of equality in gender cognitive abilities. Bird (2010) found similar results when looking at gender differences and logical reasoning ability for general chemistry students. Results found a significant effect for gender using the Group Assessment of Logical Thinking (GALT) test scores, with male students obtaining higher scores. With respect to operational level, a significant gender effect was observed with male students being more likely to be at a formal operations stage. For specific logical reasoning modes, the results showed that male students performed markedly better in proportional and probabilistic reasoning compared to female students. Similar findings regarding gender differences in test scores,
not using the GALT test, have also been reported (McKinnon & Renner, 1971). Hence, it can be seen that men and women have different cognitive abilities and will learn chemistry differently.

In addition to being aware of the cognitive differences in males and females, it is important to be aware of the gender differences in math performance. There is a link between math ability and chemistry performance. Being aware of gender differences in math performance will help to explain the differences in chemistry performance and provide suggestions on how curriculum and instruction should be tweaked to increase success for both males and females. Liu and Wilson (2009) investigated gender differences in large-scale math assessments such as the Programme for International Student Assessment (PISA) 2000 and 2003 trend. A well-agreed-on conclusion that gender differences are contextualized and vary across math domains (Buss, 1995; Gaulin, 1995; Geary, 1996; Halpern, 2000; Silverman, Phillips, & Silverman, 1996). Specifically, the two main item-related factors have been identified to influence the pattern and magnitude of gender differences: (1) the different cognitive domains measured by the math tests and (2) the item types employed to elicit information from students.

Liu and Wilson (2009) investigated the pattern of gender differences by item domain (e.g., Space and Shape, Quantity) and item type (e.g., multiple-choice items, open constructed-response items) using the U.S. portion of the PISA 2000 and 2003 mathematics assessment. A multidimensional Rasch model was used to provide student ability estimates for each comparison. Results revealed a slight, but consistent, male advantage. Students showed the largest gender difference ($d = 0.19$) in favor of males on complex multiple-choice items, an unconventional item type. In general, complex
multiple-choice items have a problem stem and several statements that surround the stem. Students are asked to make a judgment about the correctness of these statements. They obtain full credit only when all of the questions are answered correctly. This scoring scheme makes it more difficult for students to guess on complex multiple-choice items than on traditional multiple-choice items. Males and females also showed sizable differences on Space and Shape items, a domain well documented for showing robust male superiority (Casey, Nuttall, Pezaris, & Benbow, 1995; Gierl, Bisanz, Bisanz, & Boughton, 2003; Halpern, 1997). Contrary to many previous findings reporting male superiority on multiple-choice items, no measurable difference has been identified on multiple-choice items for both the PISA 2000 and the 2003 math assessment (Ben-Shakhar & Sinai, 1991; Bolger & Kellaghan, 1990; DeMars, 1998, 2000; Klein et al., 1997).

Few studies have addressed gender differences in organic chemistry achievement. Sevenair, Carmichael, O’Connor, and Hunter (1987) found that gender was a weak but significant predictor of organic chemistry grades for African-American students. Due to collinearity with other predictor variables, gender did not have a significant effect in a multiple linear regression. Turner and Lindsay (2003) found substantial gender differences in cognitive and noncognitive factors related to achievement. The regression models consistently explained greater amounts of variance for men than for women. Cognitive variables were found in both men and women at different variances; however, the noncognitive variables only entered the regression question for male students. Garcia, Yu, and Coppola (1993) reported that gender was not a significant predictor of organic
chemistry grades. Nevertheless, the authors found that task value and studying strategies were, in general, better predictors of organic chemistry grade for males than for females.

Research done by Rauschenberger and Sweeder (2010) focused on gender performance differences in a two-part biochemistry I and II course series. Even though female students maintained a statistically higher cumulative GPA than male students, they earned statistically lower grades in biochemistry I and equivalent biochemistry II grade. Thus, gender was found to be statistically significant for biochemistry I. For biochemistry I, it was found that more than half of the models with female students always predicted lower than their equivalent male counterparts, Female students were found to typically earn a final grade 0.14-0.17 lower than males. The final grades were recorded on a 0-4.0 scale in 0.5 unit increments.

Research done by Carmichael et al. (1986) found that gender had a significant effect in predicting grades for those students in the first semester of general chemistry. The positive coefficient for the sex variable showed that for students of equal high school GPA and composite ACT score males were predicted to have higher grades. The authors believe this is due to the fact that males in some high schools are more likely to take college preparatory courses, including science and mathematics, than females of equal ability. This pattern has still been noticed almost 30 years later in that there are less female students taking advanced mathematics and science courses in the later years of high school (Nix, Perez-Felkner, & Thomas, 2015). This might explain why the male students seem to be better prepared for the scientific and mathematical rigors of general chemistry.
Ethnicity/Race

There has been various research studies looking at differentials in academic success among high school and college students of different racial-ethnic categories. Comparing groups on academic performance, Massey, Charles, Lundy, and Fischer (2003) reported that among college freshmen, Asians had the highest high school GPA, followed by whites, Latinos, and African Americans. Studies that investigate immigrant status and academic performance show similar results. Tillman, Guo, and Harris (2006) report that adolescent grade retention (an early predictor of academic problems) is similar across first-, second-, and third-generation peers. Rumbaut (1999) found a negative relationship between length of high school students’ residence in the United States and their GPA. In contrast, Kao and Tienda (1995) and Kao, Tienda, and Schneider (1996) found that, for high school students, the relationship between generational status and academic performance varied across racial-ethnic groups. The strongest and clearest effect was among Asians, where the second generation did better than first- and third-generation students; on the other hand, immigrant African-American students had better grades than second- and third-generation African-Americans. Massey, Mooney, Torres, and Charles (2007) contradict that latter finding in reporting that immigrant and native-born African-American college students have equal GPAs. Several other studies, however, indicate better academic performance by immigrant students than by native-born students (Glick & White, 2004; Song & Glick, 2004; Vernez & Abrahamse, 1996).

Jaret and Reitzes (2009) investigated how college student ethnic identities vary among African-American, White, and Asian students and among immigrant, second-, and third-generation students and how those identities are related to college students’
academic performance at a large public urban university. The researchers used survey
data to create new indexes for several dimensions of college identity and ethnic identity
and obtained self-reported GPAs. The researchers found that whites have higher GPAs
than African Americans or Asians with no statistical difference between the GPA for
African Americans and Asians. Immigrant students report significantly higher GPA than
do second- and third-generation students. Higher GPA among immigrants holds for all
three racial categories examined. Among African-American and white students,
immigrants have the highest GPA followed by second and then third generation. There
were no third-generation Asian students, so the pattern only holds for immigrants and
second generation students. These results, specifically the overall research topic, are
important in understanding how young adults conceive of themselves as college students
and the way they formulate their own racial-ethnic identities because of how it relates to
their academic performance.

African Americans are severely underrepresented in natural and health sciences
with the National Science Foundation (1983) reporting less than 2% of the nation’s
scientists are African American. Mississippi’s population is 37% African-American (U.S.
Census Bureau, 2014). Students of color usually score much lower than Whites on
traditional multiple-choice tests. For example, the mean for fourth grade Whites on the
1990 National Assessment of Educational Progress (NAEP) science test was 30 points
higher than the mean for Hispanics and 37 points higher than the mean for African
Americans (Klein et al., 1997). Any learning or achievement differences found for this
particular ethnicity is very important in determining which curriculum to implement in
the general chemistry courses.
Klein et al. (1997) examined whether the differences in mean scores among racial/ethnic groups on science performance assessments are comparable to the differences that are typically found among these groups on traditional multiple-choice tests. To accomplish this, several hands-on science performance assessments and other measures were administered to over 2,000 students in Grades 5, 6, and 9 as part of a field test of California’s statewide testing program. Differences in mean scores among racial/ethnic groups were not related to test or question type. No matter which type was used, Whites had much higher means than African Americans or Hispanics. Thus, changing test or question type is unlikely to have much effect on the differences in mean scores among racial/ethnic groups. Additionally, the researchers found no empirical support for the hypothesis that because performance assessments involve “changing the game” from the familiar to the unfamiliar, they will be detrimental to minority groups (Baker & O’Neil, 1994). Overall, the results suggest that the type of science test used is unlikely to have much effect on racial/ethnic differences in scores.

Carmichael et al. (1986) investigated the possible predictors of first-year chemistry grades for African Americans. It was found that the predictors used to successfully determine the academic performance of the majority students, in this case White students, fail in predicting for African American students. The authors imply that possible reasons for this difference is due to the specific academic difficulties experience by minorities. Hence, it is not the traditional indicators of academic performance; however, a noncognitive factor or possibly a cultural factor that is interfering with the academic process.
ACT Score (Composite and Math Subscore)

Tai, Sadler, and Loehr (2005) investigated the factors that influence success in introductory college chemistry. The researchers examined the link between high school chemistry pedagogical experiences and performance in introductory college chemistry while accounting for individual educational and demographic difference. The most influential predictor on course grades was the students’ grade in their last mathematics course in high school with a standardized coefficient of 0.20. The difference in course grade between a student who earned an “A” in his or her last high school mathematics class and a student who earned a “B” is 2.79 points, or one-third of a letter grade. The second most influential predictor was SAT Mathematics with a coefficient of 0.17 followed by a group of predictors with coefficients ranging from 0.12 to 0.14. This group of predictors include last high school science grade, AP Calculus AB enrollment, and AP Calculus BC enrollment (Tai et al., 2005). This demonstrates the importance of taking the student’s mathematics background into account in determining the curriculum of choice. The easiest way to take the student’s mathematics background into account at the college level is their Math subscore on the ACT examination that all students must take before entering into the university.

Tai et al. (2005) found that using the SAT mathematics and SAT verbal scores accounted for 0.4% more variance than entering the SAT composite score. Disentangling the effect of mathematics and verbal skills as measured through the SAT test, improves the variance explained by the final model. A comparison of the standardized coefficients indicate that SAT mathematics has three times the influence on the outcome than SAT verbal, a result that has an intuitive appeal given the importance of quantitative skills in
science coursework. The researchers pointed out that the large standardized coefficients for calculus while controlling for grades, SAT mathematics, and SAT verbal scores calls attention to the striking role of preparation in advanced mathematics on college chemistry success. Thus, in this research both predictors, ACT composite and ACT mathematics scores, will be used to check this expectation of ACT mathematics score explaining more variance than the ACT composite score.

Turner and Lindsay (2003) found that the ACT subscores have strong correlations with organic chemistry achievement. It was observed that second-semester general chemistry grade and ACT-math score accounted for 39% of the variance associated with organic chemistry achievement. Sevenair et al. (1987) found that the ACT score explained 19% of the variance in predicting first semester organic chemistry achievement. When grades from first-year chemistry were not used in predicting first semester organic grades, adding the ACT composite to high school GPA increased the variance of the grade explained from 7% to 29% of the total. Grades in the two semesters of first-year chemistry gave the highest correlation coefficients, while high school GPA and composite ACT gave the best prediction of the factors available on admission (Sevenair et. al., 1987).

Carmichael et al. (1986) found that the correlation coefficient of the mathematics subsection of the ACT with first semester of chemistry grades were roughly equal to the correlation coefficient found previously for the SAT mathematics subscore at the University of California – Berkeley. This significant correlation confirms the widely held belief that mathematics sections of aptitude/achievement tests are reasonable predictors of grades in general chemistry.
Research by Steiner and Sullivan (1984) showed contradicting results when looking at variables correlating with student success in organic chemistry. Organic chemistry requires different cognitive skills compared to mathematics and general chemistry courses. Some of these cognitive skills are seen in the organic focused sections of the general chemistry sequence, but is very minimal. Steiner and Sullivan (1984) found that students who received a final grade of C or less (including students who dropped the course because of poor performance) reported having had much more math and more previous chemistry courses compared to students who received a C+ grade or better in organic chemistry. The previous math courses ranged from elementary algebra to trigonometry. Additionally, these students had a slightly higher avowed preference for math and a better performance on the math ACT. These results support the hypothesis that different cognitive skills are needed for the two chemistry courses, general chemistry and organic. These results can guide researchers’ expectations regarding which curriculum would be preferential regarding the performance of students with varying mathematical levels.

Nordstrom (1990) carried out a 10-year study at Embry-Riddle Aeronautical University from 1980-1989 that included 980 chemistry students. Instead of using multiple linear regression, which is the most commonly used analysis technique, Nordstrom (1990) used the method of discriminant analysis to predict membership of the target sample of freshman students into one of two groups: those that received a grade of “C” or better in their first semester of Chemistry and those that received a “D”, “F”, or “W”. The model correctly predicted the discriminant group for 73.7 percent of students. He found that students earning a C or higher in chemistry had higher SAT/ACT scores,
high school GPA, high school chemistry grade, high school math grade, and high school English grade than their peers. The factor identified as the best predictor of performance in college Chemistry, meaning having the highest standardized relative weight, was the mathematics score on the student’s college examination.

**Grade Point Average (GPA)**

As mentioned in the previous section, research done by Nordstrom (1990) investigated multiple predictors of performance in college chemistry. The discriminant analysis model correctly predicted the discriminant group for 73.7% of students. The second best predictor based on the standardized relative weights was high school GPA.

Wagner, Sasser, and DiBiase (2002) developed a pre-semester assessment to accompany demographic information in predicting students at risk in general chemistry. One of the evaluative variables was the predicted grade point indices (PGI), which using a multivariate regression model. The model uses SAT score, high school GPA, high school class rank, and GPA at the university to predict student success in course work at the university. The results showed that their developed pre-assessment was more accurate in predicting student success in general chemistry than the PGI (Wagner et al., 2002). These results, however, do not provide enough evidence to remove GPA as a tested variable, because the PGI involved GPA and multiple other variables that may have affected the results.

Research done by Rauschenberger and Sweeder (2010) focused on student performance differences in a two-part biochemistry I and II course series. Overall, the student’s cumulative GPA had the primary impact on the students’ biochemistry grade in biochemistry I. In biochemistry II, either cumulative GPA or biochemistry I performance
had the primary impact on the students’ grade. Wright, Cotner, and Winkel (2009) found that a strong positive correlation between students’ biochemistry grades and cumulative GPA exists for students in biochemistry at the University of Minnesota. The researchers found that GPA explains 51.88% or 60.22% of the sample variance in biochemistry grade for students with the organic prerequisite and with the prerequisite, respectively. Their data suggested that excluding students without organic chemistry would have less positive impact on student success in biochemistry than would providing additional support for all students who enroll in biochemistry with a cumulative GPA below 2.5.

These results support the commonsense idea that a student’s record of overall academic performance as measured by grades would be relatively consistent. That is, a student who has high average grades in his/her overall course work is more likely to earn a high grade in any particular course than one who has low average grades.

**Conclusion**

The first goal of this project is to determine if the “atoms first” approach better aligns to the curricular expectations established by research best practices. These best practices were established in the theoretical framework under the sections covering the essential elements of effective science instruction, sequential and spiraling learning theory, and curricular considerations. Whichever approach embeds the essential elements of science instruction and the chemistry curriculum guidelines into their curriculum the most will allow students to develop a more in-depth and rich understanding of chemistry. Investigating each approach on these factors will determine if the “atoms first” approach truly aligns to the curricular expectations better than the “traditional” approach.
In regards to learning theory, if it is found that the “atoms first” approach leads to higher student achievement this would provide strong evidence supporting the micro to macro ordering system and the use of spiraling content. It was shown in the theoretical framework that the “bottom-up” sequencing method leads to increased student understanding in the field of chemistry. This understanding can be further increased through the use of spiraling concepts. However, the combination of these two learning theories used specifically in a college level general chemistry course curriculum has not been investigated. This research will provide evidence in how these two learning theories can be directly applied in chemistry.

The second goal of this project is to determine if the “atoms first” curriculum leads to higher student success compared to the “traditional” curriculum for all students when all other sub-factors are considered as covariates. This is followed by the last goal of the project in which the two curricula are compared when the students are differentiated into each of the sub-factor groupings. The results of the first goal will be compared to the work done by Esterling and Bartels (2013) in which the researchers investigated the effects of an “atoms first” approach at UCR. As mentioned, the study examined the efficacy of the “atoms first” approach by contrasting students’ quarterly letter grades to the “traditional” approach. The work produced mixed results which showed that neither approach was more effective overall. The results of the second goal of this project will provide additional evidence in determining the better curricular approach. These results will also provide more detailed and specialized information, since this preliminary work did not examine students from a similar population as those
at Mississippi State University, did not use an unbiased final comparison factor, and was limited in the variety of factors studied.

The results of the third research goal will help fill in a large gap in the literature. At this time there are no articles, including the previous study mentioned, that investigated the two curricular approaches for each of the subgroups. However, there are several articles that discuss the effect of these subgroups on student achievement. This study will not only determine if the “atoms first” curriculum is better for each subgroup, but the study will also provide more evidence regarding the effects of the subgroups on student achievement. This research will fill in the multiple identified gaps such as: the effect on student achievement for the bottom-up (“atoms first”) and the top-down (“traditional”) sequencing methods specifically in chemistry; the effect on student achievement for the two curricula for all students combined; research on the two general chemistry curricula and the various subgroups; and research focused specifically on college level general chemistry courses for those specific subgroups.
CHAPTER III
METHODS

The researcher will conduct a detailed analysis of curricular resources from both the “atoms first” and the “traditional” chemistry curricula. This qualitative content analysis will be aligned to the ideal chemistry curricular framework established in the theoretical framework. To establish an understanding of the curricular influence on student achievement, the researcher has conducted a multiple year study where the classes will be taught using the “atoms first” approach and then analyzed against the data from previous years of teaching using the “traditional” approach. This is a basic, causal-comparative research study design in which the two groups will differ in only the curricular method and will be compared based on their final exam score and their final letter grade. There is no manipulation involved in this research study. The basic causal-comparative design can be seen in Table 5.
Table 5

The basic causal-comparative design

<table>
<thead>
<tr>
<th>Group</th>
<th>Sub-Group</th>
<th>Course Dates</th>
<th>Independent Variable</th>
<th>Dependent Variable</th>
</tr>
</thead>
<tbody>
<tr>
<td>I</td>
<td>A (Chem I)</td>
<td>Fall '12</td>
<td>C₁</td>
<td>Final Exam Score / Final Letter Grade</td>
</tr>
<tr>
<td></td>
<td></td>
<td>Spring '13</td>
<td>(“Traditional” Approach)</td>
<td></td>
</tr>
<tr>
<td></td>
<td></td>
<td>Fall '13</td>
<td></td>
<td></td>
</tr>
<tr>
<td></td>
<td></td>
<td>Spring '14</td>
<td></td>
<td></td>
</tr>
<tr>
<td></td>
<td>B (Chem II)</td>
<td>Fall '12</td>
<td>C₁</td>
<td>Final Exam Score / Final Letter Grade</td>
</tr>
<tr>
<td></td>
<td></td>
<td>Spring '13</td>
<td>(“Traditional” Approach)</td>
<td></td>
</tr>
<tr>
<td></td>
<td></td>
<td>Fall '13</td>
<td></td>
<td></td>
</tr>
<tr>
<td></td>
<td></td>
<td>Spring '14</td>
<td></td>
<td></td>
</tr>
<tr>
<td>II</td>
<td>A (Chem I)</td>
<td>Fall '14</td>
<td>C₂</td>
<td>Final Exam Score / Final Letter Grade</td>
</tr>
<tr>
<td></td>
<td></td>
<td>Spring '15</td>
<td>(“Atoms First” Approach)</td>
<td></td>
</tr>
<tr>
<td></td>
<td></td>
<td>Fall '15</td>
<td></td>
<td></td>
</tr>
<tr>
<td></td>
<td>B (Chem II)</td>
<td>Fall '14</td>
<td>C₂</td>
<td>Final Exam Score / Final Letter Grade</td>
</tr>
<tr>
<td></td>
<td></td>
<td>Spring '15</td>
<td>(“Atoms First” Approach)</td>
<td></td>
</tr>
<tr>
<td></td>
<td></td>
<td>Fall '15</td>
<td></td>
<td></td>
</tr>
</tbody>
</table>

Research Questions

The goal of this proposal is to answer the following questions:

1. Does the “atoms first” curriculum better align to the curricular expectations established by research supported best practices?

2. Does the “atoms first” curriculum lead to higher student success compared to the “traditional” curriculum for all students when all other sub-factors are considered as covariates?
3. Does the “atoms first” curriculum lead to higher student success compared to the “traditional” curriculum when students are differentiated into each of the sub-factors? The sub-factors analyzed in this study are classroom setting size (large versus small), major (chemistry majors versus non-majors), gender, ethnicity/race, composite ACT score, math ACT subscore, and GPA.

**Participants (Students and Faculty)**

The large setting general chemistry course at Mississippi State University consists of six sections per semester with 200 students per section in four sections and 300 students in the other two sections. The majors-only general chemistry course is taught once per semester with 30 students per section. The study will include seven faculty members teaching the year sequence, general chemistry I and general chemistry II.
Table 6

Mississippi State University’s demographic profile for three groupings

<table>
<thead>
<tr>
<th>Gender</th>
<th>Fall 2013 Student Pop.</th>
<th>Chemistry 1 Sections</th>
<th>Chemistry 2 Sections</th>
</tr>
</thead>
<tbody>
<tr>
<td>Women</td>
<td>7,876</td>
<td>2,862</td>
<td>1,530</td>
</tr>
<tr>
<td>Men</td>
<td>8,523</td>
<td>3,466</td>
<td>1,744</td>
</tr>
<tr>
<td>Race/Ethnicity</td>
<td>Fall 2013 Student Pop.</td>
<td>Chemistry 1 Sections</td>
<td>Chemistry 2 Sections</td>
</tr>
<tr>
<td>White</td>
<td>11,735</td>
<td>4,697</td>
<td>2,512</td>
</tr>
<tr>
<td>African American / Black</td>
<td>3,480</td>
<td>1,116</td>
<td>491</td>
</tr>
<tr>
<td>Hispanic</td>
<td>307</td>
<td>156</td>
<td>79</td>
</tr>
<tr>
<td>American Indian / Alaskan Native</td>
<td>99</td>
<td>37</td>
<td>12</td>
</tr>
<tr>
<td>Asian</td>
<td>178</td>
<td>125</td>
<td>74</td>
</tr>
<tr>
<td>Two or More Races</td>
<td>209</td>
<td>105</td>
<td>41</td>
</tr>
<tr>
<td>International</td>
<td>243</td>
<td>0</td>
<td>0</td>
</tr>
<tr>
<td>Native Hawaiian or Other Pacific Islander</td>
<td>15</td>
<td>2</td>
<td>0</td>
</tr>
<tr>
<td>Race/Ethnicity Not Reported</td>
<td>133</td>
<td>90</td>
<td>65</td>
</tr>
<tr>
<td><strong>Total Undergraduate Students</strong></td>
<td><strong>16,399</strong></td>
<td><strong>6,328</strong></td>
<td><strong>3,274</strong></td>
</tr>
</tbody>
</table>

Note: College Portrait of Undergraduate Education (2014).

Table 6 shows the demographic profile for three different groups of Mississippi State University students: 1) an overview of the entire Fall 2013 student population, 2) both the chemistry 1 general sections and majors only sections for Fall 2012 to Fall 2015, and 3) both the chemistry 2 general sections and majors only sections for Fall 2012 to Fall 2015. The table shows that students in both the chemistry 1 and 2 courses have a similar demographic profile as the entire university student population.
Table 7

Mississippi State University’s demographic profile for chemistry 1 and 2 for each curricular approach

<table>
<thead>
<tr>
<th>Gender</th>
<th>Chemistry 1 Traditional</th>
<th>Chemistry 1 Atoms First</th>
<th>Chemistry 2 Traditional</th>
<th>Chemistry 2 Atoms First</th>
</tr>
</thead>
<tbody>
<tr>
<td>Women</td>
<td>1,488 46%</td>
<td>1,374 44%</td>
<td>904 47%</td>
<td>626 46%</td>
</tr>
<tr>
<td>Men</td>
<td>1,746 54%</td>
<td>1,720 56%</td>
<td>1,016 53%</td>
<td>728 54%</td>
</tr>
<tr>
<td>Race/Ethnicity</td>
<td>Chemistry 1 Traditional</td>
<td>Chemistry 1 Atoms First</td>
<td>Chemistry 2 Traditional</td>
<td>Chemistry 2 Atoms First</td>
</tr>
<tr>
<td>White</td>
<td>2,370 73%</td>
<td>2,327 75%</td>
<td>1,480 77%</td>
<td>1,032 76%</td>
</tr>
<tr>
<td>African American / Black</td>
<td>603 19%</td>
<td>513 17%</td>
<td>284 15%</td>
<td>207 15%</td>
</tr>
<tr>
<td>Hispanic</td>
<td>79 2%</td>
<td>77 2%</td>
<td>42 3%</td>
<td>37 3%</td>
</tr>
<tr>
<td>American Indian / Alaskan Native</td>
<td>21 &lt;1%</td>
<td>16 &lt;1%</td>
<td>7 &lt;1%</td>
<td>5 &lt;1%</td>
</tr>
<tr>
<td>Asian</td>
<td>63 2%</td>
<td>62 2%</td>
<td>45 2%</td>
<td>29 2%</td>
</tr>
<tr>
<td>Two or More Races</td>
<td>54 2%</td>
<td>51 2%</td>
<td>23 1%</td>
<td>18 1%</td>
</tr>
<tr>
<td>International</td>
<td>0 0%</td>
<td>0 0%</td>
<td>0 0%</td>
<td>0 0%</td>
</tr>
<tr>
<td>Native Hawaiian or Other Pacific Islander</td>
<td>0 0%</td>
<td>2 &lt;1%</td>
<td>0 0%</td>
<td>0 0%</td>
</tr>
<tr>
<td>Race/Ethnicity Not Reported</td>
<td>44 1%</td>
<td>46 1%</td>
<td>39 2%</td>
<td>26 2%</td>
</tr>
<tr>
<td>Total Undergraduate Students</td>
<td>3,234</td>
<td>3,094</td>
<td>1,920</td>
<td>1,354</td>
</tr>
</tbody>
</table>

Table 7 shows the demographic profile for four different groups of Mississippi State University students: 1) Chemistry 1 students taught under the “traditional” curriculum from Fall 2012 to Spring 2014, 2) Chemistry 1 students taught under the “atoms first” curriculum from Fall 2012 to Spring 2014, 3) Chemistry 2 students taught under the “traditional” curriculum from Fall 2014 to Fall 2015, and 4) Chemistry 2 students taught under the “atoms first” curriculum Fall 2014 to Fall 2015. The table
shows that students taught under the two different curricula in both the chemistry 1 and 2 courses have similar demographic profiles.

**Final Letter Grade**

When selecting an outcome measure of student success, several factors come into consideration. Validity and overall acceptance of this outcome as a measure of success are two major considerations (Tai et al., 2005). In turning to the existing literature connecting various factors to college chemistry performance, the outcome measure that consistently arises is course grade. Studies as early as 1921 have relied on course grade as outcomes (Brasted, 1957; Herrmann, 1931; McQuary, Williams, & Willard, 1952; Powers, 1921). More recent work by Nordstrom (1990) also used grades as a measure of performance. Apart from this approach having been taken by other researchers in the past, there are several reasons for choosing grades. One important reason behind the selection of this outcome is that course grades represent the fulfillment of certain course standards listed in syllabi and known to all enrolled students (Tai et al., 2005). The course standards include various types of assessments such as passing examinations and writing lab reports; therefore, course grades serve as a summative evaluation of student performance. This conclusion supports the claim of validity. In addition, employers and admissions committees frequently use course grades to gauge student past performance and predict future success. This fact is well understood among students and supports the claim of overall acceptance (Tai, Sadler, & Loehr, 2005).
American Chemical Society (ACS) Final Examination

The success of the two approaches will be determined in part by evaluating scores on the ACS final examination given at the end of each semester. The first semester ACS final exam covers the same material taught irrespective of approach. The first semester ACS exam has 70 questions and covers the following topics: elementary conversions, chemical formulas, nomenclature, chemical reactions and equations, oxidation numbers, descriptive chemistry (solubility, acids/bases, etc.), stoichiometry, solutions (molarity and stoichiometry), thermochemistry, electron configurations and quantum number rules, ionic and covalent bonding, periodic trends, Lewis structures including resonance and formal charges, VSEPR theory, and gas laws and gas stoichiometry (Examinations Institute of the American Chemical Society Division of Education, 2014). The second semester ACS final exam will help to demonstrate if one approach gives a long term improvement in understanding for the topics covered during the second semester portion of the course.

The ACS Examinations Institute produces nationally available secure chemistry assessments for various levels of secondary and postsecondary chemistry courses. A committee of faculty members who regularly teach the courses that the exam targets is selected nationally and meets to construct the exam. Prior to setting the final version, the examination construction process includes committee deliberations and trial testing of the instrument. Content validity is supported by the committee deliberations which ensure that the content is relevant and representative of the intended courses (Holme, 2003).

The threat of content irrelevancy is removed via trial testing of the instrument to screen out improperly functioning test items. This is done using item statistics that show
low discriminatory ability or distractors that were rarely selected and evidently implausible to the intended audience. Structural validity is promoted by how the content informs the development of a rational scoring system for the test. When there is sufficient data, there is also an investigation into item bias by gender during trial testing (Kendhammer et al., 2013). Items containing bias are removed via the committee members from the released version of the exam.

These processes support the validity of the exam in terms of soundness of scoring structure and content appropriateness regarding the accuracy and interpretation of the scores. Lewis (2014) investigated the external and consequential validity of the first term general chemistry exam. The focus is that the ACS exam should offer relevant information regarding students’ preparation for the following course especially when the exam serves as a significant portion of the final letter grade. The results of the study support the argument that the students’ knowledge of general chemistry I measured by the First Term ACS Exam was indicative of performance in the follow-on courses. The use of this exam as a final exam in general chemistry I was supported via the positive correlation between the exam and the follow-on course (Lewis, 2014). Item bias within the test was also investigated with differential item functioning (DIF) results finding out of the 70 items overall, three by gender and one by ethnicity. Thus indicating minimal evidence of item bias for the examination. It was determined that the minimal evidence of item bias did not lead to differential consequences based on student subgroups such as gender and ethnicity (Lewis, 2014).
Data Analysis

To answer research question 1, the researcher will conduct a detailed analysis of curricular resources from both the “atoms first” and the “traditional” chemistry curricula. A qualitative review of two chemistry textbooks written by the same author, but in the two curricular approaches, will be performed using the content analysis procedure as suggested by Neuendorf (2002) and Krippendorff (2004). The review will focus on the essential elements of effective science instruction and the chemistry curriculum development guidelines mentioned in the literature review section. The two textbooks reviewed will be *Chemistry*, 3rd edition, by Burdge (2014) and *Chemistry: Atoms First* by Burdge and Overby (2012).

To answer research questions 2 and 3, the following methodology will be performed. Prior to data collection, the researcher will obtain Institutional Review Board (IRB) approval. The approved IRB study paperwork can be found in the appendix. The students’ final ACS exam score, the final letter grade, and other descriptive data will be provided by each lecture instructor. The missing descriptive and/or demographic data will be obtained through the information technology (IT) department. The analysis of the data obtained will be done using Statistical Package for the Social Sciences (SPSS) 23 and Excel 2013 statistical analysis programs. SPSS 23 will be used to perform an ANCOVA to determine if there is a significant difference between the “atoms first” and the “traditional” general chemistry curricula. The independent variable will be the curricular method either the “traditional” approach or the “atoms first” approach. The dependent variable will be the final exam score or the final letter grade. Also, the one-way ANCOVA will be used to keep all the other variables (classroom size, major,
gender/ethnicity, ACT, and GPA) constant and to determine which covariant is significantly affecting the data. All analysis will be done at an alpha of .05. The effect sizes of the data will be reported based on Cohen’s $f$ statistic.

Additionally, a multiple linear regression will be run using all of the subgroups (classroom size, major, gender/ethnicity, ACT, and GPA) as possible predictor variables to determine if there are any significant interactions between the curricular methods and the different subgroups (predictor variables). A hierarchical linear modeling (HLM) may be thought of as a more effective analytical method with clustering students within their specific sections. In previous research related to this topic (Littell, Milliken, Stroup & Wolfinger, 1996; Tai et al., 2005), it was seen that the between-group correlation is very small, less than 0.10 correlation or 10% of the variance, in comparison to the within group correlation or variance. The common perception among statisticians is that, in samples were greater than 10% of the variance occurs between clusters, HLM would be a useful tool to account for additional variance in the fitted model. On the other hand, in samples where less than 10% of the variance occurs between clusters, multiple regression would provide ample rigor in forming a fitted model (Tai et al., 2005). The between-section correlation will be calculated to determine if the variance accounted for is greater than 10%. If the variance is greater than 10%, the HLM model will still not be used but the multiple regression model will be modified to include a variable for section. One reason for not using the HLM in this analysis is due to the small number of different sections per semester or per year if grouped together. This small number would limit the statistical advantage of HLM. The sections are all from the same school for the same course with some of the sections being taught by the same instructor. Thus, it is believed
that there would be very minimal differences in the stringency of grading or background of students between sections. Thus, the multiple linear regression will be used simply because it provides the greatest analytical advantages with the least statistical complexity.

Multiple linear regression will be run using all of the subgroups (classroom size, major, gender/ethnicity, ACT, and GPA) as possible predictor variables with the addition of a term sequence predictor variable if determined needed based on the between groups correlation. The curricular method will be set as a predictor variable with two levels; “traditional” approach and “atoms first” approach. The outcome variable will be the final exam score and the final letter grade (coded for number of quality points earned). It is known that the order of variable entry in regression procedures may be impacted by sampling error and, when sample sizes are large enough, cross-validation analysis provides insight into the impact of sampling error on the ordering of predictor variables (House & Johnson, 1993). A commonly proposed cross-validation procedure is to divide the original sample into two cross-validation samples and perform multiple regression analyses on each cross-validation sample to examine consistency in the ordering of the predictor variables (Henderson & Denison, 1989). A cross-validation will be performed for the entire sample using all the stated variables as predictors. The entire sample will be divided into two random samples and multiple regression analyses will be performed on each cross-validation sample. Similarities and differences between the two cross-validation samples for ordering of the predictor variables will be examined. Additionally, multinomial and binary logistic regression will be run using the same predictor variables and the outcome variable set as the final letter grade. The multinomial logistic regression will use all letter grade options (A, B, C, D, and F). Whereas, the binary logistic
regression will group grades into pass (A, B, and C letter grades) and fail (D and F letter grades) categories. The leave-one-out cross validation method will be used to determine the classification accuracy of the model.

The linear and logistic regression analyses will show if the curricular method is effective for a certain subgroup of students. If specific interactions are determined for either of the curricular methods and any of the subgroups, then an analysis of variance (ANOVA) will be run to determine the specific differences between the two variables via a pairwise analysis. This will be conducted using the Fisher’s least significant difference (LSD) test based on a familywise alpha of .05.

**Potential Internal Threats**

There are several possible threats in interval validity in this research study. The first threat is from subject characteristics, which could contain many different levels. The main characteristics that will be focused on are gender, ethnicity, and intelligence. As mentioned in the literature review, it is expected that gender and ethnicity will have an impact on student performance in chemistry and their preference towards one of the two chemistry curricula. Intelligence was not discussed in the literature review, but it undoubtedly will have an impact on student performance and will most likely have an effect on curriculum preference, because learning styles have been associated with intelligence levels (Liu, Joy, & Griffiths, 2009; Muehlenbrock, 2006; Muuro, Oboko, & Wagacha, 2016). To address these threats, the comparison groups will have the same gender and ethnicity proportions. Also, as mentioned, the research study will further investigate gender and ethnicity to determine if one curriculum leads to increased student performance. As for intelligence, the two comparison groups will have an insignificant
statistical difference in average ACT composite and math subscores. This will ensure that the comparison groups were at the same level before instruction began. By ensuring that the comparison groups are similar on several characteristics this will help to eliminate the effect of nonrandom assignments. The goal is to have the two groups to be similar in all possible aspects besides the curricular method.

The second type of threat is implementation. This could occur in that the instructors teaching the two different curricula might be better at teaching one curriculum over another. The students being taught under the curriculum that the teacher is better at teaching might have higher grades simply due to the teacher and not the curriculum. Since the majority of the teachers in the study have taught both curricula the effect of their preferred teaching curriculum or any possible instructor characteristics such as teaching ability or experience may be equal for the two groups. Additionally, since there are several teachers implementing the different curricula, this will reduce the chances of an advantage to either method. This will cause the threat to have no overall effect on the study. Another possible solution to this threat would be to remove any sections that were taught by a teacher who only taught one curriculum. This may cause more issues by reducing the sample size and is not preferred. Another aspect of an implementation threat is the possible personal bias in favor of one method over the other by the instructors. Their preference for the method, rather than the method itself, may account for the superior performance of students taught by that method. One solution is to provide the instructors with a survey to determine their preferences before they started the new curriculum and afterward. This will help to determine if their preference for a method was a results of using the method or was a preference before using the method. If the
preference is a result of the method, then it does not constitute a threat and is simply one of the by-products of the methods itself.

**Limitations**

One possible limitation in interpreting the results of the study is the effect of changing from one curriculum to a new curriculum. Esterling and Bartels (2013) found that the change in curriculum caused an apparently lower student success rate in the first year, followed by significant improvement in the second year for both general chemistry courses. It is believed that this initial drop in student success is due to the instructors adjusting to the new curriculum. As the instructors become more familiar with the “atoms first” curriculum in the second year, the students’ success increases. Therefore, this could also be an effect in my research in that this initial decrease in student success during the first year of teaching the new curriculum could affect my results. This limitation will need to be taken into account in the interpretation and discussion of the results.

A second possible limitation is the lack of reliability information for the ACS final examination. This could mean that the exam is not providing reliable information for each of the sections per semester and for each of the semesters and years being analyzed and compared. This possible unreliability could mean that the difference in exam scores could be due to the exam itself and not the curricular method chosen. To determine if the exam is having an effect on the results a comparison of the final exam scores per section to each other will be conducted. This will determine if the scores for the final exam for one curricular method are similar enough to each other to be reliable. The same comparison for the scores from the second curricular method will also be conducted. This will help to provide some reliability information concerning the final
exam. Additionally, the use of the final letter grade as a second comparison or dependent variable ensures that the results correspond. Thus, one should expect to get the same results using the final letter grade as with the final exam score if the final exam score is a reliable measure.

There are also limitations due to the generalizability of the results, since the sample was not randomly assigned to a specific curricular approach. However, all of the students that took the general chemistry I and II courses during the studied time period were used in the research study. Thus, random sampling was not used, because all of the available participants were included in the research study. However, since the study used non-randomization in grouping with complete sample usage, there can be non-causal inferences extended to other populations.

Lastly, there are limitations due to the specific data analysis techniques used in the research design. The ANCOVA is limited by the multicollinearity of the covariates used. This limits the number of covariates that could be included in the final analysis. Secondly, some of the covariates were found to be dependent of the treatment type and could not be included. This decreases the ability of the statistical analysis to remove the possible effect of the student characteristics that were not included in the analysis. The three regression methods are limited by the conclusions that can be deduced from the results. You can only ascertain relationships, but never be sure about the underlying causal mechanism. One of the limitations of multiple linear regression (MLR) is that it only looks at the mean of the dependent variable, which is useful for looking at the relationship overall. However, it does not provide the detailed picture specifically the relationship at the extremes in the data. The two logistic regressions are also limited in
that the outcome variable must be categorical rather than continuous. This favors the
dependent variable final letter grade, but the final exam scores cannot be used. Thus, the
final exam cannot be triangulated using the three regression methods and results can only
be obtained through multiple linear regression. Additionally, the two logistic regression
models are vulnerable to overconfidence. These models can appear to have more
predictive power than they actually do as a result of sampling bias. Thus, these models
need to be heavily compared to the multiple linear regression model in determining the
final sub-factors to further analyze.
CHAPTER IV

RESULTS

Research Question 1

The first research question states does the “atoms first” curriculum better align to the curricular expectations established by research supported best practices? To answer this research question, a qualitative review of two chemistry textbooks written by the same author, but in the two curricular approaches was performed. The review focused on the essential elements of effective science instruction and the chemistry curriculum development guidelines mentioned in the literature review section. The two textbooks reviewed were Chemistry, 3rd edition, by Burdge (2014) and Chemistry: Atoms First by Burdge and Overby (2012).

Essential Elements of Effective Science Instruction

There are three essential elements of effective science instruction: history/nature of science, content knowledge, and inquiry. If embedded into the curriculum students will develop an understanding of these components through experiential learning, developing ownership of content, and the ability to perceive themselves as a scientist. Table 8 shows the number of pages dedicated to each of the essential elements of science instruction that were found in the “atoms first” and the “traditional” approaches. The HOS and the NOS elements were separated out for a more detailed analysis. Additionally, the scientific
method was used for the inquiry elements since it can be found in the textbooks; whereas inquiry is found in the laboratory manuals.

Table 8

*Essential Elements of Effective Science Instruction – Analysis Summary*

<table>
<thead>
<tr>
<th>Factors</th>
<th>Atoms First (Burdge &amp; Overby, 2012)</th>
<th>Traditional (Burdge, 2014)</th>
</tr>
</thead>
<tbody>
<tr>
<td>History of Science (HOS)</td>
<td>18 Chapter 2 &quot;Atoms and the Periodic Table&quot; - Discovery of the Electron</td>
<td>19 Chapter 7 &quot;Electron Configuration and the Periodic Table&quot; - Development of the Periodic Table</td>
</tr>
<tr>
<td>Nature of Science (NOS)</td>
<td>2 The new hypothesis will then be tested by experiment. When a hypothesis stands the test of extensive experimentation, it may evolve into a theory.</td>
<td>2 Scientists study these data and try to identify patterns or trends. When they find a pattern or trend, they may summarize their findings with a law.</td>
</tr>
<tr>
<td>Content</td>
<td>462 See Tables 1 and 2 - Chapter and Content Comparisons</td>
<td>428 See Tables 1 and 2 - Chapter and Content Comparisons</td>
</tr>
<tr>
<td>Scientific Method</td>
<td>3 Example of the use of the scientific method through the story of how smallpox was eradicated.</td>
<td>4 Scientists follow a set of guidelines known as the scientific method to add their results to the larger body of knowledge within a given field.</td>
</tr>
</tbody>
</table>

The first comparison is that of the HOS. The two curricular approaches have approximately the same number of pages. However, the biggest difference is the distribution of these pages throughout the chapters of the textbook. For the “atoms first”
approach, 14 of the 18 pages are found within chapters 2 and 3. This is followed by 2 pages in both chapters 4 and 11. This shows that the history of science is presented at the very beginning of the semester. Whereas, the “traditional” approach has only 7 pages in chapters 2 and 3 designated for the history of science. The remaining pages are found in chapters 6, 7, and 10 with 8, 2, and 2 pages; respectively. This shows that the history of science is distributed throughout the text. The history is presented not in one specific section like the “atoms first” approach, but presented when the relevant concept is discussed in the text.

In the “atoms first” approach example, Chapter 2 “Atoms and the Periodic Table” goes through chronologically the discovery of the subatomic particles and then moves into the different atomic models that were proposed and the experiments that were used to determine our current understanding of the atomic structure. This leads into the determining of elements and the creation of the periodic table. The goal of this chapter is to use history to lay the foundation of the atom and the concept that everything builds off of it. Whereas, in the “traditional” approach the structure of the atom is mentioned, but it is glossed over very quickly with very little detail regarding the experiments used and the various models proposed. Additionally, the creation of the periodic table is not mentioned until later in Chapter 7, “Electronic Configuration and the Periodic Table.” The “traditional” approach provides the material but not in a chronological format nor does it explain how the scientists came to understand this content.

The second comparison is that of the NOS. The two curricular approaches have exactly the same number of pages designated to the terms law and theory. In both of the approaches, the terms are briefly introduced in the first chapter of the text. Neither
approach, however, does a thorough job of explaining the difference between a theory and a law. The “atoms first” approach makes a marginally better attempt in this area in that there is mention as to how a theory is formed, but this is still not entirely accurate. This can be seen in the example provided in the table, which states that a theory is formed from the extensive experimentation of a hypothesis. Additionally, the “traditional” approach mentions the creation of a law through the finding of patterns and trends in scientific data.

The third comparison is that of content knowledge. The “atoms first” approach has more pages at 462 compared to the “traditional” approach as 428 pages. Even though the “atoms first” approach has more pages, it does not cover any more material than the “traditional” approach. The additional pages are due to the increase in worked-out example problems included throughout the chapter pages. Additionally, the “atoms first” approach provides a more in-depth coverage of the history of the atom and its development. Besides the addition of the HOS topics, the other concepts and topics are given approximately the same amount of space in each of the two approaches as seen in Table 2. The biggest difference regarding content is that the first 11 chapters are in a different order as seen in Table 1. Neither chapter is spending more time on this first half of content, but just simply the order of approaching the content is different.

The last comparison is the scientific method. The “traditional” approach includes the scientific method, but it is very brief and not described in a flexible concept, but rather as a more step-by-step procedure. The “traditional” approach describes the scientific method as a set of guidelines followed by scientists. However, the “atoms first” approach contains a description of the scientific method that is detailed and accompanied
by an example of how the method works in a real-world setting. For example, the scientific method is explained through the story of how smallpox was eradicated. This is an attempt to become closer to the actual definition and application of the scientific method. There are still a lot of inaccuracies in how the scientific method is presented in this approach, however. It is still visually shown as a flowchart of steps and the application of the method does not mention the trials and errors, the length of time it can take, and the thought process and creativity of the scientist. Overall, the “atoms first” approach appears to be making a stronger move to an accurate description of the scientific method.

**Chemistry Curriculum Guidelines**

Mbajiorgu and Reid (2006) detailed ten chemistry curriculum development guidelines with the goal of developing responsible and knowledgeable citizens who can make informed decisions based on a sound understanding of the chemical issues involved. These guidelines include: 1) meet needs of all learners; 2) relate to life; 3) reveal chemistry’s role in society; 4) have a low content base; 5) be within information processing capacity; 6) take account of language and communication; 7) aim at conceptual understanding; 8) offer genuine problem solving experience; 9) use lab work appropriately; and 10) involve appropriate assessment. The review of these guidelines will be slightly different in that some of these are not in either of the two curricular approaches or would not be found in the textbook, but rather in the laboratory or the classroom environment. For those that a direct comparison cannot be made, discussion will focus on how the two curricula are expected to be implemented based on their formats.
1. Meet needs of all learners – meet the needs of all students meaning those who will never become scientists up to those who will become bench chemists. This guideline is the primary focus of the “atoms first” approach. This approach arranges the content leading to a more cohesive and ordered curriculum. By examining the atom, the student is able to slowly build up to more challenging concepts. This gives the student time to learn the vocabulary and slowly introduces the mathematical formulas. The “traditional” approach tries to meet this guideline through examples and sample problems that are worked out step-by-step to help guide learners. However, this guideline is not one of the stated focuses of the “traditional” approach.

2. Relate to life – should relate tightly to applications in life. This guideline is meet in both approaches. The authors use a wide range of examples in the texts. Such as, cross-disciplinary examples involving biology or medicine to help some students relate more to everyday life. For example, both texts have a section discussing the everyday occurrences of the photoelectric effect. Some of the everyday applications mentioned include the type of device that prevents a garage door from closing when something is in the door’s path, motion-detection systems used in museums, and night-vision googles. Both curricular approaches use approximately the same number of real-life examples and applications in their texts.

3. Reveal chemistry’s role in society – What questions does chemistry ask? How does chemistry obtain its answers? How does chemistry relate to life? This guideline is not answered in either of the two approaches’ textbooks. It is generally not a focus in general chemistry textbooks. The area of society and science is not something
that is discussed at all in the field of chemistry and thus would not be in either approach.

The texts try to relate to society. For example, the “atoms first” approach has a “Thinking Outside the Box” section with one focusing on acid rain, its effects on society, and the legislation that has occurred due to its discovery. Additionally, the “traditional” approach has a “Bringing Chemistry to Life” section and one such section focuses on heat capacity and hypothermia and how understanding this relationship has helped victims survive and recover. However, both approaches do not go far enough in relating to society especially in regards to discussing chemistry’s role in society. This is one of the major gaps in the two approaches and chemistry instruction in general.

### 4. Have a low content base – not be too “content-laden”, provide adequate time to pursue misconceptions and obtain a deep understanding of ideas.

This was already discussed in the essential elements of science instruction content analysis review. Both approaches cover the same amount of material for both chemistry courses and go into approximately the same depth. The only difference is the more in-depth coverage of the history of chemistry by the “atoms first” approach. However, the amount of time spent on each chapter or concept is approximately the same. But this amount of time could be improved by allowing students more time for each topic. The focus should be more in-depth with fewer topics then on many topics at a shallow level. However, this would be dependent on the course instructor or the curriculum coordinator who determines what chapters or concepts are required to be covered in each semester course.

### 5. Be within information processing capacity – introduce sub-micro, symbolic, or macro ideas one at a time gradually increasing to two groups at the
same time. The “atoms first” approach slowly guides students through the atom and slowly introduces them to the vocabulary and mathematics. By focusing on students that are not science concentrations, you are also helping students to ease into the topics. For example, the “atoms first” approach introduces the complex calculation of empirical and molecular formulas using percent composition in chapter 5 starting on page 170. Whereas, the “traditional” approach introduces this same concept in chapter 3 starting on page 92. As seen, the “traditional” approach introduces the symbolic and macro ideas combined with complex mathematics within the first few chapters. This overload of processing capacity makes it difficult for students to fully understand all of the information presented in the beginning of the course. This may cause students to fall behind or have a weak understanding of foundational chemistry concepts.

6. Take account of language and communication – use accessible language and provide opportunities to express chemical ideas both verbally and in writing.

This guideline is not answered in either of the two approaches’ textbooks. The first segment – accessible language – could be easily achieved in the two approaches, but neither textbook approach does a better job of using everyday language to explain complex topics. This is one area where the differences in the two approaches is non-existent. It appears that the author did not change the verbiage when creating the new curricular approach, but simply changed the chapter ordering and included some supplemental material. The only differences in text are in the extended sections or new sections within the “atoms first” approach, such as the history of chemistry section. The second segment – opportunities to express chemical ideas both verbally and in writing – is not found in either approach’s textbooks, but could be accomplished through inquiry-
based laboratory activities. This guideline could also be achieved by having students write formal lab reports early in the semester instead of cookie cutter lab reports. As previously mentioned, the “atoms first” approach does not have hands-on labs early in the semester. This provides an opportunity for activities focused on improving chemical communication and language to be incorporated in these early lab experiments. Whereas, in the “traditional” approach these activities would need to be sprinkled into the experiments throughout the semester, since there isn’t a readily available section to dedicate to this guideline.

7. **Aim at conceptual understanding – aim to develop conceptual understanding rather than recall of information, be aware of misconceptions and alternatives.** This guideline is not addressed in either of the two approaches’ textbooks, but depends on the specific course instructor and what was focused on during the lecture period and examinations. To achieve this guideline, the tests should focus more on concepts and understanding rather than memorization. This can be accomplished in both approaches if the teacher choices to focus on authentic assessments that align to this goal as opposed to multiple choice information unloading focused examinations.

8. **Offer genuine problem solving experience – offer more open-ended problems, use group work to solve “real-life” problems in chemistry.** This guideline is also not addressed in either of the two approaches’ textbooks, but depends on the specific course instructor and what assignments were assigned to the students. The two approaches’ specific texts have real-world examples, but they may or may not be assigned to the students. The instructor could use these examples to show students who
chemistry relate to everyday life and how it can be used to solve problems. However, an even better way to accomplish this guideline is through lab experiments that focus on real-world problems instead of theory checking experiments. These labs would give students the experience of how to approach problems through the lens of chemistry and the practical skills of how to actually do the experiments.

9. Use lab work appropriately – have clear aims, make chemistry real as well as developing or challenging ideas, offer opportunities for genuine problem solving.

It has been mentioned previously that the “traditional” approach is better suited for courses that have a concurrent lab. Since the “atoms first” spends a significant amount of time at the beginning of the course detailing the history of the atom and the periodic table, this leaves little room for concurrent labs that are directly related. In the majority of the “atoms first” laboratories the students have to do theoretical or mathematics focused labs instead of hands-on reaction based experiments. These hands-on reaction based experiments come at the end of the semester once the material has been presented. For example, the “atoms first” students take mass and dimension related measurements of a zinc cylinder and then have to perform several mathematical calculations to determine the size of a zinc atom. The students are learning how to make basic measurements and use a digital scale, but the focus of the experiment is the mathematical calculations needed to convert from mass to the atom size. Whereas in the “traditional” approach the students are introduced to the material earlier in lecture and thus can do these hands-on experiments much sooner. An early lab in the “traditional” curriculum would be determining the limiting reagent of a reaction using stoichiometry via various chemical reactions. However, this lab is later in the “atoms first” approach given that this topic is
not covered until later in the ordering of topics. Therefore, it appears that the “traditional” approach provides more opportunities for inquiry based laboratory experiments. However, this is dependent on how the laboratory activities are developed. The mathematical activities in the “atoms first” approach may help the students develop their ability to do inquiry and later maximize their outcomes during the hands-on reaction based portions of the lab. Additionally, some of these hands-on activities used in the “traditional” approach are cookbook or verification labs, which do not allow students the opportunity to develop a thorough understanding of the inquiry process. Overall if inquiry labs are used, the “traditional” approach provides students with more hands-on reaction based experimental time compared to the “atoms first” approach.

10. **Involve appropriate assessment – integrated into the curriculum, mixture of formative and summative, gives credit to understanding rather than recall.** This guideline is also not addressed in either of the two approaches’ textbooks, but depends on how the specific course instructor develops the assessments and determines the goals of each. One way to move closer to this guideline is moving away from standardized final examinations to more appropriate assessments that involve more testing options besides multiple choice questions.

The results of research questions two and three will first be divided by the chemistry course. It will be useful to see the results of the first semester chemistry course, Chemistry I, followed by the results of the second semester chemistry course, Chemistry II. This will show if there are any long term retention impacts from the curricular approaches. For each chemistry course, the results will be presented in order of the research question first the overall curricular approach analysis followed by the sub-factor
analysis. Lastly, in each of the research questions the final exam percentage results will be shown followed by the results using the final letter grade. This will allow for easy comparison of the two different dependent variable measures for the same research question.

**Research Question 2 – Chemistry I**

The second research question states does the “atoms first” curriculum lead to higher student success compared to the “traditional” curriculum for all students when all other sub-factors are considered as covariates? To answer this research question, an ANCOVA was performed to determine if there is a significant difference between the “atoms first” and the “traditional” general chemistry curricula. The independent variable was the curricular method either the “traditional” approach or the “atoms first” approach. The dependent variable was the final exam percentage score or the final letter grade. The covariates tested were gender, ethnicity, major, ACT composite score, ACT math score, overall GPA, and classroom size. All analysis was done at an alpha level of .05.

**Final Exam Percentage Results**

The data from the first semester Chemistry I course were analyzed to determine if there is a statistical difference between the “atoms first” and the “traditional” curricular approaches. The following analysis shows the results when all semesters taught for each of the curricula were combined and compared overall regardless of the specific semester the course was taught. Levene’s test was not significant, $F(1, 5874) = 3.664, p = .056$, indicating that the assumption of homogeneity of variance had been met. The assumption of homogeneity of regression slopes was met due to the non-significant results for both
the curriculum and gender interaction, $F(1, 5868) = 1.701, p = .192$, and the curriculum and overall GPA interaction, $F(1, 5868) = 2.675, p = .102$. However, the assumption of multicollinearity was not met. The main effect of curriculum was significant, $F(1, 5872) = 251.058, p < .001$, partial $\eta^2 = .041$, indicating that the final exam percentage scores were higher using the “traditional” curriculum ($M = 68.849, Std. Dev. = 20.569$) compared to the “atoms first” curriculum ($M = 62.950, Std. Dev. = 19.021$).

Table 9

*ANCOVA tests of between-subjects effects – Curriculum comparison overall – Final exam percentage – Chemistry I*

<table>
<thead>
<tr>
<th>Source</th>
<th>Type III Sum of Squares</th>
<th>df</th>
<th>Mean Square</th>
<th>F</th>
<th>Sig.</th>
<th>Partial Eta Squared</th>
</tr>
</thead>
<tbody>
<tr>
<td>Intercept</td>
<td>45811.188</td>
<td>1</td>
<td>45811.188</td>
<td>189.772</td>
<td>.000</td>
<td>.031</td>
</tr>
<tr>
<td>Gender</td>
<td>42476.631</td>
<td>1</td>
<td>42476.631</td>
<td>175.959</td>
<td>.000</td>
<td>.029</td>
</tr>
<tr>
<td>Overall GPA</td>
<td>892486.696</td>
<td>1</td>
<td>892486.696</td>
<td>3697.118</td>
<td>.000</td>
<td>.386</td>
</tr>
<tr>
<td>Curriculum</td>
<td>60605.581</td>
<td>1</td>
<td>60605.581</td>
<td>251.058</td>
<td>.000</td>
<td>.041</td>
</tr>
<tr>
<td>Error</td>
<td>1417504.566</td>
<td>5872</td>
<td>241.401</td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>Total</td>
<td>27985862.647</td>
<td>5876</td>
<td></td>
<td></td>
<td></td>
<td></td>
</tr>
</tbody>
</table>

Dependent variable: Final exam percentage, $R^2 = .400$, Adjusted-$R^2 = .400$

All seven covariates, gender, ethnicity, major, ACT composite, ACT math, overall GPA, and classroom size, were tested regarding their independence from the treatment. Only gender, $F(1, 6326) = 1.639, p = .200$, and overall GPA, $F(1, 6326) = 3.811, p = .051$, were found to be non-significant and thus are independent of the curricular approach. The covariate, gender, was also significant, $F(1, 5872) = 175.959, p < .001$, partial $\eta^2 = .029$, indicating that gender had a significant effect on the final exam percentage scores for the two curricular approaches. The covariate, overall GPA, was
also significant, $F(1, 5872) = 3697.118$, $p < .001$, partial $\eta^2 = .386$, indicating that overall GPA had a significant effect on the final exam percentage scores for the two curricular approaches (there was a positive relationship between these two variables).

**Figure 1.** Overview of final exam percentage averages for each academic semester and curricular approach – Chemistry I.

Green checkered filled bars represent the “traditional” curricular approach, blue solid filled bars represent the “atoms first” curricular approach.

Figure 1 shows the overview of the final exam percentage averages for each academic semester based on the curricular approach used. Additionally, the figure separates the fall semester averages from the spring semester averages. This was done to show the differences in student performance for those students considered to be on-sequence versus those off-sequence. On-sequence refers to those students who took Chemistry I during the fall semester, which is the first semester the course would be offered for those students. Off-sequence refers to those students who took Chemistry I during the spring semester, which is the second semester or off-semester for the course.
There are several factors impacting when a student takes Chemistry I such as their schedule, meeting the mathematics requirements, the available capacity of the classroom, and so on. Additionally, this staggered approach also allows students in the on-sequence who fail the class to repeat it immediately. Because the on-sequence and off-sequence populations may differ, they have been separated in the figure with on-sequence on the left side and off-sequence on the right side. The figure shows that for those students on-sequence the “atoms first” approach had lower final exam percentage averages per semester compared to the “traditional” approach. These same results were seen when looking at the off-sequence students.

The data from the first semester Chemistry I course were divided into the on-sequence semesters and the off-sequence semesters and then analyzed to determine if there is a statistical difference between the “atoms first” and the “traditional” curricular approaches for each sequence. The following on-sequence analysis shows the results of the fall 2012 and 2013 “traditional” curricular semesters compared to the fall 2014 and 2015 “atoms first” curricular semesters. Levene’s test was significant, $F(1, 4512) = 8.337, p = .004$, indicating that the assumption of homogeneity of variance had not been met. Secondly, the assumption of homogeneity of regression slopes was not met due to the significant results for both the curriculum and gender interaction, $F(1, 4507) = 4.488, p = .034$, and the curriculum and overall GPA interaction, $F(1, 4507) = 8.051, p = .005$. Lastly, the assumption of multicollinearity was not met. The main effect of curriculum was significant, $F(1, 4510) = 214.229, p < .001$, partial $\eta^2 = .045$, indicating that the final exam percentage scores were higher using the “traditional” curriculum ($M = 71.555$, Std.}
Dev. = 19.803) compared to the “atoms first” curriculum (M = 64.967, Std. Dev. = 18.584).

Table 10

*ANCOVA tests of between-subjects effects – Curriculum comparison for on-sequence – Final exam percentage – Chemistry I*

<table>
<thead>
<tr>
<th>Source</th>
<th>Type III Sum of Squares</th>
<th>df</th>
<th>Mean Square</th>
<th>F</th>
<th>Sig.</th>
<th>Partial Eta Squared</th>
</tr>
</thead>
<tbody>
<tr>
<td>Intercept</td>
<td>50412.472</td>
<td>1</td>
<td>50412.472</td>
<td>223.082</td>
<td>.000</td>
<td>.047</td>
</tr>
<tr>
<td>Gender</td>
<td>33302.994</td>
<td>1</td>
<td>33302.994</td>
<td>147.370</td>
<td>.000</td>
<td>.032</td>
</tr>
<tr>
<td>Overall GPA</td>
<td>639515.594</td>
<td>1</td>
<td>639515.594</td>
<td>2829.941</td>
<td>.000</td>
<td>.386</td>
</tr>
<tr>
<td>Curriculum</td>
<td>48411.792</td>
<td>1</td>
<td>48411.792</td>
<td>214.229</td>
<td>.000</td>
<td>.045</td>
</tr>
<tr>
<td>Error</td>
<td>1019178.741</td>
<td>4510</td>
<td>225.982</td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>Total</td>
<td>22722382.754</td>
<td>4514</td>
<td></td>
<td></td>
<td></td>
<td></td>
</tr>
</tbody>
</table>

Dependent variable: Final exam percentage, $R^2 = .405$, Adjusted-$R^2 = .404$

To stay consistent with the overall analysis performed the same two covariates, gender and overall GPA, were used in the analysis. Both gender, $F(1, 4944) = 1.146, p = .284$, and overall GPA, $F(1, 4944) = .015, p = .901$, were found to be non-significant and independent of the curricular approach. The covariate, gender, was also significant, $F(1, 4510) = 147.370, p < .001$, partial $\eta^2 = .032$, indicating that gender had a significant effect on the final exam percentage scores for the two curricular approaches. The covariate, overall GPA, was also significant, $F(1, 4510) = 2829.941, p < .001$, partial $\eta^2 = .386$, indicating that overall GPA had a significant effect on the final exam percentage scores for the two curricular approaches (there was a positive relationship between these two variables).
The following off-sequence analysis shows the results of the spring 2013 and 2014 “traditional” curricular semesters compared to the spring 2015 “atoms first” curricular semester. Levene’s test was not significant, $F(1, 1360) = .231, p = .631$, indicating that the assumption of homogeneity of variance had been met. The assumption of homogeneity of regression slopes was met due to the non-significant results for both the curriculum and gender interaction, $F(1, 1356) = 2.708, p = .100$, and the curriculum and overall GPA interaction, $F(1, 1356) = 3.458, p = .063$. However, the assumption of multicollinearity was not met. The main effect of curriculum was significant, $F(1, 1358) = 78.194, p \leq .001$, partial $\eta^2 = .054$, indicating that the final exam percentage scores were higher using the “traditional” curriculum ($M = 61.651, \text{Std. Dev.} = 20.846$) compared to the “atoms first” curriculum ($M = 54.149, \text{Std. Dev.} = 18.413$).

Table 11

\textit{ANCOVA tests of between-subjects effects – Curriculum comparison for off-sequence – Final exam percentage – Chemistry I}

<table>
<thead>
<tr>
<th>Source</th>
<th>Type III Sum of Squares</th>
<th>df</th>
<th>Mean Square</th>
<th>F</th>
<th>Sig.</th>
<th>Partial Eta Squared</th>
</tr>
</thead>
<tbody>
<tr>
<td>Intercept</td>
<td>8068.211</td>
<td>1</td>
<td>8068.211</td>
<td>29.892</td>
<td>.000</td>
<td>.022</td>
</tr>
<tr>
<td>Gender</td>
<td>3376.465</td>
<td>1</td>
<td>3376.465</td>
<td>12.510</td>
<td>.000</td>
<td>.009</td>
</tr>
<tr>
<td>Overall GPA</td>
<td>172785.761</td>
<td>1</td>
<td>172785.761</td>
<td>640.160</td>
<td>.000</td>
<td>.320</td>
</tr>
<tr>
<td>Curriculum</td>
<td>21105.475</td>
<td>1</td>
<td>21105.475</td>
<td>78.194</td>
<td>.000</td>
<td>.054</td>
</tr>
<tr>
<td>Error</td>
<td>366538.072</td>
<td>1358</td>
<td>269.910</td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>Total</td>
<td>5263479.893</td>
<td>1362</td>
<td></td>
<td></td>
<td></td>
<td></td>
</tr>
</tbody>
</table>

Dependent variable: Final exam percentage, $R^2 = .345$, Adjusted-$R^2 = .343$

To stay consistent with the overall analysis performed the same two covariates, gender and overall GPA, were used in the analysis. Both gender, $F(1, 1380) = .394, p =$
.531, and overall GPA, $F(1, 1380) = 2.017, p = .156$, were found to be non-significant and independent of the curricular approach. The covariate, gender, was also significant, $F(1, 1358) = 12.510, p < .001$, partial $\eta^2 = .009$, indicating that gender had a significant effect on the final exam percentage scores for the two curricular approaches. The covariate, overall GPA, was also significant, $F(1, 1358) = 640.160, p < .001$, partial $\eta^2 = .320$, indicating that overall GPA had a significant effect on the final exam percentage scores for the two curricular approaches (there was a positive relationship between these two variables).

**Final Letter Grade Results**

The data from the first semester Chemistry I course were analyzed to determine if there is a statistical difference between the “atoms first” and the “traditional” curricular approaches. The following analysis shows the results when all semesters taught for each of the curricula were combined and compared overall regardless of the specific semester the course was taught. Levene’s test was significant, $F(1, 6326) = 5.007, p = .025$, indicating that the assumption of homogeneity of variance had not been met. Also, the assumption of multicollinearity was not met. The assumption of homogeneity of regression slopes was partially met due to the non-significant result for the curriculum and gender interaction, $F(1, 6322) = .042, p = .837$, and the significant result for the curriculum and overall GPA interaction, $F(1, 6322) = 7.644, p = .006$. The main effect of curriculum was non-significant, $F(1, 6324) = .138, p = .710$, partial $\eta^2 = .000$, indicating that the final letter grades were not statistically different using the “traditional” curriculum ($M = 2.289, Std. Dev. = 1.410$) compared to the “atoms first” curriculum ($M = 2.356, Std. Dev. = 1.348$).
Table 12

ANCOVA tests of between-subjects effects – Curriculum comparison overall – Final letter grade – Chemistry I

<table>
<thead>
<tr>
<th>Source</th>
<th>Type III Sum of Squares</th>
<th>df</th>
<th>Mean Square</th>
<th>F</th>
<th>Sig.</th>
<th>Partial η Squared</th>
</tr>
</thead>
<tbody>
<tr>
<td>Intercept</td>
<td>1512.382</td>
<td>1</td>
<td>1512.382</td>
<td>2142.049</td>
<td>.000</td>
<td>.253</td>
</tr>
<tr>
<td>Gender</td>
<td>131.903</td>
<td>1</td>
<td>131.903</td>
<td>186.820</td>
<td>.000</td>
<td>.029</td>
</tr>
<tr>
<td>Overall GPA</td>
<td>7581.230</td>
<td>1</td>
<td>7581.230</td>
<td>10737.613</td>
<td>.000</td>
<td>.629</td>
</tr>
<tr>
<td>Curriculum</td>
<td>.098</td>
<td>1</td>
<td>.098</td>
<td>.138</td>
<td>.710</td>
<td>.000</td>
</tr>
<tr>
<td>Error</td>
<td>4465.024</td>
<td>6324</td>
<td>.706</td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>Total</td>
<td>46177.000</td>
<td>6328</td>
<td></td>
<td></td>
<td></td>
<td></td>
</tr>
</tbody>
</table>

Dependent variable: Final letter grade, $R^2 = .630$, Adjusted-$R^2 = .630$

All seven covariates, gender, ethnicity, major, ACT composite, ACT math, overall GPA, and classroom size, were tested regarding their independence from the treatment. Only gender, $F(1, 6326) = 1.639, p = .200$, and overall GPA, $F(1, 6326) = 3.811, p = .051$, were found to be non-significant and thus are independent of the curricular approach. The covariate, gender, was also significant, $F(1, 6324) = 186.820, p < .001$, partial $\eta^2 = .029$, indicating that gender had a significant effect on the final letter grades for the two curricular approaches. The covariate, overall GPA, was also significant, $F(1, 6324) = 10737.613, p < .001$, partial $\eta^2 = .629$, indicating that overall GPA had a significant effect on the final letter grades for the two curricular approaches.
Figure 2. Overview of final letter grade averages for each academic semester and curricular approach – Chemistry I.

Green checkered filled bars represent the “traditional” curricular approach, blue solid filled bars represent the “atoms first” curricular approach.

Figure 2 shows the overview of the final letter grade averages for each academic semester based on the curricular approach used. Additionally, the figure separates the fall semester averages, on-sequence students, from the spring semester averages, off-sequence students. The figure shows that for those students on-sequence the “atoms first” approach had similar final letter grade averages per semester compared to the “traditional” approach. However, for those students off-sequence the “atoms first” approach had higher final letter grade averages per semester compared to the “traditional” approach.

The data from the first semester Chemistry I course were divided into the on-sequence semesters and the off-sequence semesters and then analyzed to determine if there is a statistical difference between the “atoms first” and the “traditional” curricular approaches for each sequence. The following on-sequence analysis shows the results of
the fall 2012 and 2013 “traditional” curricular semesters compared to the fall 2014 and 2015 “atoms first” curricular semesters. Levene’s test was non-significant, \(F(1, 4944) = 1.282, p = .258\), indicating that the assumption of homogeneity of variance had been met. The assumption of homogeneity of regression slopes was partially met due to the non-significant result for the curriculum and gender interaction, \(F(1, 4940) = .904, p = .342\), and the significant result for the curriculum and overall GPA interaction, \(F(1, 4940) = 7.383, p = .007\). However, the assumption of multicollinearity was not met. The main effect of curriculum was non-significant, \(F(1, 4942) = 2.916, p = .088\), partial \(\eta^2 = .001\), indicating that the final letter grades were not statistically different using the “traditional” curriculum (\(M = 2.422, Std. Dev. = 1.396\)) compared to the “atoms first” curriculum (\(M = 2.391, Std. Dev. = 1.344\)).

Table 13

**ANOVA tests of between-subjects effects – Curriculum comparison for on-sequence – Final letter grade – Chemistry I**

<table>
<thead>
<tr>
<th>Source</th>
<th>Type III Sum of Squares</th>
<th>df</th>
<th>Mean Square</th>
<th>F</th>
<th>Sig.</th>
<th>Partial Eta Squared</th>
</tr>
</thead>
<tbody>
<tr>
<td>Intercept</td>
<td>1146.349</td>
<td>1</td>
<td>1146.349</td>
<td>1682.919</td>
<td>.000</td>
<td>.254</td>
</tr>
<tr>
<td>Gender</td>
<td>136.235</td>
<td>1</td>
<td>136.235</td>
<td>200.003</td>
<td>.000</td>
<td>.039</td>
</tr>
<tr>
<td>Overall GPA</td>
<td>5905.211</td>
<td>1</td>
<td>5905.211</td>
<td>8669.256</td>
<td>.000</td>
<td>.637</td>
</tr>
<tr>
<td>Curriculum</td>
<td>1.986</td>
<td>1</td>
<td>1.986</td>
<td>2.916</td>
<td>.088</td>
<td>.001</td>
</tr>
<tr>
<td>Error</td>
<td>3366.327</td>
<td>4942</td>
<td>.681</td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>Total</td>
<td>37904.000</td>
<td>4946</td>
<td></td>
<td></td>
<td></td>
<td></td>
</tr>
</tbody>
</table>

Dependent variable: Final letter grade, \(R^2 = .637\), Adjusted-\(R^2 = .637\)

To stay consistent with the overall analysis performed the same two covariates, gender and overall GPA, were used in the analysis. Both gender, \(F(1, 4944) = 1.146, p =\)
.284, and overall GPA, $F(1, 4944) = .015, p = .901$, were found to be non-significant and independent of the curricular approach. The covariate, gender, was also significant, $F(1, 4942) = 200.003, p < .001$, partial $\eta^2 = .039$, indicating that gender had a significant effect on the final letter grades for the two curricular approaches. The covariate, overall GPA, was also significant, $F(1, 4942) = 8669.256, p < .001$, partial $\eta^2 = .637$, indicating that overall GPA had a significant effect on the final letter grades for the two curricular approaches.

The following off-sequence analysis shows the results of the spring 2013 and 2014 “traditional” curricular semesters compared to the spring 2015 “atoms first” curricular semester. Levene’s test was not significant, $F(1, 1380) = 1.076, p = .300$, indicating that the assumption of homogeneity of variance had been met. The assumption of homogeneity of regression slopes was partially met due to the significant result for the curriculum and gender interaction, $F(1, 1376) = 4.713, p = .030$, and the non-significant result for the curriculum and overall GPA interaction, $F(1, 1376) = 1.426, p = .233$. However, the assumption of multicollinearity was not met. The main effect of curriculum was significant, $F(1, 1378) = 13.921, p \leq .001$, partial $\eta^2 = .010$, indicating that the final letter grades were higher using the “atoms first” curriculum ($M = 2.185, \text{Std. Dev.} = 1.358$) compared to the “traditional” curriculum ($M = 1.921, \text{Std. Dev.} = 1.384$).
Table 14

**ANCOVA tests of between-subjects effects – Curriculum comparison for off-sequence –**

**Final letter grade – Chemistry I**

<table>
<thead>
<tr>
<th>Source</th>
<th>Type III Sum of Squares</th>
<th>df</th>
<th>Mean Square</th>
<th>F</th>
<th>Sig.</th>
<th>Partial Eta Squared</th>
</tr>
</thead>
<tbody>
<tr>
<td>Intercept</td>
<td>315.876</td>
<td>1</td>
<td>315.876</td>
<td>405.721</td>
<td>.000</td>
<td>.227</td>
</tr>
<tr>
<td>Gender</td>
<td>6.643</td>
<td>1</td>
<td>6.643</td>
<td>8.532</td>
<td>.004</td>
<td>.006</td>
</tr>
<tr>
<td>Overall GPA</td>
<td>1481.121</td>
<td>1</td>
<td>1481.121</td>
<td>1902.395</td>
<td>.000</td>
<td>.580</td>
</tr>
<tr>
<td>Curriculum</td>
<td>10.838</td>
<td>1</td>
<td>10.838</td>
<td>13.921</td>
<td>.000</td>
<td>.010</td>
</tr>
<tr>
<td>Error</td>
<td>1072.850</td>
<td>1378</td>
<td>.779</td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>Total</td>
<td>8273.000</td>
<td>1382</td>
<td></td>
<td></td>
<td></td>
<td></td>
</tr>
</tbody>
</table>

Dependent variable: Final letter grade, $R^2 = .592$, Adjusted-$R^2 = .591$

To stay consistent with the overall analysis performed the same two covariates, gender and overall GPA, were used in the analysis. Both gender, $F(1, 1380) = .394, p = .531$, and overall GPA, $F(1, 1380) = 2.017, p = .156$, were found to be non-significant and independent of the curricular approach. The covariate, gender, was also significant, $F(1, 1378) = 8.532, p = .004$, partial $\eta^2 = .006$, indicating that gender had a significant effect on the final letter grades for the two curricular approaches. The covariate, overall GPA, was also significant, $F(1, 1378) = 1902.395, p < .001$, partial $\eta^2 = .580$, indicating that overall GPA had a significant effect on the final letter grades for the two curricular approaches.

**Research Question 3 – Chemistry I**

The third research question states does the “atoms first” curriculum lead to higher student success compared to the “traditional” curriculum when students are differentiated into each of the sub-factors? The sub-factors analyzed in this study are gender, ethnicity/race, major (chemistry majors versus non-majors), composite ACT score, math
ACT subscore, GPA, and classroom setting size (large versus small). To answer this research question, a multiple linear regression, multinomial logistic regression, and a binary logistic regression were performed using all of the subgroups (gender, ethnicity/race, major, ACT composite, ACT math, GPA, and classroom size) as possible predictor variables to determine if there are any significant interactions between the curricular methods and the different subgroups (predictor variables). In addition to the subgroups, a semester sequence variable, specifying whether the student was enrolled in chemistry I during an on- or off-sequence semester, was added based on the between groups correlation. The curricular method was set as a predictor variable with two levels; “traditional” approach and “atoms first” approach. The outcome variable will be the final exam percentage scores or the final letter grades.

**Final Exam Percentage Results**

The initial regression model was determined using all seven sub-group factors (gender, ethnicity/race, major, ACT composite, ACT math, GPA, and classroom size), term sequence, curricular approach, and all interaction terms involving curricular approach, the seven sub-factors, and the term sequence variable. Ethnicity/race was tested in three different formats: 1) using all eight individual categories – American Indian or Alaskan Native, Asian, Black or African American, Hispanic or Latino, Multiracial, Native Hawaiian or Other Pacific Islander, Unknown, and White; 2) using four major categories – Other, Black or African American, Hispanic or Latino, and White; and 3) using three major categories – Other, Black or African American, and White. The same results were found using all three different ethnicity breakdowns. For simplicity of result
presentation, the ethnicity breakdown using only the three major categories will be displayed.

Table 15 provides the means and standard deviations for the dependent variable (final exam percentage), the seven sub-factors, the term sequence variable, the curriculum variable, and all interaction variables.

Table 15

*Descriptive statistics for full regression model using final exam percentage – Chemistry I*

<table>
<thead>
<tr>
<th></th>
<th>Mean</th>
<th>Standard Deviation</th>
</tr>
</thead>
<tbody>
<tr>
<td>Final Exam Percentage</td>
<td>66.069</td>
<td>19.929</td>
</tr>
<tr>
<td>Gender</td>
<td>.547</td>
<td>.498</td>
</tr>
<tr>
<td>Ethnicity - Other</td>
<td>.070</td>
<td>.256</td>
</tr>
<tr>
<td>Ethnicity - Black or African American</td>
<td>.173</td>
<td>.378</td>
</tr>
<tr>
<td>Non-Major</td>
<td>.896</td>
<td>.305</td>
</tr>
<tr>
<td>Major - Other</td>
<td>.086</td>
<td>.280</td>
</tr>
<tr>
<td>ACT Composite</td>
<td>25.610</td>
<td>4.395</td>
</tr>
<tr>
<td>ACT Math</td>
<td>25.098</td>
<td>4.537</td>
</tr>
<tr>
<td>Overall GPA</td>
<td>3.067</td>
<td>.765</td>
</tr>
<tr>
<td>Classroom Size</td>
<td>.059</td>
<td>.235</td>
</tr>
<tr>
<td>Term - Sequence</td>
<td>.232</td>
<td>.422</td>
</tr>
<tr>
<td>Curriculum</td>
<td>.525</td>
<td>.499</td>
</tr>
<tr>
<td>Gender * Curriculum</td>
<td>.284</td>
<td>.451</td>
</tr>
<tr>
<td>EthnicityOther * Curriculum</td>
<td>.038</td>
<td>.192</td>
</tr>
<tr>
<td>EthnicityBlack * Curriculum</td>
<td>.094</td>
<td>.292</td>
</tr>
<tr>
<td>Non-Major * Curriculum</td>
<td>.465</td>
<td>.499</td>
</tr>
<tr>
<td>MajorOther * Curriculum</td>
<td>.049</td>
<td>.216</td>
</tr>
<tr>
<td>ACTComposite * Curriculum</td>
<td>13.334</td>
<td>13.071</td>
</tr>
<tr>
<td>ACTMath * Curriculum</td>
<td>13.089</td>
<td>12.876</td>
</tr>
<tr>
<td>GPA * Curriculum</td>
<td>1.604</td>
<td>1.623</td>
</tr>
<tr>
<td>Classroom * Curriculum</td>
<td>.036</td>
<td>.187</td>
</tr>
<tr>
<td>TermSequence * Curriculum</td>
<td>.144</td>
<td>.351</td>
</tr>
</tbody>
</table>

Note. *N* = 5555
The sample obtained an \( R \) value and an \( R \)-squared value of .717 and .514, respectively. The independent variables in the model explain 51.4% of the total sample variation of final exam percentage scores (\( y \)). The adjusted \( R \)-squared value is .512. This implies that the least squares model has explained 51.2% of the total sample variation in final exam percentage scores (\( y \)), after adjusting for sample size and number of independent variables in the model.

Table 16

*Model summary of full regression analysis – Final exam percentage – Chemistry I*

<table>
<thead>
<tr>
<th>Model</th>
<th>( R )</th>
<th>( R ) Square</th>
<th>Adjusted ( R ) Square</th>
<th>Std. Error of the Estimate</th>
</tr>
</thead>
<tbody>
<tr>
<td>1</td>
<td>.717</td>
<td>.514</td>
<td>.512</td>
<td>13.926</td>
</tr>
</tbody>
</table>

Note. Predictors: (Constant), Gender, Ethnicity - Other, Ethnicity - Black or African American, Non-Major, Major-Other, ACT Composite, ACT Math, Overall GPA, Classroom Size, Term – Sequence, Curriculum, Gender * Curriculum, EthnicityOther * Curriculum, EthnicityBlack * Curriculum, Non-Major * Curriculum, MajorOther * Curriculum, ACTComp * Curriculum, ACTMath * Curriculum, GPA * Curriculum, Classroom * Curriculum, TermSequence * Curriculum.

At an alpha of .05, there were 12 of the 21 tested variables found to be statistically significant in the model. These 12 variables were used for the finalized regression model. These include: gender, major, ACT composite, ACT math, overall GPA, classroom size, term sequence, curriculum approach, gender and curriculum interaction, GPA and curriculum interaction, and classroom size and curriculum interaction variables. Table 17 provides the correlations for the dependent variable (final exam percentage) and those 12 statistically significant variables used in the finalized regression model.
Table 17

*Correlations among statistically significant finalized regression model variables – Final exam percentage – Chemistry I*

<table>
<thead>
<tr>
<th></th>
<th>Gender</th>
<th>Non-Major</th>
<th>Major-Other</th>
<th>ACT Composite</th>
<th>ACT Math</th>
<th>Overall GPA</th>
<th>Classroom Size</th>
<th>Term-Sequence</th>
<th>Curriculum</th>
<th>Gender * Curriculum</th>
<th>GPA * Curriculum</th>
<th>Classroom * Curriculum</th>
</tr>
</thead>
<tbody>
<tr>
<td>Final Exam Percentage</td>
<td>0.034**</td>
<td>0.098*</td>
<td>-0.156*</td>
<td>0.547*</td>
<td>0.556*</td>
<td>0.603*</td>
<td>-0.202*</td>
<td>0.152*</td>
<td>0.089*</td>
<td>0.302*</td>
<td>0.054**</td>
<td>0.187**</td>
</tr>
<tr>
<td>Gender</td>
<td>-0.073*</td>
<td>0.112*</td>
<td>0.073*</td>
<td>0.147*</td>
<td>-0.162*</td>
<td>-0.037**</td>
<td>-0.076*</td>
<td>-0.014</td>
<td>0.573*</td>
<td>-0.053*</td>
<td>-0.028*</td>
<td></td>
</tr>
<tr>
<td>Non-Major</td>
<td>-0.901*</td>
<td>0.202*</td>
<td>0.165*</td>
<td>0.167*</td>
<td>-0.207*</td>
<td>-0.066*</td>
<td>-0.038**</td>
<td>-0.063*</td>
<td>0.005</td>
<td>-0.187**</td>
<td></td>
<td></td>
</tr>
<tr>
<td>Major-Other</td>
<td>-0.240*</td>
<td>-0.200*</td>
<td>-0.217*</td>
<td>0.005</td>
<td>0.097*</td>
<td>0.028**</td>
<td>0.084*</td>
<td>0.029**</td>
<td>0.016</td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>ACT Composite</td>
<td>0.864*</td>
<td>0.483*</td>
<td>0.020</td>
<td>-0.285*</td>
<td>-0.054*</td>
<td>0.000</td>
<td>0.071*</td>
<td>-0.017</td>
<td></td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>ACT Math</td>
<td>0.453*</td>
<td>0.021</td>
<td>-0.313*</td>
<td>-0.042**</td>
<td>0.048*</td>
<td>0.074*</td>
<td>-0.011</td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>Overall GPA</td>
<td>0.006</td>
<td>-0.153*</td>
<td>-0.018</td>
<td>-0.105*</td>
<td>0.231*</td>
<td>-0.011</td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>Classroom Size</td>
<td>-0.137*</td>
<td>0.048*</td>
<td>0.006</td>
<td>0.042**</td>
<td>0.779*</td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
</tr>
</tbody>
</table>

Note. N = 5555, *p < .001, **p ≤ .05
Table 17 (continued)

<table>
<thead>
<tr>
<th>Curriculum</th>
<th>Gender * Curriculum</th>
<th>GPA * Curriculum</th>
<th>Classroom * Curriculum</th>
</tr>
</thead>
<tbody>
<tr>
<td>Term - Sequence</td>
<td>.104*</td>
<td>.020</td>
<td>.053*</td>
</tr>
<tr>
<td>Curriculum</td>
<td>.599*</td>
<td>.940*</td>
<td>.185*</td>
</tr>
<tr>
<td>Gender * Curriculum</td>
<td>.518*</td>
<td>.082*</td>
<td></td>
</tr>
<tr>
<td>GPA * Curriculum</td>
<td>.170*</td>
<td></td>
<td></td>
</tr>
</tbody>
</table>

Note. $N = 5555$, *$p < .001$

The model summary results for the finalized regression model are slightly different than the full regression model containing all variables. The sample obtained an $R$ value and an $R$-squared value of .714 and .510, respectively. These values are very close to the full model values with only differences of .003 and .004, respectively. The independent variables in the model explain 51.0% of the total sample variation of final exam percentage scores ($y$). The adjusted $R$-squared value is .509. This implies that the least squares model has explained 50.9% of the total sample variation in final exam percentage scores ($y$), after adjusting for sample size and number of independent variables in the model.
Table 18

*Model summary of finalized regression analysis – Final exam percentage – Chemistry I*

<table>
<thead>
<tr>
<th>Model</th>
<th>R</th>
<th>R Square</th>
<th>Adjusted R Square</th>
<th>Std. Error of the Estimate</th>
</tr>
</thead>
<tbody>
<tr>
<td>1</td>
<td>.714</td>
<td>.510</td>
<td>.509</td>
<td>13.966</td>
</tr>
</tbody>
</table>

Note. Predictors: (Constant), Gender, Non-Major, Major-Other, ACT Composite, ACT Math, Overall GPA, Classroom Size, Term – Sequence, Curriculum, Gender * Curriculum, GPA * Curriculum, Classroom * Curriculum.

The finalized linear regression model shows three curriculum interactions with gender, GPA, and classroom. The Gender * Curriculum interaction ($\beta = -.050, p = .004$), GPA * Curriculum interaction ($\beta = .144, p \leq .001$) and the Classroom * Curriculum interaction ($\beta = -.034, p = .028$) were significant. These three interactions will be further investigated using a two-way ANOVA with the follow-up post hoc analyses to determine the specific curricular approach that produces higher student success.

**Gender.** The two-way ANOVA was run using final exam percentage as the dependent variable and curriculum approach, gender, and the gender and curriculum interaction variables as the independent variables. Table 19 provides the means and standard deviations for the dependent and independent variables.
Table 19

*Descriptive statistics for gender and curriculum variables – Chemistry I*

<table>
<thead>
<tr>
<th>Gender</th>
<th>Curriculum</th>
<th>Mean</th>
<th>Standard Deviation</th>
<th>N</th>
</tr>
</thead>
<tbody>
<tr>
<td>Female</td>
<td>Atoms First</td>
<td>61.260</td>
<td>18.477</td>
<td>1249</td>
</tr>
<tr>
<td></td>
<td>Traditional</td>
<td>68.764</td>
<td>19.887</td>
<td>1407</td>
</tr>
<tr>
<td></td>
<td>Total</td>
<td>65.235</td>
<td>19.595</td>
<td>2656</td>
</tr>
<tr>
<td>Male</td>
<td>Atoms First</td>
<td>64.307</td>
<td>19.346</td>
<td>1556</td>
</tr>
<tr>
<td></td>
<td>Traditional</td>
<td>68.921</td>
<td>21.135</td>
<td>1664</td>
</tr>
<tr>
<td></td>
<td>Total</td>
<td>66.691</td>
<td>20.418</td>
<td>3220</td>
</tr>
</tbody>
</table>

Note. Dependent variable = Final exam percentage

The Gender * Curriculum interaction was significant, \( F(1, 5872) = 7.715, p = .005 \), indicating that the two teaching approaches had different effects on male and female students. Specifically, female students performed higher on the final exam when taught under the “traditional” approach \( (M = 68.764, SD = 19.887) \) compared to the “atoms first” approach \( (M = 61.260, SD = 18.477) \). Similarly, male students performed higher on the final exam when taught under the “traditional” approach \( (M = 68.921, SD = 21.135) \) compared to the “atoms fist” approach \( (M = 64.307, SD = 19.346) \).

**Grade point average (GPA).** GPA was divided into two groups to determine if above and below average learners perform better under a specific curricular approach. The cases were divided in half using the calculated median for GPA, which was calculated at 3.16. Those above 3.16 were determined as above average learners and those at or below 3.16 labeled as below average learners. The two-way ANOVA was run using final exam percentage as the dependent variable and curriculum approach, GPA learner group (above and below average), and the GPA and curriculum interaction...
variables as the independent variables. Table 20 provides the means and standard deviations for the dependent and independent variables.

Table 20

*Descriptive statistics for GPA and curriculum variables – Chemistry I*

<table>
<thead>
<tr>
<th>GPA Categories</th>
<th>Curriculum</th>
<th>Mean</th>
<th>Standard Deviation</th>
<th>N</th>
</tr>
</thead>
<tbody>
<tr>
<td>Below Average</td>
<td>Atoms First</td>
<td>52.796</td>
<td>17.197</td>
<td>1340</td>
</tr>
<tr>
<td></td>
<td>Traditional</td>
<td>57.846</td>
<td>20.546</td>
<td>1534</td>
</tr>
<tr>
<td></td>
<td>Total</td>
<td>55.491</td>
<td>19.220</td>
<td>2874</td>
</tr>
<tr>
<td>Above Average</td>
<td>Atoms First</td>
<td>72.238</td>
<td>15.550</td>
<td>1465</td>
</tr>
<tr>
<td></td>
<td>Traditional</td>
<td>79.830</td>
<td>13.519</td>
<td>1537</td>
</tr>
<tr>
<td></td>
<td>Total</td>
<td>76.125</td>
<td>15.030</td>
<td>3002</td>
</tr>
</tbody>
</table>

Note. Dependent variable = Final exam percentage

The GPA * Curriculum interaction was significant, $F(1, 5872) = 8.275, p = .004$, indicating that the two teaching approaches had different effects on below and above average students. Specifically, below average students performed higher on the final exam when taught under the “traditional” approach ($M = 57.846, SD = 20.546$) compared to the “atoms first” approach ($M = 52.796, SD = 17.197$). Similarly, above average students performed higher on the final exam when taught under the “traditional” approach ($M = 79.830, SD = 13.519$) compared to the “atoms fist” approach ($M = 72.238, SD = 15.550$).

**Classroom size.** The two-way ANOVA was run using final exam percentage as the dependent variable and curriculum approach, classroom size (large or small), and the classroom size and curriculum interaction variables as the independent variables. Table
Table 21

*Descriptive statistics for classroom size and curriculum variables – Chemistry I*

<table>
<thead>
<tr>
<th>Classroom Size</th>
<th>Curriculum</th>
<th>Mean</th>
<th>Standard Deviation</th>
<th>N</th>
</tr>
</thead>
<tbody>
<tr>
<td>Large</td>
<td>Atoms First</td>
<td>62.512</td>
<td>19.024</td>
<td>2678</td>
</tr>
<tr>
<td></td>
<td>Traditional</td>
<td>68.600</td>
<td>20.702</td>
<td>2846</td>
</tr>
<tr>
<td></td>
<td>Total</td>
<td>65.649</td>
<td>20.136</td>
<td>5524</td>
</tr>
<tr>
<td>Small</td>
<td>Atoms First</td>
<td>72.179</td>
<td>16.503</td>
<td>127</td>
</tr>
<tr>
<td></td>
<td>Traditional</td>
<td>71.997</td>
<td>18.568</td>
<td>225</td>
</tr>
<tr>
<td></td>
<td>Total</td>
<td>72.063</td>
<td>17.827</td>
<td>352</td>
</tr>
</tbody>
</table>

Note. Dependent variable = Final exam percentage

The ClassroomSize * Curriculum interaction was significant, $F(1, 5872) = 7.696$, $p = .006$, indicating that the two teaching approaches had different effects on students in a large compared to a small classroom setting. Specifically, students in a large classroom setting performed higher on the final exam when taught under the “traditional” approach ($M = 68.600$, $SD = 20.702$) compared to the “atoms first” approach ($M = 62.512$, $SD = 19.024$). However, there is no statistical difference between the two curricular approaches for students in a small classroom setting, $p = .934$.

**Final Letter Grade Results**

The initial regression model was determined using all seven sub-group factors (gender, ethnicity/race, major, ACT composite, ACT math, GPA, and classroom size), term sequence, curriculum approach, and all interaction terms involving curriculum approach, the seven sub-factors, and the term sequence variable. Ethnicity/race was tested
in three different formats: 1) using all eight individual categories – American Indian or Alaskan Native, Asian, Black or African American, Hispanic or Latino, Multiracial, Native Hawaiian or Other Pacific Islander, Unknown, and White; 2) using four major categories – Other, Black or African American, Hispanic or Latino, and White; and 3) using three major categories – Other, Black or African American, and White. The same results were found using all three different ethnicity breakdowns. For simplicity of result presentation, the ethnicity breakdown using only the three major categories will be displayed.

Table 22 provides the means and standard deviations for the dependent variable (final letter grade), the seven sub-factors, the term sequence variable, and the curriculum approach variable.
Table 22

*Descriptive statistics for full regression model using final letter grade – Chemistry I*

<table>
<thead>
<tr>
<th></th>
<th>Mean</th>
<th>Standard Deviation</th>
</tr>
</thead>
<tbody>
<tr>
<td>Final Letter Grade</td>
<td>2.330</td>
<td>1.378</td>
</tr>
<tr>
<td>Gender</td>
<td>.546</td>
<td>.498</td>
</tr>
<tr>
<td>Ethnicity - Other</td>
<td>.071</td>
<td>.257</td>
</tr>
<tr>
<td>Ethnicity - Black or African American</td>
<td>.176</td>
<td>.381</td>
</tr>
<tr>
<td>Non-Major</td>
<td>.890</td>
<td>.313</td>
</tr>
<tr>
<td>Major - Other</td>
<td>.087</td>
<td>.281</td>
</tr>
<tr>
<td>ACT Composite</td>
<td>25.553</td>
<td>4.422</td>
</tr>
<tr>
<td>ACT Math</td>
<td>25.033</td>
<td>4.567</td>
</tr>
<tr>
<td>Overall GPA</td>
<td>3.040</td>
<td>.789</td>
</tr>
<tr>
<td>Classroom Size</td>
<td>.064</td>
<td>.244</td>
</tr>
<tr>
<td>Term - Sequence</td>
<td>.218</td>
<td>.413</td>
</tr>
<tr>
<td>Curriculum</td>
<td>.513</td>
<td>.500</td>
</tr>
<tr>
<td>Gender * Curriculum</td>
<td>.276</td>
<td>.447</td>
</tr>
<tr>
<td>EthnicityOther * Curriculum</td>
<td>.037</td>
<td>.189</td>
</tr>
<tr>
<td>EthnicityBlack * Curriculum</td>
<td>.095</td>
<td>.293</td>
</tr>
<tr>
<td>Non-Major * Curriculum</td>
<td>.453</td>
<td>.498</td>
</tr>
<tr>
<td>MajorOther * Curriculum</td>
<td>.049</td>
<td>.216</td>
</tr>
<tr>
<td>ACTComposite * Curriculum</td>
<td>12.976</td>
<td>13.025</td>
</tr>
<tr>
<td>ACTMath * Curriculum</td>
<td>12.730</td>
<td>12.823</td>
</tr>
<tr>
<td>GPA * Curriculum</td>
<td>1.551</td>
<td>1.612</td>
</tr>
<tr>
<td>Classroom * Curriculum</td>
<td>.036</td>
<td>.186</td>
</tr>
<tr>
<td>TermSequence * Curriculum</td>
<td>.136</td>
<td>.343</td>
</tr>
</tbody>
</table>

*Note. N = 5988*

The sample obtained an $R$ value and an $R$-squared value of .835 and .697, respectively. The independent variables in the model explain 69.7% of the total sample variation of final letter grades ($y$). The adjusted $R$-squared value is .696. This implies that the least squares model has explained 69.6% of the total sample variation in final letter grades ($y$), after adjusting for sample size and number of independent variables in the model.
Table 23

Model summary of full regression analysis – Final letter grade – Chemistry I

<table>
<thead>
<tr>
<th>Model</th>
<th>R</th>
<th>R Square</th>
<th>Adjusted R Square</th>
<th>Std. Error of the Estimate</th>
</tr>
</thead>
<tbody>
<tr>
<td>1</td>
<td>.835</td>
<td>.697</td>
<td>.696</td>
<td>.760</td>
</tr>
</tbody>
</table>

Note. Predictors: (Constant), Gender, Ethnicity - Other, Ethnicity - Black or African American, Non-Major, Major-Other, ACT Composite, ACT Math, Overall GPA, Classroom Size, Term – Sequence, Curriculum, Gender * Curriculum, EthnicityOther * Curriculum, EthnicityBlack * Curriculum, Non-Major * Curriculum, MajorOther * Curriculum, ACTComp * Curriculum, ACTMath * Curriculum, GPA * Curriculum, Classroom * Curriculum, TermSequence * Curriculum.

At an alpha of .05, there were 10 of the 21 tested variables found to be statistically significant in the model. These 10 variables were used for the finalized regression model. These include: gender, major, ACT composite, ACT math, overall GPA, term sequence, curriculum approach, ACT composite and curriculum interaction, and term sequence and curriculum interaction variables. Table 24 provides the correlations for the dependent variable (final letter grade) and those 10 statistically significant variables used in the finalized regression model.
Table 24

*Correlations among statistically significant finalized regression model variables – Final letter grade – Chemistry I*

<table>
<thead>
<tr>
<th>Final Letter Grade</th>
<th>Gender</th>
<th>Non-Major</th>
<th>Major-Other</th>
<th>ACT Composite</th>
<th>ACT Math</th>
<th>Overall GPA</th>
<th>Term-Sequence</th>
<th>Curriculum</th>
<th>ACTComp *Curriculum</th>
<th>TermSeq *Curriculum</th>
</tr>
</thead>
<tbody>
<tr>
<td></td>
<td>-.028**</td>
<td>.128*</td>
<td>-.192*</td>
<td>.564*</td>
<td>.572*</td>
<td>.790*</td>
<td>-.117*</td>
<td>-.024**</td>
<td>.081*</td>
<td>-.116*</td>
</tr>
<tr>
<td>Gender</td>
<td>-.066*</td>
<td>.117*</td>
<td>.077*</td>
<td>.151*</td>
<td>-.168*</td>
<td>-.070*</td>
<td>-.017</td>
<td>-.005</td>
<td>-.045*</td>
<td></td>
</tr>
<tr>
<td>Non-Major</td>
<td>-.877*</td>
<td>.198*</td>
<td>.164*</td>
<td>.161*</td>
<td>-.050*</td>
<td>-.025**</td>
<td>.008</td>
<td>-.035**</td>
<td></td>
<td></td>
</tr>
<tr>
<td>Major-Other</td>
<td>-.244*</td>
<td>-.203*</td>
<td>-.221*</td>
<td>.091*</td>
<td>.035**</td>
<td>-.009</td>
<td>.067*</td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>ACT Composite</td>
<td>.865*</td>
<td>.468*</td>
<td>-.265*</td>
<td>-.064*</td>
<td>.111*</td>
<td>-.196*</td>
<td></td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>ACT Math</td>
<td>.441*</td>
<td>-.291*</td>
<td>-.053*</td>
<td>.100*</td>
<td></td>
<td>-.207*</td>
<td></td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>Overall GPA</td>
<td>-.133*</td>
<td>-.025**</td>
<td>.059*</td>
<td>-.111*</td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
</tr>
</tbody>
</table>

Note. N = 5988, *p < .001, **p ≤ .05
The model summary results for the finalized regression model are slightly different than the full regression model containing all variables. The sample obtained an $R$ value and an $R^2$ value of .834 and .696, respectively. These values are very close to the full model values with only differences of .001 and .001, respectively. The independent variables in the model explain 69.6% of the total sample variation of final letter grade ($y$). The adjusted $R^2$ value is .695. This implies that the least squares model has explained 69.5% of the total sample variation in final letter grade ($y$), after adjusting for sample size and number of independent variables in the model.

Table 25

Model summary of finalized regression analysis – Final letter grade – Chemistry I

<table>
<thead>
<tr>
<th>Model</th>
<th>$R$</th>
<th>$R^2$</th>
<th>Adjusted $R^2$</th>
<th>Std. Error of the Estimate</th>
</tr>
</thead>
<tbody>
<tr>
<td>1</td>
<td>.834</td>
<td>.696</td>
<td>.695</td>
<td>.761</td>
</tr>
</tbody>
</table>

Note. Predictors: (Constant), Gender, Non-Major, Major-Other, ACT Composite, ACT Math, Overall GPA, Term – Sequence, Curriculum, ACTComp * Curriculum, TermSeq * Curriculum.
The finalized linear regression model shows two curriculum interactions with ACT composite and term-sequence. The ACTComp * Curriculum interaction ($\beta = .111$, $p = .011$) and the TermSequence * Curriculum interaction ($\beta = -.062$, $p \leq .001$) were significant. The ACT composite interaction will be further investigated using a two-way ANOVA with the follow-up post hoc analysis to determine the specific curricular approach that produces higher student success. However, the term-sequence interaction will not be further investigated since it has already been discussed in the ANCOVA analyses discussed earlier. This significant interaction result supports the ANCOVA breakdown of on- and off-sequence semesters.

**ACT composite.** ACT composite was divided into two groups to determine if above and below average learners perform better under a specific curricular approach. The cases were divided in half using the calculated median for ACT composite, which was calculated at 26. Those at or above 26 were determined as above average learners and those below 26 labeled as below average learners. The two-way ANOVA was run using final letter grade as the dependent variable and curriculum approach, ACT composite leaner group (above and below average), and the ACT composite and curriculum interaction variables as the independent variables. Table 26 provides the means and standard deviations for the dependent and independent variables.
Table 26

*Descriptive statistics for ACT composite and curriculum variables – Chemistry I*

<table>
<thead>
<tr>
<th>ACT Composite Categories</th>
<th>Curriculum</th>
<th>Mean</th>
<th>Standard Deviation</th>
<th>N</th>
</tr>
</thead>
<tbody>
<tr>
<td>Below Average</td>
<td>Atoms First</td>
<td>1.697</td>
<td>1.231</td>
<td>1361</td>
</tr>
<tr>
<td></td>
<td>Traditional</td>
<td>1.604</td>
<td>1.272</td>
<td>1599</td>
</tr>
<tr>
<td></td>
<td>Total</td>
<td>1.646</td>
<td>1.254</td>
<td>2960</td>
</tr>
<tr>
<td>Above Average</td>
<td>Atoms First</td>
<td>2.914</td>
<td>1.173</td>
<td>1681</td>
</tr>
<tr>
<td></td>
<td>Traditional</td>
<td>3.003</td>
<td>1.161</td>
<td>1591</td>
</tr>
<tr>
<td></td>
<td>Total</td>
<td>2.958</td>
<td>1.168</td>
<td>3272</td>
</tr>
</tbody>
</table>

Note. Dependent variable = Final letter grade

The ACTComp * Curriculum interaction was significant, $F(1, 6228) = 8.759, p = .003$, indicating that the two teaching approaches had different effects on below and above average students. Specifically, below average students earned higher final letter grades when taught under the “atoms first” approach ($M = 1.697, SD = 1.231$) compared to the “traditional” approach ($M = 1.604, SD = 1.272$). However, above average students earned higher final letter grades when taught under the “traditional” approach ($M = 3.003, SD = 1.161$) compared to the “atoms first” approach ($M = 2.914, SD = 1.173$).

**Multinomial Logistic Regression Results.** The initial multinomial logistic regression model was determined using all seven sub-group factors (gender, ethnicity/race, major, ACT composite, ACT math, GPA, and classroom size), term sequence, curriculum approach, and all interaction terms involving curriculum approach, the seven sub-factors, and the term sequence variable as independent variables. Ethnicity/race was tested using the three major categories – Other, Black or African American, and White. The dependent variable, final letter grade, had five levels, which included A, B, C, D, and F letter categories.
At an alpha of .05, there were 9 of the 21 tested variables found to be statistically significant in the model. These include: gender, major, ACT math, overall GPA, classroom size, term sequence, curriculum approach, and term sequence and curriculum interaction variables. The finalized logistic regression model shows one significant curriculum interaction with term sequence, \( \chi^2(4) = 38.962, p < .001 \). The term-sequence interaction will not be further investigated since it has already been discussed in the ANCOVA analyses discussed earlier. This significant interaction result supports the ANCOVA breakdown of on- and off-sequence semesters.

**Binary Logistic Regression Results.** The initial binary logistic regression model was determined using all seven sub-group factors (gender, ethnicity/race, major, ACT composite, ACT math, GPA, and classroom size), term sequence, curriculum approach, and all interaction terms involving curriculum approach, the seven sub-factors, and the term sequence variable as independent variables. Ethnicity/race was tested using the three major categories – Other, Black or African American, and White. The dependent variable, final letter grade, had two levels – pass and fail. Pass defined as those students earning an A, B, or C final letter grade. Fail included those students earning a D or F final letter grade.

At an alpha of .05, there were 6 of the 21 tested variables found to be statistically significant in the model. These include: gender, ACT math, overall GPA, term sequence, curriculum approach, and term sequence and curriculum interaction variables. The finalized logistic regression model shows one significant curriculum interaction with term sequence, \( B = -.474, p = .014 \). The term-sequence interaction will not be further
investigated since it has already been discussed in the ANCOVA analyses discussed earlier. This significant interaction result supports the ANCOVA breakdown of on- and off-sequence semesters.

**Research Question 2 – Chemistry II**

The second research question states does the “atoms first” curriculum lead to higher student success compared to the “traditional” curriculum for all students when all other sub-factors are considered as covariates? To answer this research question, an ANCOVA was performed to determine if there is a significant difference between the “atoms first” and the “traditional” general chemistry curricula. The independent variable was the curricular method either the “traditional” approach or the “atoms first” approach. The dependent variable was the final exam percentage score or the final letter grade. The covariates tested were gender, ethnicity, major, ACT composite score, ACT math score, overall GPA, and classroom size. All analysis was done at an alpha level of .05.

**Final Exam Percentage Results**

The data from the second semester Chemistry II course were analyzed to determine if there is a statistical difference between the “atoms first” and the “traditional” curricular approaches. The following analysis shows the results when all semesters taught for each of the curricula were combined and compared overall regardless of the specific semester the course was taught. Levene’s test was not significant, $F(1, 2691) = 1.032, p = .310$, indicating that the assumption of homogeneity of variance had been met. The assumption of homogeneity of regression slopes was met due to the non-significant results for both the curriculum and gender interaction, $F(1, 2684) = .002, p = .962$, the
curriculum and ethnicity interaction, $F(1, 2684) = 2.658, p = .103$, and the curriculum and major interaction, $F(1, 2684) = 2.048, p = .152$. However, the assumption of multicollinearity was not met. The main effect of curriculum was significant, $F(1, 2687) = 7.798, p = .005$, partial $\eta^2 = .003$, indicating that the final exam percentage scores were higher using the “traditional” curriculum ($M = 67.720, \text{Std. Dev.} = 17.467$) compared to the “atoms first” curriculum ($M = 65.763, \text{Std. Dev.} = 16.836$).

Table 27

*ANCOVA tests of between-subjects effects – Curriculum comparison overall – Final exam percentage – Chemistry II*

<table>
<thead>
<tr>
<th>Source</th>
<th>Type III Sum of Squares</th>
<th>df</th>
<th>Mean Square</th>
<th>F</th>
<th>Sig.</th>
<th>Partial Eta Squared</th>
</tr>
</thead>
<tbody>
<tr>
<td>Intercept</td>
<td>295179.083</td>
<td>1</td>
<td>295179.083</td>
<td>1024.296</td>
<td>.000</td>
<td>.276</td>
</tr>
<tr>
<td>Gender</td>
<td>1393.850</td>
<td>1</td>
<td>1393.850</td>
<td>4.837</td>
<td>.028</td>
<td>.002</td>
</tr>
<tr>
<td>Ethnicity</td>
<td>13814.181</td>
<td>1</td>
<td>13814.181</td>
<td>47.936</td>
<td>.000</td>
<td>.018</td>
</tr>
<tr>
<td>Major</td>
<td>7062.323</td>
<td>1</td>
<td>7062.323</td>
<td>24.507</td>
<td>.000</td>
<td>.009</td>
</tr>
<tr>
<td>Classroom</td>
<td>560.129</td>
<td>1</td>
<td>560.129</td>
<td>1.944</td>
<td>.163</td>
<td>.001</td>
</tr>
<tr>
<td>Curriculum</td>
<td>2247.115</td>
<td>1</td>
<td>2247.115</td>
<td>7.798</td>
<td>.005</td>
<td>.003</td>
</tr>
<tr>
<td>Error</td>
<td>774333.334</td>
<td>2687</td>
<td>288.178</td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>Total</td>
<td>12889933.806</td>
<td>2693</td>
<td></td>
<td></td>
<td></td>
<td></td>
</tr>
</tbody>
</table>

Dependent variable: Final exam percentage, $R^2 = .034$, Adjusted-$R^2 = .033$

All seven covariates, gender, ethnicity, major, ACT composite, ACT math, overall GPA, and classroom size, were tested regarding their independence from the treatment. Only gender, $F(1, 3272) = .230, p = .631$; ethnicity, $F(1, 3272) = .233, p = .630$; major, $F(1, 3272) = 2.682, p = .102$; and classroom, $F(1, 3272) = .678, p = .410$, were found to be non-significant and thus are independent of the curricular approach. The covariate, gender, was also significant, $F(1, 2687) = 4.837, p = .028$, partial $\eta^2 = .002$. 

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indicating that gender had a significant effect on the final exam percentage scores for the two curricular approaches. The covariate, ethnicity, was also significant, $F(1, 2687) = 47.936, p < .001$, partial $\eta^2 = .018$, indicating that ethnicity had a significant effect on the final exam percentage scores for the two curricular approaches. The covariate, major, was also significant, $F(1, 2687) = 24.507, p < .001$, partial $\eta^2 = .009$, indicating that major had a significant effect on the final exam percentage scores for the two curricular approaches. However, the covariate, classroom size, was not significant, $F(1, 2687) = 1.944, p = .163$, partial $\eta^2 = .001$, indicating that classroom size did not have a significant effect on the final exam percentage scores for the two curricular approaches.

![Figure 3](image)

**Figure 3.** Overview of final exam percentage averages for each academic semester and curricular approach – Chemistry II.

Green checkered filled bars represent the “traditional” curricular approach, blue solid filled bars represent the “atoms first” curricular approach.

Figure 3 shows the overview of the final exam percentage averages for each academic semester based on the curricular approach used. Additionally, the figure
separates the fall semester averages from the spring semester averages. This was done to show the differences in student performance for those students considered to be on-sequence versus those off-sequence. On-sequence refers to those students who took Chemistry II during the spring semester, which is the first semester the course would be offered for those students completing Chemistry I during the fall semester. Off-sequence refers to those students who took Chemistry II during the fall semester, which is the off-semester for the course. Because the on-sequence and off-sequence populations may differ, they have been separated in the figure with off-sequence on the left side and on-sequence on the right side. The figure shows that for those students on-sequence the “atoms first” approach had lower final exam percentage averages per semester compared to the “traditional” approach. Similar results were seen for the off-sequence students when the two traditional semesters were averaged together. However, when separated out the “atoms first” approach was higher compared to the second “traditional” semester.

The data from the second semester Chemistry II course were divided into the on-sequence semesters and the off-sequence semesters and then analyzed to determine if there is a statistical difference between the “atoms first” and the “traditional” curricular approaches for each sequence. The following on-sequence analysis shows the results of the spring 2013 and 2014 “traditional” curricular semesters compared to the spring 2015 “atoms first” curricular semester. Levene’s test was significant, $F(1, 1903) = 4.789, p = .029$, indicating that the assumption of homogeneity of variance had not been met. Also, the assumption of multicollinearity was not met. The assumption of homogeneity of regression slopes was partially met due to the non-significant results for both the curriculum and gender interaction, $F(1, 1896) = .837, p = .360$ and the curriculum and
ethnicity interaction, $F(1, 1896) = 2.790, p = .095$; and the significant result for the curriculum and major interaction, $F(1, 1896) = 4.288, p = .039$. The main effect of curriculum was significant, $F(1, 1899) = 6.434, p = .011$, partial $\eta^2 = .003$, indicating that the final exam percentage scores were higher using the “traditional” curriculum ($M = 69.350, \text{Std. Dev.} = 17.860$) compared to the “atoms first” curriculum ($M = 67.142, \text{Std. Dev.} = 18.203$).

Table 28

**ANCOVA tests of between-subjects effects – Curriculum comparison for on-sequence – Final exam percentage – Chemistry II**

<table>
<thead>
<tr>
<th>Source</th>
<th>Type III Sum of Squares</th>
<th>df</th>
<th>Mean Square</th>
<th>F</th>
<th>Sig.</th>
<th>Partial Eta Squared</th>
</tr>
</thead>
<tbody>
<tr>
<td>Intercept</td>
<td>209165.483</td>
<td>1</td>
<td>209165.483</td>
<td>667.368</td>
<td>.000</td>
<td>.260</td>
</tr>
<tr>
<td>Gender</td>
<td>1855.578</td>
<td>1</td>
<td>1855.578</td>
<td>5.920</td>
<td>.015</td>
<td>.003</td>
</tr>
<tr>
<td>Ethnicity</td>
<td>8313.127</td>
<td>1</td>
<td>8313.127</td>
<td>26.524</td>
<td>.000</td>
<td>.014</td>
</tr>
<tr>
<td>Major</td>
<td>7568.796</td>
<td>1</td>
<td>7568.796</td>
<td>24.149</td>
<td>.000</td>
<td>.013</td>
</tr>
<tr>
<td>Classroom</td>
<td>1900.645</td>
<td>1</td>
<td>1900.645</td>
<td>6.064</td>
<td>.014</td>
<td>.003</td>
</tr>
<tr>
<td>Curriculum</td>
<td>2016.521</td>
<td>1</td>
<td>2016.521</td>
<td>6.434</td>
<td>.011</td>
<td>.003</td>
</tr>
<tr>
<td>Error</td>
<td>595181.383</td>
<td>1899</td>
<td>313.418</td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>Total</td>
<td>9571852.323</td>
<td>1905</td>
<td></td>
<td></td>
<td></td>
<td></td>
</tr>
</tbody>
</table>

Dependent variable: Final exam percentage, $R^2 = .036$, Adjusted-$R^2 = .034$

To stay consistent with the overall analysis performed the same four covariates, gender, ethnicity, major, and classroom, were used in the analysis. Gender, $F(1, 2151) = 1.038, p = .308$; ethnicity, $F(1, 2151) = .038, p = .845$; major, $F(1, 2151) = .063, p = .802$; and classroom, $F(1, 2151) = .588, p = .443$, were found to be non-significant and thus are independent of the curricular approach. The covariate, gender, was also significant, $F(1, 1899) = 5.920, p = .015$, partial $\eta^2 = .003$, indicating that gender had a
significant effect on the final exam percentage scores for the two curricular approaches. The covariate, ethnicity, was also significant, \( F(1, 1899) = 26.524, p < .001, \) partial \( \eta^2 = .014 \), indicating that ethnicity had a significant effect on the final exam percentage scores for the two curricular approaches. The covariate, major, was also significant, \( F(1, 1899) = 24.149, p < .001, \) partial \( \eta^2 = .013 \), indicating that major had a significant effect on the final exam percentage scores for the two curricular approaches. Lastly, the covariate, classroom, was significant, \( F(1, 1899) = 6.064, p = .014, \) partial \( \eta^2 = .003 \), indicating that classroom size had a significant effect on the final exam percentage scores for the two curricular approaches.

The following off-sequence analysis shows the results of the fall 2012 and 2013 “traditional” curricular semesters compared to the fall 2015 “atoms first” curricular semester. Levene’s test was not significant, \( F(1, 786) = 2.388, p = .123 \), indicating that the assumption of homogeneity of variance had been met. The assumption of homogeneity of regression slopes was met due to the non-significant results for the curriculum and gender interaction, \( F(1, 780) = 1.089, p = .297 \); the curriculum and ethnicity interaction, \( F(1, 780) = .212, p = .645 \); and the curriculum and major interaction, \( F(1, 780) = .000, p = .997 \). However, the assumption of multicollinearity was not met. The main effect of curriculum was not significant, \( F(1, 783) = .682, p = .409, \) partial \( \eta^2 = .001 \), indicating that the final exam percentage scores were not statistically different between the “traditional” curriculum (\( M = 63.533, \) Std. Dev. = 15.672) and the “atoms first” curriculum (\( M = 62.747, \) Std. Dev. = 12.893).
Table 29

**ANCOVA tests of between-subjects effects – Curriculum comparison for off-sequence – Final exam percentage – Partial analysis - Chemistry II**

<table>
<thead>
<tr>
<th>Source</th>
<th>Type III Sum of Squares</th>
<th>df</th>
<th>Mean Square</th>
<th>F</th>
<th>Sig.</th>
<th>Partial Eta Squared</th>
</tr>
</thead>
<tbody>
<tr>
<td>Intercept</td>
<td>87685.749</td>
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<td>87685.749</td>
<td>416.031</td>
<td>.000</td>
<td>.347</td>
</tr>
<tr>
<td>Gender</td>
<td>62.859</td>
<td>1</td>
<td>62.859</td>
<td>.298</td>
<td>.585</td>
<td>.000</td>
</tr>
<tr>
<td>Ethnicity</td>
<td>2863.431</td>
<td>1</td>
<td>2863.431</td>
<td>13.586</td>
<td>.000</td>
<td>.017</td>
</tr>
<tr>
<td>Major</td>
<td>391.219</td>
<td>1</td>
<td>391.219</td>
<td>1.856</td>
<td>.173</td>
<td>.002</td>
</tr>
<tr>
<td>Classroom</td>
<td>.000</td>
<td>0</td>
<td>---</td>
<td>---</td>
<td>---</td>
<td>.000</td>
</tr>
<tr>
<td>Curriculum</td>
<td>143.666</td>
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<td>143.666</td>
<td>.682</td>
<td>.409</td>
<td>.001</td>
</tr>
<tr>
<td>Error</td>
<td>165030.808</td>
<td>783</td>
<td>210.767</td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>Total</td>
<td>3318081.484</td>
<td>788</td>
<td></td>
<td></td>
<td></td>
<td></td>
</tr>
</tbody>
</table>

Dependent variable: Final exam percentage, $R^2 = .020$, Adjusted-$R^2 = .015$

The non-significant main effect result for curriculum was determined using the same four covariates – gender, ethnicity, major, and classroom – used in the overall analysis. However, the main effect for curriculum is significant when all variables found to be independent of the curricular approach are used in the analysis. The covariate, classroom size, was not applicable due to there not being two different classroom sizes for the off-sequence set of data. Levene’s test was not significant, $F(1, 733) = 2.580, p = .109$, indicating that the assumption of homogeneity of variance had been met. The assumption of homogeneity of regression slopes was partially met due to the significant result for the curriculum and GPA interaction, $F(1, 721) = 4.480, p = .035$ and the non-significant results for the curriculum and gender interaction, $F(1, 721) = .040, p = .841$; the curriculum and ethnicity interaction, $F(1, 721) = .069, p = .793$; the curriculum and major interaction, $F(1, 721) = .062, p = .803$; the curriculum and ACT composite interaction, $F(1, 721) = .417, p = .519$; and the curriculum and ACT math interaction,
\( F(1, 721) = .689, p = .407 \). However, the assumption of multicollinearity was not met.

The main effect of curriculum was significant, \( F(1, 727) = 3.973, p = .047 \), partial \( \eta^2 = .005 \), indicating that the final exam percentage scores were higher for students taught under the “traditional” curriculum \((M = 63.295, Std. Dev. = 15.730)\) and the “atoms first” curriculum \((M = 62.252, Std. Dev. = 12.718)\).

Table 30

**ANCOVA tests of between-subjects effects – Curriculum comparison for off-sequence – Final exam percentage – Full analysis - Chemistry II**

<table>
<thead>
<tr>
<th>Source</th>
<th>Type III Sum of Squares</th>
<th>df</th>
<th>Mean Square</th>
<th>F</th>
<th>Sig.</th>
<th>Partial Eta Squared</th>
</tr>
</thead>
<tbody>
<tr>
<td>Intercept</td>
<td>82.503</td>
<td>1</td>
<td>82.503</td>
<td>.597</td>
<td>.440</td>
<td>.001</td>
</tr>
<tr>
<td>Gender</td>
<td>395.987</td>
<td>1</td>
<td>395.987</td>
<td>2.866</td>
<td>.091</td>
<td>.004</td>
</tr>
<tr>
<td>Ethnicity</td>
<td>1594.582</td>
<td>1</td>
<td>1594.582</td>
<td>11.542</td>
<td>.001</td>
<td>.016</td>
</tr>
<tr>
<td>Major</td>
<td>245.779</td>
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<td>245.779</td>
<td>1.779</td>
<td>.183</td>
<td>.002</td>
</tr>
<tr>
<td>Classroom</td>
<td>0.00</td>
<td>0</td>
<td>---</td>
<td>---</td>
<td>---</td>
<td>.000</td>
</tr>
<tr>
<td>ACT Composite</td>
<td>1560.462</td>
<td>1</td>
<td>1560.462</td>
<td>11.295</td>
<td>.001</td>
<td>.015</td>
</tr>
<tr>
<td>ACT Math</td>
<td>928.071</td>
<td>1</td>
<td>928.071</td>
<td>6.718</td>
<td>.010</td>
<td>.009</td>
</tr>
<tr>
<td>Overall GPA</td>
<td>24407.000</td>
<td>1</td>
<td>24407.000</td>
<td>176.665</td>
<td>.000</td>
<td>.195</td>
</tr>
<tr>
<td>Curriculum</td>
<td>548.908</td>
<td>1</td>
<td>548.908</td>
<td>3.973</td>
<td>.047</td>
<td>.005</td>
</tr>
<tr>
<td>Error</td>
<td>100437.888</td>
<td>727</td>
<td>138.154</td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>Total</td>
<td>3063243.239</td>
<td>735</td>
<td></td>
<td></td>
<td></td>
<td></td>
</tr>
</tbody>
</table>

Dependent variable: Final exam percentage, \( R^2 = .359 \), Adjusted-\( R^2 = .353 \)

All of the seven sub-factors were used as covariates in the analysis, since all were found to be non-significant and independent of the curricular approach. The covariate, classroom size, was not applicable due to there not being two different classroom sizes for the off-sequence set of data. The results are as follows: gender, \( F(1, 1119) = .050, p = .823 \); ethnicity, \( F(1, 1119) = .548, p = .459 \); major, \( F(1, 1119) = .089, p = .766 \); ACT composite, \( F(1, 1092) = .223, p = .637 \); ACT math, \( F(1, 1048) = 1.469, p = .226 \); and
overall GPA, $F(1, 1119) = .216, p = .642$. The covariate, gender, was not significant, $F(1, 727) = 2.866, p = .091$, partial $\eta^2 = .004$, indicating that gender did not have a significant effect on the final exam percentage scores for the two curricular approaches. The covariate, major, was also not significant, $F(1, 727) = 1.779, p = .183$, partial $\eta^2 = .002$, indicating that major did not have a significant effect on the final exam percentage scores for the two curricular approaches. The covariate, ethnicity, was significant, $F(1, 727) = 11.542, p = .001$, partial $\eta^2 = .016$, indicating that ethnicity had a significant effect on the final exam percentage scores for the two curricular approaches. The covariate, ACT composite, was also significant, $F(1, 727) = 11.295, p = .001$, partial $\eta^2 = .015$, indicating that composite ACT score had a significant effect on the final exam percentage scores for the two curricular approaches. The covariate, ACT math, was also significant, $F(1, 727) = 6.718, p = .010$, partial $\eta^2 = .009$, indicating that ACT math sub-score had a significant effect on the final exam percentage scores for the two curricular approaches. Lastly, the covariate, overall GPA, was significant, $F(1, 727) = 176.665, p < .001$, partial $\eta^2 = .195$, indicating that overall GPA had a significant effect on the final exam percentage scores for the two curricular approaches.

**Final Letter Grade Results**

The data from the second semester Chemistry II course were analyzed to determine if there is a statistical difference between the “atoms first” and the “traditional” curricular approaches. The following analysis shows the results when all semesters taught for each of the curricula were combined and compared overall regardless of the specific semester the course was taught. Levene’s test was significant, $F(1, 3272) = 8.093, p = .004$, indicating that the assumption of homogeneity of variance had not been met. Also,
the assumption of multicollinearity was not met. The assumption of homogeneity of regression slopes was met due to the non-significant result for the curriculum and gender interaction, \(F(1, 3264) = .033, p = .856\); the curriculum and ethnicity interaction, \(F(1, 3264) = .191, p = .662\); the curriculum and major interaction, \(F(1, 3264) = .267, p = .605\); and the curriculum and classroom interaction, \(F(1, 3264) = .163, p = .687\). The main effect of curriculum was significant, \(F(1, 3268) = 10.116, p = .001\), partial \(\eta^2 = .003\), indicating that the final letter grades were higher using the “traditional” curriculum (\(M = 2.285, \text{Std. Dev.} = 1.321\)) compared to the “atoms first” curriculum (\(M = 2.126, \text{Std. Dev.} = 1.260\)).

Table 31

*ANCOVA tests of between-subjects effects – Curriculum comparison overall – Final letter grade – Chemistry II*

<table>
<thead>
<tr>
<th>Source</th>
<th>Type III Sum of Squares</th>
<th>df</th>
<th>Mean Square</th>
<th>F</th>
<th>Sig.</th>
<th>Partial Eta Squared</th>
</tr>
</thead>
<tbody>
<tr>
<td>Intercept</td>
<td>448.817</td>
<td>1</td>
<td>448.817</td>
<td>285.792</td>
<td>.000</td>
<td>.080</td>
</tr>
<tr>
<td>Gender</td>
<td>14.595</td>
<td>1</td>
<td>14.595</td>
<td>9.294</td>
<td>.002</td>
<td>.003</td>
</tr>
<tr>
<td>Ethnicity</td>
<td>157.178</td>
<td>1</td>
<td>157.178</td>
<td>100.086</td>
<td>.000</td>
<td>.030</td>
</tr>
<tr>
<td>Major</td>
<td>74.474</td>
<td>1</td>
<td>74.474</td>
<td>47.422</td>
<td>.000</td>
<td>.014</td>
</tr>
<tr>
<td>Curriculum</td>
<td>15.887</td>
<td>1</td>
<td>15.887</td>
<td>10.116</td>
<td>.001</td>
<td>.003</td>
</tr>
<tr>
<td>Error</td>
<td>5132.175</td>
<td>3268</td>
<td>1.570</td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>Total</td>
<td>21645.000</td>
<td>3274</td>
<td></td>
<td></td>
<td></td>
<td></td>
</tr>
</tbody>
</table>

Dependent variable: Final letter grade, \(R^2 = .069\), Adjusted-\(R^2 = .068\)

All seven covariates, gender, ethnicity, major, ACT composite, ACT math, overall GPA, and classroom size, were tested regarding their independence from the treatment. Only gender, \(F(1, 3272) = .230, p = .631\); ethnicity, \(F(1, 3272) = .233, p = .631\);
.630; major, $F(1, 3272) = 2.682, p = .102$; and classroom size, $F(1, 3272) = .678, p = .410$, were found to be non-significant and thus are independent of the curricular approach. The covariate, gender, was also significant, $F(1, 3268) = 9.294, p = .002$, partial $\eta^2 = .003$, indicating that gender had a significant effect on the final letter grades for the two curricular approaches. The covariate, ethnicity, was also significant, $F(1, 3268) = 100.086, p < .001$, partial $\eta^2 = .030$, indicating that ethnicity had a significant effect on the final letter grades for the two curricular approaches. The covariate, major, was also significant, $F(1, 3268) = 47.422, p < .001$, partial $\eta^2 = .014$, indicating that major had a significant effect on the final letter grades for the two curricular approaches. Lastly, the covariate, classroom, was significant, $F(1, 3268) = 5.885, p = .015$, partial $\eta^2 = .002$, indicating that classroom size had a significant effect on the final letter grades for the two curricular approaches.

![Figure 4](image_url)

*Figure 4.* Overview of final letter grade averages for each academic semester and curricular approach – Chemistry II.

Green checkered filled bars represent the “traditional” curricular approach, blue solid filled bars represent the “atoms first” curricular approach.
Figure 4 shows the overview of the final letter grade averages for each academic semester based on the curricular approach used. Additionally, the figure separates the spring semester averages, on-sequence students, from the fall semester averages, off-sequence students. The figure shows that for those students on-sequence the “atoms first” approach had slightly higher final letter grade averages per semester compared to the “traditional” approach. This is seen when you take both “traditional” semesters into account together compared to the single “atoms first” semester. However, for those students off-sequence the “traditional” approach had higher final letter grade averages per semester compared to the “atoms first” approach.

The data from the second semester Chemistry II course were divided into the on-sequence semesters and the off-sequence semesters and then analyzed to determine if there is a statistical difference between the “atoms first” and the “traditional” curricular approaches for each sequence. The following on-sequence analysis shows the results of the spring 2013 and 2014 “traditional” curricular semesters compared to the spring 2015 “atoms first” curricular semester. Levene’s test was significant, $F(1, 2151) = 10.147, p = .001$, indicating that the assumption of homogeneity of variance had not been met. Also, the assumption of multicollinearity was not met. The assumption of homogeneity of regression slopes was met due to the non-significant result for the curriculum and gender interaction, $F(1, 2143) = .134, p = .715$; the curriculum and ethnicity interaction, $F(1, 2143) = 1.643, p = .200$; the curriculum and major interaction, $F(1, 2143) = .002, p = .966$; and the curriculum and classroom interaction, $F(1, 2143) = .004, p = .950$. The main effect of curriculum was non-significant, $F(1, 2147) = .599, p = .439$, partial $\eta^2 = .000$, indicating that the final letter grades were not statistically different using the
“traditional” curriculum ($M = 2.37$, $Std. Dev. = 1.312$) compared to the “atoms first” curriculum ($M = 2.42$, $Std. Dev. = 1.203$).

Table 32

*ANCOVA tests of between-subjects effects – Curriculum comparison for on-sequence – Final letter grade – Chemistry II*

<table>
<thead>
<tr>
<th>Source</th>
<th>Type III Sum of Squares</th>
<th>df</th>
<th>Mean Square</th>
<th>F</th>
<th>Sig.</th>
<th>Partial Eta Squared</th>
</tr>
</thead>
<tbody>
<tr>
<td>Intercept</td>
<td>257.226</td>
<td>1</td>
<td>257.226</td>
<td>169.502</td>
<td>.000</td>
<td>.073</td>
</tr>
<tr>
<td>Gender</td>
<td>7.268</td>
<td>1</td>
<td>7.268</td>
<td>4.789</td>
<td>.029</td>
<td>.002</td>
</tr>
<tr>
<td>Ethnicity</td>
<td>114.941</td>
<td>1</td>
<td>114.941</td>
<td>75.742</td>
<td>.000</td>
<td>.034</td>
</tr>
<tr>
<td>Major</td>
<td>37.896</td>
<td>1</td>
<td>37.896</td>
<td>24.972</td>
<td>.000</td>
<td>.011</td>
</tr>
<tr>
<td>Classroom Size</td>
<td>4.085</td>
<td>1</td>
<td>4.085</td>
<td>2.692</td>
<td>.101</td>
<td>.001</td>
</tr>
<tr>
<td>Curriculum</td>
<td>.909</td>
<td>1</td>
<td>.909</td>
<td>.599</td>
<td>.439</td>
<td>.000</td>
</tr>
<tr>
<td>Error</td>
<td>3258.156</td>
<td>2147</td>
<td>1.518</td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>Total</td>
<td>15783.000</td>
<td>2153</td>
<td></td>
<td></td>
<td></td>
<td></td>
</tr>
</tbody>
</table>

Dependent variable: Final letter grade, $R^2 = .071$, Adjusted-$R^2 = .069$

The non-significant main effect result for curriculum was determined using the same four covariates – gender, ethnicity, major, and classroom – used in the overall analysis. Additionally, the main effect for curriculum is still non-significant when all variables found to be independent of the curricular approach are used in the analysis. Thus, the following reported results will be using only the four covariates used in the overall analysis. Gender, $F(1, 2151) = 1.038, p = .308$; ethnicity, $F(1, 2151) = .038, p = .845$; major, $F(1, 2151) = .063, p = .802$; and classroom, $F(1, 2151) = .588, p = .443$, were found to be non-significant and thus are independent of the curricular approach. The covariate, gender, was also significant, $F(1, 2147) = 4.789, p = .029$, partial $\eta^2 = .002$, indicating that gender had a significant effect on the final exam percentage scores for the
two curricular approaches. The covariate, ethnicity, was also significant, \( F(1, 2147) = 75.742, p < .001 \), partial \( \eta^2 = .034 \), indicating that ethnicity had a significant effect on the final exam percentage scores for the two curricular approaches. The covariate, major, was also significant, \( F(1, 2147) = 24.972, p < .001 \), partial \( \eta^2 = .011 \), indicating that major had a significant effect on the final exam percentage scores for the two curricular approaches. However, the covariate, classroom, was not significant, \( F(1, 2147) = 2.692, p = .101 \), partial \( \eta^2 = .001 \), indicating that classroom size did not have a significant effect on the final exam percentage scores for the two curricular approaches.

The following off-sequence analysis shows the results of the fall 2012 and 2013 “traditional” curricular semesters compared to the fall 2014 and 2015 “atoms first” curricular semesters. Levene’s test was significant, \( F(1, 1119) = 4.095, p = .043 \), indicating that the assumption of homogeneity of variance had not been met. Also, the assumption of multicollinearity was not met. The assumption of homogeneity of regression slopes was met due to the non-significant result for the curriculum and gender interaction, \( F(1, 1113) = 1.093, p = .296 \); the curriculum and ethnicity interaction, \( F(1, 1113) = 1.079, p = .299 \); and the curriculum and major interaction, \( F(1, 1113) = .149, p = .699 \). The main effect of curriculum was significant, \( F(1, 1116) = 10.154, p = .001 \), partial \( \eta^2 = .009 \), indicating that the final letter grades were higher using the “traditional” curriculum \( (M = 2.029, \text{ Std. Dev. } = 1.313) \) compared to the “atoms first” curriculum \( (M = 1.794, \text{ Std. Dev. } = 1.242) \).
Table 33

**ANCOVA tests of between-subjects effects – Curriculum comparison for off-sequence –**

*Final letter grade – Chemistry II*

<table>
<thead>
<tr>
<th>Source</th>
<th>Type III Sum of Squares</th>
<th>df</th>
<th>Mean Square</th>
<th>F</th>
<th>Sig.</th>
<th>Partial Eta Squared</th>
</tr>
</thead>
<tbody>
<tr>
<td>Intercept</td>
<td>194.920</td>
<td>1</td>
<td>194.920</td>
<td>124.564</td>
<td>.000</td>
<td>.100</td>
</tr>
<tr>
<td>Gender</td>
<td>10.048</td>
<td>1</td>
<td>10.048</td>
<td>6.421</td>
<td>.011</td>
<td>.006</td>
</tr>
<tr>
<td>Ethnicity</td>
<td>28.447</td>
<td>1</td>
<td>28.447</td>
<td>18.179</td>
<td>.000</td>
<td>.016</td>
</tr>
<tr>
<td>Major</td>
<td>29.456</td>
<td>1</td>
<td>29.456</td>
<td>18.824</td>
<td>.000</td>
<td>.017</td>
</tr>
<tr>
<td>Classroom Size</td>
<td>.000</td>
<td>0</td>
<td>---</td>
<td>---</td>
<td>---</td>
<td>.000</td>
</tr>
<tr>
<td>Curriculum</td>
<td>15.890</td>
<td>1</td>
<td>15.890</td>
<td>10.154</td>
<td>.001</td>
<td>.009</td>
</tr>
<tr>
<td>Error</td>
<td>1746.343</td>
<td>1116</td>
<td>1.565</td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>Total</td>
<td>5862.000</td>
<td>1121</td>
<td></td>
<td></td>
<td></td>
<td></td>
</tr>
</tbody>
</table>

Dependent variable: Final letter grade, $R^2 = .046$, Adjusted-$R^2 = .042$

To stay consistent with the overall analysis performed the same four covariates, gender, ethnicity, major, and classroom, were used in the analysis. The covariate, classroom size, was not applicable due to there not being two different classroom sizes for the off-sequence set of data. Gender, $F(1, 1119) = .050, p = .823$; ethnicity, $F(1, 1119) = .548, p = .459$; and major, $F(1, 1119) = .089, p = .766$ were found to be non-significant and independent of the curricular approach. The covariate, gender, was also significant, $F(1, 1116) = 6.421, p = .011$, partial $\eta^2 = .006$, indicating that gender had a significant effect on the final letter grades for the two curricular approaches. The covariate, ethnicity, was also significant, $F(1, 1116) = 18.179, p < .001$, partial $\eta^2 = .016$, indicating that ethnicity had a significant effect on the final letter grades for the two curricular approaches. Lastly, the covariate, major, was also significant, $F(1, 1116) = 18.824, p < .001$, partial $\eta^2 = .017$, indicating that major had a significant effect on the final letter grades for the two curricular approaches.
Research Question 3 – Chemistry II

The third research question states does the “atoms first” curriculum lead to higher student success compared to the “traditional” curriculum when students are differentiated into each of the sub-factors? The sub-factors analyzed in this study are gender, ethnicity/race, major (chemistry majors versus non-majors), composite ACT score, math ACT subscore, GPA, and classroom setting size (large versus small). To answer this research question, a multiple linear regression, multinomial logistic regression, and a binary logistic regression were performed using all of the subgroups (gender, ethnicity/race, major, ACT composite, ACT math, GPA, and classroom size) as possible predictor variables to determine if there are any significant interactions between the curricular methods and the different subgroups (predictor variables). In addition to the subgroups, a semester sequence variable, specifying whether the student was enrolled in chemistry II during an on- or off-sequence semester, was added based on the between groups correlation. The curricular method was set as a predictor variable with two levels; “traditional” approach and “atoms first” approach. The outcome variable will be the final exam percentage scores or the final letter grades.

Final Exam Percentage Results

The initial regression model was determined using all seven sub-group factors (gender, ethnicity/race, major, ACT composite, ACT math, GPA, and classroom size), term sequence, curriculum approach, and all interaction terms involving curriculum approach, the seven sub-factors, and the term sequence variable. Ethnicity/race was tested in three different formats: 1) using seven individual categories – American Indian or Alaskan Native, Asian, Black or African American, Hispanic or Latino, Multiracial,
Unknown, and White (the category Native Hawaiian or Other Pacific Islander was not included due no students in the category); 2) using four major categories – Other, Black or African American, Hispanic or Latino, and White; and 3) using three major categories – Other, Black or African American, and White. The same results were found using all three different ethnicity breakdowns. For simplicity of result presentation, the ethnicity breakdown using only the three major categories will be displayed.

Table 34 provides the means and standard deviations for the dependent variable (final exam percentage), the seven sub-factors, the term sequence variable, the curriculum variable, and all interaction variables.
Table 34

*Descriptive statistics for full regression model using final exam percentage – Chemistry*

<table>
<thead>
<tr>
<th></th>
<th>Mean</th>
<th>Standard Deviation</th>
</tr>
</thead>
<tbody>
<tr>
<td><strong>Final Exam Percentage</strong></td>
<td>66.916</td>
<td>17.319</td>
</tr>
<tr>
<td><strong>Gender</strong></td>
<td>.537</td>
<td>.499</td>
</tr>
<tr>
<td><strong>Ethnicity - Other</strong></td>
<td>.072</td>
<td>.259</td>
</tr>
<tr>
<td><strong>Ethnicity - Black or African American</strong></td>
<td>.149</td>
<td>.356</td>
</tr>
<tr>
<td><strong>Non-Major</strong></td>
<td>.945</td>
<td>.228</td>
</tr>
<tr>
<td><strong>Major - Other</strong></td>
<td>.032</td>
<td>.175</td>
</tr>
<tr>
<td><strong>ACT Composite</strong></td>
<td>26.054</td>
<td>4.246</td>
</tr>
<tr>
<td><strong>ACT Math</strong></td>
<td>25.669</td>
<td>4.435</td>
</tr>
<tr>
<td><strong>Overall GPA</strong></td>
<td>3.159</td>
<td>.628</td>
</tr>
<tr>
<td><strong>Classroom Size</strong></td>
<td>.021</td>
<td>.145</td>
</tr>
<tr>
<td><strong>Term - Sequence</strong></td>
<td>.710</td>
<td>.454</td>
</tr>
<tr>
<td><strong>Curriculum</strong></td>
<td>.633</td>
<td>.482</td>
</tr>
<tr>
<td><strong>Gender * Curriculum</strong></td>
<td>.339</td>
<td>.474</td>
</tr>
<tr>
<td><strong>EthnicityOther * Curriculum</strong></td>
<td>.043</td>
<td>.204</td>
</tr>
<tr>
<td><strong>EthnicityBlack * Curriculum</strong></td>
<td>.096</td>
<td>.295</td>
</tr>
<tr>
<td><strong>Non-Major * Curriculum</strong></td>
<td>.591</td>
<td>.492</td>
</tr>
<tr>
<td><strong>MajorOther * Curriculum</strong></td>
<td>.021</td>
<td>.142</td>
</tr>
<tr>
<td><strong>ACTComposite * Curriculum</strong></td>
<td>16.432</td>
<td>12.973</td>
</tr>
<tr>
<td><strong>ACTMath * Curriculum</strong></td>
<td>16.223</td>
<td>12.864</td>
</tr>
<tr>
<td><strong>GPA * Curriculum</strong></td>
<td>1.995</td>
<td>1.600</td>
</tr>
<tr>
<td><strong>Classroom * Curriculum</strong></td>
<td>.021</td>
<td>.145</td>
</tr>
<tr>
<td><strong>TermSequence * Curriculum</strong></td>
<td>.457</td>
<td>.498</td>
</tr>
</tbody>
</table>

*Note. N = 2532*

The sample obtained an $R$ value and an $R$-squared value of .669 and .448, respectively. The independent variables in the model explain 44.8% of the total sample variation of final exam percentage scores ($y$). The adjusted $R$-squared value is .444. This implies that the least squares model has explained 44.4% of the total sample variation in
final exam percentage scores \((y)\), after adjusting for sample size and number of independent variables in the model.

Table 35

*Model summary of full regression analysis – Final exam percentage – Chemistry II*

<table>
<thead>
<tr>
<th>Model</th>
<th>R</th>
<th>R Square</th>
<th>Adjusted R Square</th>
<th>Std. Error of the Estimate</th>
</tr>
</thead>
<tbody>
<tr>
<td>1</td>
<td>.669</td>
<td>.448</td>
<td>.444</td>
<td>12.917</td>
</tr>
</tbody>
</table>

Note. Predictors: (Constant), Gender, Ethnicity - Other, Ethnicity - Black or African American, Non-Major, Major-Other, ACT Composite, ACT Math, Overall GPA, Classroom Size, Term – Sequence, Curriculum, Gender * Curriculum, EthnicityOther * Curriculum, EthnicityBlack * Curriculum, Non-Major * Curriculum, MajorOther * Curriculum, ACTComp * Curriculum, ACTMath * Curriculum, GPA * Curriculum, Classroom * Curriculum, TermSequence * Curriculum.

At an alpha of .05, four of the 21 tested variables were found to be statistically significant in the model. These four variables – ACT composite, ACT math, overall GPA, and curriculum – were used for the finalized regression model. Table 36 provides the correlations for the dependent variable (final exam percentage) and those four statistically significant variables used in the finalized regression model.
Table 36

*Correlations among statistically significant finalized regression model variables – Final exam percentage – Chemistry II*

<table>
<thead>
<tr>
<th></th>
<th>ACT Composite</th>
<th>ACT Math</th>
<th>Overall GPA</th>
<th>Curriculum</th>
</tr>
</thead>
<tbody>
<tr>
<td>Final Exam Percentage</td>
<td>.487*</td>
<td>.473*</td>
<td>.617*</td>
<td>.064**</td>
</tr>
<tr>
<td>ACT Composite</td>
<td>.850*</td>
<td>.492*</td>
<td>-.030</td>
<td></td>
</tr>
<tr>
<td>ACT Math</td>
<td></td>
<td>.454*</td>
<td>-.013</td>
<td></td>
</tr>
<tr>
<td>Overall GPA</td>
<td></td>
<td></td>
<td>-.015</td>
<td></td>
</tr>
</tbody>
</table>

Note. N = 2532, *p < .001, **p ≤ .05

The model summary results for the finalized regression model are slightly different than the full regression model containing all variables. The sample obtained an R value and an R-squared value of .661 and .437, respectively. These values are very close to the full model values with only differences of .008 and .011, respectively. The independent variables in the model explain 43.7% of the total sample variation of final exam percentage scores (y). The adjusted R-squared value is .436. This implies that the least squares model has explained 43.6% of the total sample variation in final exam percentage scores (y), after adjusting for sample size and number of independent variables in the model.
Table 37

*Model summary of finalized regression analysis – Final exam percentage – Chemistry II*

<table>
<thead>
<tr>
<th>Model</th>
<th>R</th>
<th>R Square</th>
<th>Adjusted R Square</th>
<th>Std. Error of the Estimate</th>
</tr>
</thead>
<tbody>
<tr>
<td>1</td>
<td>.661</td>
<td>.437</td>
<td>.436</td>
<td>13.006</td>
</tr>
</tbody>
</table>

Note. Predictors: (Constant), ACT Composite, ACT Math, Overall GPA, Curriculum.

The finalized linear regression model has no significant curriculum interactions. Thus, there will be no follow-up two-way ANOVA analyses. To further determine if a specific curricular approach produces higher student success, the final letter grade will be analyzed.

**Final Letter Grade Results**

The initial regression model was determined using all seven sub-group factors (gender, ethnicity/race, major, ACT composite, ACT math, GPA, and classroom size), term sequence, curriculum approach, and all interaction terms involving curriculum approach, the seven sub-factors, and the term sequence variable. Ethnicity/race was tested in three different formats: 1) using seven individual categories – American Indian or Alaskan Native, Asian, Black or African American, Hispanic or Latino, Multiracial, Unknown, and White (the category Native Hawaiian or Other Pacific Islander was not included due no students in the category); 2) using four major categories – Other, Black or African American, Hispanic or Latino, and White; and 3) using three major categories – Other, Black or African American, and White. The same results were found using all
three different ethnicity breakdowns. For simplicity of result presentation, the ethnicity breakdown using only the three major categories will be displayed.

Table 38 provides the means and standard deviations for the dependent variable (final letter grade), the seven sub-factors, the term sequence variable, and the curriculum variable.

Table 38

*Descriptive statistics for full regression model using final letter grade – Chemistry II*

<table>
<thead>
<tr>
<th></th>
<th>Mean</th>
<th>Standard Deviation</th>
</tr>
</thead>
<tbody>
<tr>
<td>Final Letter Grade</td>
<td>2.225</td>
<td>1.301</td>
</tr>
<tr>
<td>Gender</td>
<td>.531</td>
<td>.499</td>
</tr>
<tr>
<td>Ethnicity - Other</td>
<td>.070</td>
<td>.254</td>
</tr>
<tr>
<td>Ethnicity - Black or African American</td>
<td>.151</td>
<td>.358</td>
</tr>
<tr>
<td>Non-Major</td>
<td>.940</td>
<td>.238</td>
</tr>
<tr>
<td>Major - Other</td>
<td>.033</td>
<td>.178</td>
</tr>
<tr>
<td>ACT Composite</td>
<td>25.976</td>
<td>4.263</td>
</tr>
<tr>
<td>ACT Math</td>
<td>25.542</td>
<td>4.449</td>
</tr>
<tr>
<td>Overall GPA</td>
<td>3.148</td>
<td>.631</td>
</tr>
<tr>
<td>Classroom Size</td>
<td>.028</td>
<td>.166</td>
</tr>
<tr>
<td>Term - Sequence</td>
<td>.660</td>
<td>.474</td>
</tr>
<tr>
<td>Curriculum</td>
<td>.589</td>
<td>.492</td>
</tr>
<tr>
<td>Gender * Curriculum</td>
<td>.311</td>
<td>.463</td>
</tr>
<tr>
<td>EthnicityOther * Curriculum</td>
<td>.040</td>
<td>.197</td>
</tr>
<tr>
<td>EthnicityBlack * Curriculum</td>
<td>.085</td>
<td>.279</td>
</tr>
<tr>
<td>Non-Major * Curriculum</td>
<td>.553</td>
<td>.497</td>
</tr>
<tr>
<td>MajorOther * Curriculum</td>
<td>.018</td>
<td>.132</td>
</tr>
<tr>
<td>ACTComposite * Curriculum</td>
<td>15.394</td>
<td>13.275</td>
</tr>
<tr>
<td>ACTMath * Curriculum</td>
<td>15.183</td>
<td>13.145</td>
</tr>
<tr>
<td>GPA * Curriculum</td>
<td>1.867</td>
<td>1.633</td>
</tr>
<tr>
<td>Classroom * Curriculum</td>
<td>.017</td>
<td>.131</td>
</tr>
<tr>
<td>TermSequence * Curriculum</td>
<td>.441</td>
<td>.497</td>
</tr>
</tbody>
</table>

Note. N = 3092
The sample obtained an $R$ value and an $R$-squared value of .787 and .619, respectively. The independent variables in the model explain 61.9% of the total sample variation of final letter grades ($y$). The adjusted $R$-squared value is .617. This implies that the least squares model has explained 61.7% of the total sample variation in final letter grades ($y$), after adjusting for sample size and number of independent variables in the model.

Table 39

*Model summary of full regression analysis – Final letter grade – Chemistry II*

<table>
<thead>
<tr>
<th>Model</th>
<th>R</th>
<th>R Square</th>
<th>Adjusted R Square</th>
<th>Std. Error of the Estimate</th>
</tr>
</thead>
<tbody>
<tr>
<td>1</td>
<td>.787</td>
<td>.619</td>
<td>.617</td>
<td>.805</td>
</tr>
</tbody>
</table>

Note. Predictors: (Constant), Gender, Ethnicity - Other, Ethnicity - Black or African American, Non-Major, Major-Other, ACT Composite, ACT Math, Overall GPA, Classroom Size, Term – Sequence, Curriculum, Gender * Curriculum, EthnicityOther * Curriculum, EthnicityBlack * Curriculum, Non-Major * Curriculum, MajorOther * Curriculum, ACTComp * Curriculum, ACTMath * Curriculum, GPA * Curriculum, Classroom * Curriculum, TermSequence * Curriculum.

At an alpha of .05, there were 8 of the 21 tested variables found to be statistically significant in the model. These eight variables were used for the finalized regression model. These include: gender, major, ACT math, overall GPA, term sequence, curriculum approach, GPA and curriculum interaction, and term sequence and curriculum interaction variables. Table 40 provides the correlations for the dependent variable (final letter grade) and those eight statistically significant variables used in the finalized regression model.
Table 40

*Correlations among statistically significant finalized regression model variables – Final letter grade – Chemistry II*

<table>
<thead>
<tr>
<th></th>
<th>Gender</th>
<th>Non-Major</th>
<th>Major - Other</th>
<th>ACT Math</th>
<th>Overall GPA</th>
<th>Term - Sequence</th>
<th>Curriculum</th>
<th>GPA * Curriculum</th>
<th>TermSeq * Curriculum</th>
</tr>
</thead>
<tbody>
<tr>
<td>Final Letter Grade</td>
<td>-0.062*</td>
<td>0.002</td>
<td>-0.131*</td>
<td>0.501*</td>
<td>0.759*</td>
<td>0.188*</td>
<td>0.064*</td>
<td>0.236*</td>
<td>0.111*</td>
</tr>
<tr>
<td>Gender</td>
<td></td>
<td>0.024</td>
<td>0.045**</td>
<td>0.120*</td>
<td>-0.186*</td>
<td>0.012</td>
<td>-0.007</td>
<td>-0.048**</td>
<td>-0.004</td>
</tr>
<tr>
<td>Non - Major</td>
<td>-0.726*</td>
<td></td>
<td>0.035**</td>
<td>0.057**</td>
<td>-0.026</td>
<td>-0.004</td>
<td>0.006</td>
<td>-0.022</td>
<td></td>
</tr>
<tr>
<td>Major - Other</td>
<td>-0.103*</td>
<td>-0.158*</td>
<td>-0.053**</td>
<td>-0.017</td>
<td>-0.048**</td>
<td>-0.031**</td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>ACT Math</td>
<td></td>
<td>0.461*</td>
<td>0.296*</td>
<td>0.064*</td>
<td>0.168*</td>
<td>0.174*</td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>Overall GPA</td>
<td></td>
<td></td>
<td>0.221*</td>
<td>0.043**</td>
<td>0.266*</td>
<td>0.139*</td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>Term - Sequence</td>
<td></td>
<td></td>
<td></td>
<td>0.223*</td>
<td>0.256*</td>
<td>0.637*</td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>Curriculum</td>
<td></td>
<td></td>
<td></td>
<td></td>
<td>.955*</td>
<td>.742*</td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>GPA * Curriculum</td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td>.750*</td>
<td></td>
<td></td>
<td></td>
</tr>
</tbody>
</table>

Note. N = 3092, *p < .001, **p < .05
The model summary results for the finalized regression model are slightly different than the full regression model containing all variables. The sample obtained an \( R \) value and an \( R \)-squared value of .785 and .617, respectively. These values are very close to the full model values with only differences of .002 and .002, respectively. The independent variables in the model explain 61.7% of the total sample variation of final letter grade (\( y \)). The adjusted \( R \)-squared value is .616. This implies that the least squares model has explained 61.6% of the total sample variation in final letter grade (\( y \)), after adjusting for sample size and number of independent variables in the model.

Table 41

*Model summary of finalized regression analysis – Final letter grade – Chemistry II*

<table>
<thead>
<tr>
<th>Model</th>
<th>R</th>
<th>R Square</th>
<th>Adjusted R Square</th>
<th>Std. Error of the Estimate</th>
</tr>
</thead>
<tbody>
<tr>
<td>1</td>
<td>.785</td>
<td>.617</td>
<td>.616</td>
<td>.807</td>
</tr>
</tbody>
</table>

Note. Predictors: (Constant), Gender, Non-Major, Major-Other, ACT Math, Overall GPA, Term – Sequence, Curriculum, GPA * Curriculum, TermSequence * Curriculum.

The finalized linear regression model shows two curriculum interactions with GPA and term – sequence. The GPA * Curriculum interaction (\( \beta = .134, p = .025 \)) and the TermSequence * Curriculum interaction (\( \beta = -.115, p \leq .001 \)) were significant. The GPA interaction will be further investigated using a two-way ANOVA with the follow-up post hoc analysis to determine the specific curricular approach that produces higher student success. However, the term-sequence interaction will not be further investigated since it has already been discussed in the ANCOVA analyses discussed earlier. This
A significant interaction result supports the ANCOVA breakdown of on- and off-sequence semesters.

**Grade point average (GPA).** GPA was divided into two groups to determine if above and below average learners perform better under a specific curricular approach. The cases were divided in half using the calculated median for GPA, which was calculated at 3.22. Those at or above 3.22 were determined as above average learners and those below 3.22 labeled as below average learners. The two-way ANOVA was run using final letter grade as the dependent variable and curriculum approach, GPA learner group (above and below average), and the GPA and curriculum interaction variables as the independent variables. Table 42 provides the means and standard deviations for the dependent and independent variables.

Table 42

*Descriptive statistics for GPA and curriculum variables – Chemistry II*

<table>
<thead>
<tr>
<th>GPA Categories</th>
<th>Curriculum</th>
<th>Mean</th>
<th>Standard Deviation</th>
<th>N</th>
</tr>
</thead>
<tbody>
<tr>
<td>Below Average</td>
<td>Atoms First</td>
<td>1.352</td>
<td>.962</td>
<td>707</td>
</tr>
<tr>
<td></td>
<td>Traditional</td>
<td>1.391</td>
<td>1.054</td>
<td>930</td>
</tr>
<tr>
<td></td>
<td>Total</td>
<td>1.374</td>
<td>1.015</td>
<td>1637</td>
</tr>
<tr>
<td>Above Average</td>
<td>Atoms First</td>
<td>2.972</td>
<td>.970</td>
<td>647</td>
</tr>
<tr>
<td></td>
<td>Traditional</td>
<td>3.125</td>
<td>.940</td>
<td>990</td>
</tr>
<tr>
<td></td>
<td>Total</td>
<td>3.065</td>
<td>.955</td>
<td>1637</td>
</tr>
</tbody>
</table>

Note. Dependent variable = Final letter grade

The GPA * Curriculum interaction was not significant, $F(1, 3270) = 2.654, p = .103$, indicating that the two teaching approaches do not produce statistically different effects on below and above average students.
**Multinomial Logistic Regression Results.** The initial multinomial logistic regression model was determined using all seven sub-group factors (gender, ethnicity/race, major, ACT composite, ACT math, GPA, and classroom size), term sequence, curriculum approach, and all interaction terms involving curriculum approach, the seven sub-factors, and the term sequence variable as independent variables. Ethnicity/race was tested using the three major categories – Other, Black or African American, and White. The dependent variable, final letter grade, had five levels, which included A, B, C, D, and F letter categories.

At an alpha of .05, there were 8 of the 21 tested variables found to be statistically significant in the model. These include: gender, major, ACT math, overall GPA, term sequence, curriculum approach, GPA and curriculum interaction, and term sequence and curriculum interaction variables. The finalized logistic regression model shows two curriculum interactions; one with GPA and the other with term sequence. The GPA * Curriculum interaction, $\chi^2(4) = 13.350, p = .010$, and the TermSequence * Curriculum interaction, $\chi^2(4) = 28.159, p < .001$, were significant. The GPA interaction has already been further analyzed using a two-way ANOVA with follow-up post hoc analysis. Additionally, the term-sequence interaction will not be further investigated since it has already been discussed in the ANCOVA analyses discussed earlier. This significant interaction result supports the ANCOVA breakdown of on- and off-sequence semesters.

**Binary Logistic Regression Results.** The initial binary logistic regression model was determined using all seven sub-group factors (gender, ethnicity/race, major, ACT composite, ACT math, GPA, and classroom size), term sequence, curriculum approach,
and all interaction terms involving curriculum approach, the seven sub-factors, and the term sequence variable as independent variables. Ethnicity/race was tested using the three major categories – Other, Black or African American, and White. The dependent variable, final letter grade, had two levels – pass and fail. Pass defined as those students earning an A, B, or C final letter grade. Fail included those students earning a D or F final letter grade.

At an alpha of .05, there were 7 of the 21 tested variables found to be statistically significant in the model. These include: gender, ACT math, overall GPA, classroom size, term sequence, curriculum approach, and term sequence and curriculum interaction variables. The finalized logistic regression model shows one significant curriculum interaction with term sequence, \( B = -1.065, p \leq .001 \). The term-sequence interaction will not be further investigated since it has already been discussed in the ANCOVA analyses discussed earlier. This significant interaction result supports the ANCOVA breakdown of on- and off-sequence semesters.
CHAPTER V
DISCUSSION AND CONCLUSIONS

Research Question 1

Research question 1 asked does the “atoms first” curriculum better align to the curricular expectations established by research supported best practices? To answer this research question, a qualitative review of two chemistry textbooks written by the same author, but in the two curricular approaches was performed. The review focused on the essential elements of effective science instruction and the chemistry curriculum guidelines mentioned in the literature review. The two textbooks reviewed were *Chemistry*, 3rd edition, by Burdge (2014) and *Chemistry: Atoms First* by Burdge and Overby (2012).

**Essential Elements of Effective Science Instruction**

In regards to the results of the textbook comparison, research question 1 would be answered as follows:

- **HOS** – The “atoms first” curriculum better aligns to curricular expectations compared to the “traditional” curriculum. This is seen through the specific sections dedicated to the history of chemistry.

- **NOS** – Marginally, the “atoms first” curriculum better aligns to curricular expectations compared to the “traditional” curriculum. This is seen through the explanation regarding the development of laws and theories.
• Content Knowledge – Neither curriculum aligns to curricular expectations better than the other. This is seen through the same material being covered, but just in a different order.

• Scientific Method – The “atoms first” curriculum better aligns to curricular expectations compared to the “traditional” curriculum. This is seen through the real-world example of how the scientific method works and its detailed description.

Overall, these results show that the “atoms first” curriculum better aligns to the curricular expectations established by research supported best practices. This means that the “atoms first” approach provides more of the essential elements needed for students to thrive as effective scientists.

Chemistry Curriculum Guidelines

In regards to the results of the textbook comparison, research question 1 would be answered as follows:

• Meet needs of all learners – The “atoms first” curriculum better aligns to curricular expectations compared to the “traditional” curriculum. This is due to this guideline being the primary focus of the “atoms first” approach.

• Relate to life - Neither curriculum aligns to curricular expectations better than the other. This is due to the same number of real-life examples and applications being used by both approaches.
- Reveal chemistry’s role in society - Neither curriculum aligns to curricular expectations better than the other. This is due to neither approach containing this guideline in their texts.

- Have a low content base – Neither curriculum aligns to curricular expectations better than the other. This is seen through the same material being covered, but just in a different order.

- Be within information processing capacity – The “atoms first” curriculum better aligns to curricular expectations compared to the “traditional” curriculum. This is due to the gradual introduction of the atom followed by vocabulary and math.

- Take account of language and communication – Marginally, the “atoms first” curriculum better aligns to curricular expectations compared to the “traditional” curriculum. This is due to the open sections of the lab at the beginning of the semester that this guideline could easily be incorporated.

- Aim at conceptual understanding – Neither curriculum aligns to curricular expectations better than the other. This is due to this guideline being dependent on the specific course instructor and what he/she deems important.

- Offer genuine problem solving experience – Neither curriculum aligns to curricular expectations better than the other. This is due to this guideline being dependent on the specific course instructor. Specifically, what the instructor assigns in the course and what types of laboratory experiments are required.
• Use lab work appropriately – The “traditional” curriculum better aligns to curricular expectations compared to the “atoms first” curriculum. This is due to the “traditional” approach being able to provide more hands-on reaction based experimental time throughout the entire semester.

• Involve appropriate assessment – Neither curriculum aligns to curricular expectations better than the other. This is due to this guideline being dependent on the specific course instructor. Specifically, how he/she develops the assessments and determines the goals of each.

Overall, these results show that the “atoms first” curriculum marginally aligns to the curricular expectations established by research supported best practices better than the “traditional” curriculum. This means that the “atoms first” approach provides more of the chemistry curriculum development guidelines needed for students to be successful and understand chemistry as a whole. However, there are several guidelines that both approaches are lacking and need to improve on in order to prepare all students to be responsible and knowledgeable citizens.

**Research Question 2**

Research question 2 asked does the “atoms first” curriculum lead to higher student success compared to the “traditional” curriculum for all students when all other sub-factors are considered as covariates? To answer this research question, an ANCOVA was performed to determine if there is a significant difference between the “atoms first” and the “traditional” general chemistry curricula. The independent variables was the curricular method and the dependent variables were either the final exam percentage or the final letter grade. The sub-factors or covariates tested were gender, ethnicity, major,
ACT composite score, ACT math sub-score, overall GPA, and classroom size. The discussion of research question 2 will be divided into two parts – chemistry I and II. In each of the chemistry courses the discussion will cover the results using the final examination percentage scores followed by the results using the final letter grades.

Chemistry I

Final examination. The final exam percentage scores produced the same results when the semesters were combined as when they were separated into on- and off-sequence terms. The final exam results found that the main effect of curriculum was significant. This means that there is a significant difference between the two curricular approaches when taking into account other influencing factors. The “traditional” approach produced higher final examination percentages compared to the “atoms first” approach.

When looking at the overview results, meaning when the semesters where combined, the sub-factors that were found to be independent of the curricular approach were also found to be significant. This informs us that the difference in curricular approach could only be measured when the gender and the GPA of the student was held constant. Meaning that the gender and the GPA of the student impacts their performance on the final exam without the curricular approach factor.

When looking at the on-sequence results, meaning the fall semesters, the “traditional” and the “atoms first” averages appear to be staying steady at their specific averages. This strengthens the argument for the “traditional” approach in that it is steadily higher than the “atoms first” approach. Additionally, it does not appear that the “atoms first” approach is changing.
When looking at the off-sequence results, meaning the spring semesters, the argument for the “traditional” approach is not directly strengthened. This is mainly due to there being only one semester of data for the “atoms first” approach. This semester is lower than the two semesters for the “traditional” approach, but it cannot be determined if this level would stay steady or increase with additional semesters.

**Final letter grade.** The final letter grades produced varying results between the combined semester analysis and the on- and off-sequence analysis. The final letter results found that the main effect of curriculum was not significant for the combined and the on-sequence terms, but significant for the off-sequence terms. This means that the difference between the two curricular approaches could not be seen except for those students in the off-sequence. The “atoms first” approach produced higher final letter grades compared to the “traditional” approach for those students taking the course off-sequence. The off-sequence semesters usually have lower performing students who are weaker in math ability. The results show that the “atoms first” curriculum helps these students perform better compared to the “traditional” approach.

When looking at the overview or combined semester results, the same two sub-factors, gender and GPA, were found to be independent of the curricular approach. This supports the final examination results that gender and GPA impact student performance individually without the effect of curricular approach and must be taken into consideration. Also, the overview results show that there is no difference in final letter grade for students when comparing the two curricular approaches.

When looking at the on-sequence or fall semester results, there was no difference in final letter grade averages when comparing the two approaches. However, when
looking at the break-down, the “atoms first” approach was increasing in final letter grade average. An additional semester of data for the “atoms first” approach may provide insight regarding if the curricular approach will hold steady at that final letter grade average or if the increase will continue. If the increase continues, the “atoms first” approach would produce statistically higher final letter grade averages compared to the “traditional” approach.

When looking at the off-sequence or spring semester results, the “atoms first” approach is statistically higher in final letter grades compared to the “traditional” approach. Since there is only one semester of data, it cannot be determined if that is the highest the “atoms first” approach averages will get or if there will be an increase in performance over time.

**Conclusion.** In regards to the chemistry I results using both the final examination scores and the final letter grades, research question 2 would be answered as follows:

- Combined semesters - The “traditional” approach leads to higher student success compared to the “atoms first” approach. However, this can only be seen using the final examination scores.

- On-sequence semesters - The “traditional” approach leads to higher student success compared to the “atoms first” approach. However, this can only be seen using the final examination scores.
• Off-sequence semesters – The results are inconclusive in that the final exam favors one approach and the final letter grade favors the other approach. Thus, it cannot be stated which approach leads to higher student success.

Chemistry II

The results from the Chemistry II course are used to determine if there is a long term effect of curricular approach. This will show if the sequence of teaching foundational concepts at the beginning of a course has impacts ranging into later courses.

Final examination. The final exam percentage scores produced the same results when the semesters were combined as when they were separated into on- and off-sequence terms. The final exam results found that the main effect of curriculum was significant. This means that there is a significant difference between the two curricular approaches when taking into account other influencing factors. The “traditional” approach produced higher final examination percentages compared to the “atoms first” approach.

When looking at the overview results, meaning when the semesters were combined, three of the four sub-factors that were found to be independent of the curricular approach were also found to be significant. This informs us that the difference in curricular approach could only be measured when the gender, ethnicity, and major of the student was held constant. Meaning that the gender, ethnicity, and major of the student impacts their performance on the final exam without the curricular approach factor.
When looking at the on-sequence results, meaning the spring semesters, there is only one available semester for the “atoms first” approach due to the research study range. This semester’s average was lower than the “traditional” approach semesters. However, since there is only one semester we cannot determine if the “atoms first” approach has hit the highest achievement level or will increase in additional semesters. The “traditional” approach lead to higher final examination averages compared to the “atoms first” approach.

When looking at the off-sequence results, meaning the fall semesters, there is only one semester of “atoms first” data. This is due to a computer crash for the only professor teaching the fall 2014 semester, so that final examination data is missing. Since this semester is missing, it cannot be determined if the final examination averages are decreasing, leveling out, or increasing. However, the final examination average for the one available semester was in between the two “traditional” approach semesters. This tells us that the “atoms first” approach is around the average for the “traditional” approach, but not statistically higher. The significant difference between curricular approaches was only noticed when all of the independent sub-factors were used compared to using only those that were found to be independent in the combined overall analysis. The insignificant result came when using only gender, ethnicity, major, and classroom. However, when ACT composite, ACT math, and overall GPA were added as covariates there was a significant difference between the two approaches. The “traditional” approach lead to higher final examination averages compared to the “atoms first” approach. This result is consistent to the overall combined analysis and the on-sequence analysis.
Final letter grade. The final letter grades produced varying results between the combined semester analysis and the on- and off-sequence analysis. The final letter results found that the main effect of curriculum was significant for the combined and the off-sequence terms, but not significant for the on-sequence terms. This means that the difference between the two curricular approaches could not be seen for those students in the on-sequence. The “traditional” approach produced higher final letter grades compared to the “atoms first” approach for those students in the combined analysis and those taking the off-sequence course.

When looking at the overview or combined semester results, the same four sub-factors - gender, ethnicity, major, and classroom - were found to be independent of the curricular approach. However, all four were found to be significant in the model; whereas, classroom was not significant in the final examination model. These results support the final examination results that gender, ethnicity, and major impact student performance individually without the effect of curricular approach and must be taken into consideration. Also, the overview results show that the “traditional” approach leads to higher final letter grades than the “atoms first” approach.

When looking at the on-sequence or spring semester results, there was no difference in final letter grade averages when comparing the two approaches. This was seen when only the sub-factors in the overview analysis were used and when all independent covariates were used. However, there is only one semester of data for the “atoms first” approach, so it cannot be determined if this is the highest final letter grade averages or if the approach will increase with additional semesters. If the approach
increases then it is possible for the “atoms first” approach to be statistically higher than the “traditional” approach.

When looking at the off-sequence or fall semester results, the “traditional” approach is statistically higher in final letter grades compared to the “atoms first” approach. However, when looking at the semester break-down, the “atoms first” approach was increasing in final letter grade average. An additional semester of data for the “atoms first” approach may provide insight regarding if the curricular approach will hold steady at that final letter grade average or if the increase will continue. If the increase continues, the “atoms first” approach could produce statistically higher final letter grade averages compared to the “traditional” approach.

**Conclusion.** In regards to the chemistry II results using both the final examination scores and the final letter grades, research question 2 would be answered as follows:

- Combined semesters - The “traditional” approach leads to higher student success compared to the “atoms first” approach.
- On-sequence semesters - The “traditional” approach leads to higher student success compared to the “atoms first” approach. However, this can only be seen using the final examination scores.
- Off-sequence semesters – The “traditional” approach leads to higher student success compared to the “atoms first” approach.

**Research Question 3**

Research question 3 asked does the “atoms first” curriculum lead to higher student success compared to the “traditional” curriculum when students are differentiated
into each of the sub-factors? The sub-factors analyzed in this study are gender, ethnicity/race, major (chemistry majors versus non-majors), composite ACT score, math ACT subscore, GPA, and classroom setting size (large versus small). To answer this research question, a multiple linear regression, multinomial logistic regression, and a binary logistic regression were performed using all of the subgroups (gender, ethnicity/race, major, ACT composite, ACT math, GPA, and classroom size) as possible predictor variables to determine if there are any significant interactions between the curricular methods and the different subgroups (predictor variables). In addition to the subgroups, a semester sequence variable, specifying whether the student was enrolled in chemistry I or II during an on- or an off-sequence semester, was added based on the between groups correlation. The curricular method was set as a predictor variable with two levels; “traditional” approach and “atoms first” approach. The outcome variable will be the final exam percentage scores or the final letter grades.

Chemistry I

Final examination. The final examination data were used in a multiple linear regression model to determine which if any curriculum interaction variables were significant. The initial model was run with 11 main effect and 10 interaction variables. This model was reduced until only those significant variables were remaining. This is the normal procedure in determining the finalized and most accurate regression model for the given data. This finalized model contained nine main effect and three curriculum interaction variables. The finalized model had very close $R$-values compared to the complete model. This supports the concept that the removed variables did not explain a significant portion of the variation in the final examination scores. Thus, with their
removal the amount of variation explained did not change dramatically. The finalized model explained approximately 51% of the sample variation. This amount of variation explained is on the lower side; however, since the regression model is not being used for prediction the percentage is not as important.

The most important information from the finalized regression model is what curriculum interaction variables remained and found significant in the model. In this model, gender, GPA, and classroom interactions with curricular approach were found to be significant. These are the three sub-factors that have been deemed as statistically significant in regards to academic achievement and curricular approach. Thus, only these three groupings will be analyzed to determine which approach leads to higher student success.

The results of the two-way ANOVA for gender showed that the gender of the student effects which curricular approach leads to higher student achievement. These results confirm the multiple linear regression significant interaction result between gender and curriculum. But they also show that the relationship between gender and curriculum holds when other factors are not included in the analysis as they were in the regression model. Additionally, it was found that both males and females performed higher when taught under the “traditional” approach. This was different than expected, because men and women think differently and would most likely prefer the approach that favors their thinking style. The “atoms first” approach was expected to be favored by females due to the progression of concepts.

The results of the two-way ANOVA for GPA showed that the GPA grouping – above or below average – effects which curricular approach leads to higher student
achievement. These results confirm the multiple linear regression significant interaction result between GPA and curriculum when other factors are not included. However, the regression model used the specific GPA scores; whereas, the ANOVA used GPA groupings. The results also showed that both below and above average performers scored higher on the final examination when taught under the “traditional” approach. This was different than expected, because the “atoms first” approach introduces mathematics concepts after the foundational abstract concepts have been understood. Thus, the “atoms first” approach was expected to assist below average performers better than the “traditional” approach, which teaches both concepts from the beginning of the course.

Lastly, the results of the two-way ANOVA for classroom size showed that the classroom size grouping – small or large – effects which curricular approach leads to higher student achievement. These results confirm the multiple linear regression significant interaction result between classroom and curriculum when other factors are not included. Additionally, it was found that students in large classroom settings performed higher when taught under the “traditional” approach. However, students in small classroom settings did not statistically favor one curricular approach. These results were not unexpected in that small classroom settings have other benefits that significantly increase student performance. These results show that these benefits outweighed the benefits of the different curricular approaches.

**Final letter grade.** The final letter grade data were used in a multiple linear regression model to determine which if any curriculum interaction variables were significant. The initial model was run with 11 main effect and 10 interaction variables. This model was reduced using the normal procedure until only those significant variables
were remaining. This finalized model contained eight main effect and two curriculum interaction variables. The finalized model had very close $R$-values compared to the complete model. This supports the concept that the removed variables did not explain a significant portion of the variation in the final examination scores. Thus, with their removal the amount of variation explained did not change dramatically. The finalized model explained approximately 69.5% of the sample variation. This amount of variation explained was higher compared to the model using the final examination scores.

The most important information from the finalized regression model is what curriculum interaction variables remained and found significant in the model. In this model, ACT composite and term sequence interactions with curricular approach were found to be significant. These are the two sub-factors that have been deemed as statistically significant in regards to academic achievement and curricular approach. The term sequence sub-group has already been analyzed and discussed in research question 2. However, the ACT composite grouping still needs to be analyzed to determine which approach leads to higher student success.

The results of the two-way ANOVA for ACT composite showed that the ACT composite grouping – above or below average – effects which curricular approach leads to higher student achievement. These results confirm the multiple linear regression significant interaction result between ACT composite and curriculum when other factors are not included. However, the regression model used the specific ACT composite scores; whereas, the ANOVA used ACT composite groupings. The results showed that below average students earned higher final letter grades when taught under the “atoms first” approach. Whereas, above average students earned higher final letter grades when taught
under the “traditional” approach. The results for below average students were not unexpected in that the “atoms first” approach is expected to assist below average performers in understanding the complex concepts. There were no expectations regarding the above average students, because it was believed that these students would perform well under either curricular approach.

The final letter grade data were also used in a multinomial logistic regression model to determine which if any curriculum interaction variables were significant. The initial model was run with 11 main effect and 10 interaction variables. This model was reduced using the normal procedure until only those significant variables were remaining. This finalized model contained eight main effect variables and the term sequence and curriculum interaction variable. These results partially support the multiple linear regression model in that the term sequence and curriculum interaction variable was found to be significant. However, the ACT composite interaction variable was not found to be significant in the multinomial logistic regression model. This result brings into question the significant result found in the multiple linear regression model, since in that model the final letter grades were coded based on their quality point values. However, final letter grades are not continuous but rather stepwise in that you cannot receive 3.5 quality points or a B and a half. These result will be compared to the binary logistic regression to determine the importance of the ACT composite finding.

Lastly, the final letter grade data were also used in a binary logistic regression model to determine which if any curriculum interaction variables were significant. The initial model was run with 11 main effect and 10 interaction variables. This model was reduced using the normal procedure until only those significant variables were remaining.
This finalized model contained five main effect variables and the term sequence and curriculum interaction variable. These results support the multinomial logistic regression model in that the term sequence and curriculum interaction variable was found to be significant and the ACT composite interaction variable was non-significant. This result supports the notion that the ACT composite interaction is not a continuously significant result in all models. Thus, this result should be taken with a grain of salt. Instead other groupings should be used in determining the curricular approach to use for a given sub-group of students.

**Conclusion.** In regards to the chemistry I results using both the final examination scores and the final letter grades, research question 3 would be answered as follows:

- Gender – Determined to be a significant sub-factor grouping using final examination scores only. The “traditional” approach leads to higher student success compared to the “atoms first” approach for both male and female students.
- Ethnicity/Race – Determined not to be a significant sub-factor grouping.
- Major – Determined not to be a significant sub-factor grouping.
- Composite ACT – Results inconclusive in that the three regression methods did not agree regarding significance. Final decision would be to not use as a determining sub-group for curricular decisions.
- Math ACT – Determined not to be a significant sub-factor grouping.
Overall GPA – Determined to be a significant sub-factor grouping using final examination scores only. The “traditional” approach leads to higher student success compared to the “atoms first” approach for both below and above average students.

Classroom size – Determined to be a significant sub-factor grouping using final examination scores only. The “traditional” approach leads to higher student success compared to the “atoms first” approach for students in large classroom settings. However, there was no difference in student success between the two curricular approaches for those students in a small classroom setting.

Chemistry II

The results from the Chemistry II course are used to determine if there is a long term effect of curricular approach. This will show if the sequence of teaching foundational concepts at the beginning of a course has impacts ranging into later courses.

Final examination. The final examination data were used in a multiple linear regression model to determine which if any curriculum interaction variables were significant. The initial model was run with 11 main effect and 10 interaction variables. This model was reduced until only those significant variables were remaining. This is the normal procedure in determining the finalized and most accurate regression model for the given data. This finalized model contained 4 main effect and no curriculum interaction variables. The finalized model had very close $R$-values compared to the complete model. This supports the concept that the removed variables did not explain a significant portion
of the variation in the final examination scores. Thus, with their removal the amount of variation explained did not change dramatically. The finalized model explained approximately 43.5% of the sample variation. This amount of variation explained is on the lower side; however, since the regression model is not being used for prediction the percentage is not as important.

The most important information from the finalized regression model is what curriculum interaction variables remained and found significant in the model. In this model, there were no significant interactions with curricular approach. Thus, there are no sub-factors that were deemed as statistically significant in regards to academic achievement and curricular approach. Hence, there are no groupings that were analyzed to determine which approach leads to higher student success. This non-significant result shows that there is no difference in curricular approach for the different sub-groupings. This means that in the chemistry II course, academic success is not determined by the curricular approach and sub-factor relationship. Instead it is determined by the student’s ACT composite score, ACT math score, and the overall GPA. The curricular approach makes a difference in an overall sense, similar to research question 2. But when the students are sub-divided the effect is no longer present.

**Final letter grade.** The final letter grade data were used in a multiple linear regression model to determine which if any curriculum interaction variables were significant. The initial model was run with 11 main effect and 10 interaction variables. This model was reduced using the normal procedure until only those significant variables were remaining. This finalized model contained seven main effect and two curriculum interaction variables. The finalized model had very close $R$-values compared to the
complete model. This supports the concept that the removed variables did not explain a significant portion of the variation in the final examination scores. Thus, with their removal the amount of variation explained did not change dramatically. The finalized model explained approximately 62% of the sample variation. This amount of variation explained was higher compared to the model using the final examination scores.

The most important information from the finalized regression model is what curriculum interaction variables remained and found significant in the model. In this model, GPA and term sequence interactions with curricular approach were found to be significant. These are the two sub-factors that have been deemed as statistically significant in regards to academic achievement and curricular approach. The term sequence sub-group has already been analyzed and discussed in research question 2. However, the GPA grouping still needs to be analyzed to determine which approach leads to higher student success.

The results of the two-way ANOVA for GPA showed that the curriculum and GPA interaction is non-significant. This means that the two teaching approaches do not lead to different student achievement results for below and above average students. This result differs from the multiple linear regression significant interaction result. The multiple linear regression result occurs when other factors are included in the regression equation. However, the two-way ANOVA tests the significance of the interaction when all other factors are not included. Additionally, the regression model used the specific grade point averages; whereas, the ANOVA used GPA groupings. This means that GPA groupings should not be used as a sub-factor grouping in determining which curricular approach is preferred.
The final letter grade data were also used in a multinomial logistic regression model to determine which if any curriculum interaction variables were significant. The initial model was run with 11 main effect and 10 interaction variables. This model was reduced using the normal procedure until only those significant variables were remaining. This finalized model contained seven main effect and two curriculum interaction variables. In this model, GPA and term sequence interactions with curricular approach were found to be significant. These results support the multiple linear regression model in that both curriculum interaction terms were found to be significant. This supports the notion that the GPA and curriculum interaction term is significant when other terms are included.

Lastly, the final letter grade data were also used in a binary logistic regression model to determine which if any curriculum interaction variables were significant. The initial model was run with 11 main effect and 10 interaction variables. This model was reduced using the normal procedure until only those significant variables were remaining. This finalized model contained six main effect variables and the term sequence and curriculum interaction variable. These results partially support the multinomial logistic regression model in that the term sequence and curriculum interaction variable was found to be significant. However, the GPA and curriculum interaction variable was non-significant. This result may be due to the pass or fail groupings of final letter grades, which may not allow for more detailed differences in performance to be seen. Thus, these results should not be considered over the multiple linear and the multinomial logistic regression models.
Conclusion. In regards to the chemistry II results using both the final examination scores and the final letter grades, research question 3 would be answered as follows:

- Gender – Determined not to be a significant sub-factor grouping.
- Ethnicity/Race – Determined not to be a significant sub-factor grouping.
- Major – Determined not to be a significant sub-factor grouping.
- Composite ACT – Determined not to be a significant sub-factor grouping.
- Math ACT – Determined not to be a significant sub-factor grouping.
- Overall GPA – Determined not to be a significant sub-factor grouping.

However, was determined to have a significant interaction with curriculum when other factors are included in the model.

- Classroom size – Determined not to be a significant sub-factor grouping.

Other Possible Factors

There are several possible factors that may have affected the results of the research study that need to be taken into account when implementing these findings. These factors may have caused the “traditional” curriculum to be more favored or cause the “atoms first” to not be fully implemented or implemented in its intended fashion. These factors will be discussed individually in the following sections.

American Chemical Society (ACS) Final Examination

The ACS final examination given at the end of each semester was used to determine the academic success of the two approaches. The first semester ACS final exam covers the same material taught irrespective of approach. Additionally, the second semester ACS final exam was used to determine if one approach provides long term
improvement in understanding for the topics covered during the second semester portion of the course. The ACS final examination was used to provide an objective criterion to measure student success in chemistry when taught under the two curricular approaches. The final examination does provide an objective measure on student understanding of content knowledge, but it does not measure the NOS, the HOS, and inquiry. These three factors were mentioned in chapter 2 theoretical framework as being essential elements of effective science instruction. The “atoms first” approach spends more time covering these factors in the provided textbooks. This is one area that differentiates the two curricular approaches. However, the ACS final examination only focuses on content knowledge and does not include these three factors. Thus, the final examination is not assessing several areas that the “atoms first” curriculum is teaching and is suggested to be strengths of the curriculum in regards to student achievement. Hence, changing the curriculum to one that teaches the all the essential elements of science makes no difference if the assessment used to determine student achievement only tests for content knowledge. Consequently, the ACS final examination only tests which curriculum is better for increasing content understanding only. This provides insights into the final examination percentage results for research questions 2 and 3. For all of the results that found a statistically significant difference between the two curricula, it was found that the “traditional” approach led to higher student success compared to the “atoms first” approach. However, this could also be interpreted that the “traditional” approach led to higher student content knowledge compared to the “atoms first” approach. It cannot specifically conclude that the “traditional” approach leads to higher overall student success in all essential aspects of science instruction.
New Teachers

Another factor that can affect the results of the curricular approach used is the teacher. It has been mentioned that when transitioning from one curriculum to a new curriculum there is a transition period in which the new curriculum has lower achievement results than expected. This is due to the professors having to adjust to the new curriculum and settle into the best methods and strategies for teaching. This transition period can also be exacerbated by the experience of the professor. If there is a new professor to the department or even if the professor is teaching the course for the first time, adjusting to the course combined with the new curricular approach can lead to lower student achievement. Additionally, if the professor is new to the department this adds the additional layer of adjusting to the department and getting into a teaching/research rhythm.

For this research study, the effect of a new professor to the department and new to teaching the course was found for both chemistry I and II courses. For the chemistry I course, there was only one professor that was consistent across the two curricular approaches. There were five professors for the “traditional” curricular period and eight professors for the “atoms first” curricular period. For the “traditional” approach period, there was only one professor that was new to the department and new to teaching the chemistry I course. However, for the “atoms first” approach, there were three new professors to the department and seven of the professors had not taught chemistry I in the previous three years. Thus, the chemistry I course using the “atoms first” approach was taught almost entirely by either new professors to the department or new to the course.
As for chemistry II, the “new teacher” factor is not as extreme. There was only one professor that was consistent across the two curricular approaches. There were five professors for the “traditional” curricular period and two professors for the “atoms first” curricular period. For the “traditional” approach period, there was only one professor that was new to teaching the chemistry II course. For the “atoms first” approach, there was one professor who was new to the department and new to teaching the chemistry II course. Thus, the chemistry II course was almost balanced out. However, the “atoms first” approach may have felt the effects slightly more since the professor was new to the department in addition to the course. As can be seen, the “new teacher” effect combined with the new curricular approach could be one explanation for the “traditional” approach showing higher student achievement in the research study.

**Teacher’s Own Image of Science**

There is another factor besides curricular approach that can greatly influence student achievement in chemistry. Teachers represent the most important variable in the classroom learning equation. Teachers have a large effect on what students understand and how they learn in the classroom. Even well designed curricular approaches that are at odds with the philosophical orientations of teachers may not be effective or at least as effective as they were intended to be. Duschl (1987) writes that in spite of attempts to “teacher proof” schooling through the enforcement of strict curriculum guidelines and teaching models, teachers will continue to make the most critical decisions in the education of students. Research states that the most important factors determining attitudes toward science are teaching style (Evans & Baker, 1977; Rubba, Horner & Smith, 1981) and the teacher’s own image of science (Jungwirth, 1971).
The teacher’s own image of science and of how their students relate to science will greatly impact how they teach the different curricular approaches. Regardless of the curricular approach used, it is important that the chemistry teachers and professors see their students as chemists. If the students are viewed as chemists, or more generally as scientists, than the teacher’s expectations of the students will be different. The teachers will expect a higher level of student achievement from the student and will motivate the student to be engaged and interested in the material. This positive attitude that all students can do chemistry will motivate the student to do their best. When a positive image of science and students’ roles in science are combined with the curricular approach designed to nurture this development are implemented in the classroom, it will lead to increased student understanding and achievement.

**Student Withdraw**

The last factor that may have affected the results of the research study in favor of the “traditional” curriculum is the withdrawal of students from the chemistry courses. As previously mentioned, the only major difference regarding content between the two curricular approaches is the ordering of the chapters during the chemistry I course. The ordering of content in the Chemistry II course is the same. One of the effects of this ordering change is when the students are introduced to algebraic mathematical manipulations. In the “traditional” approach the students see mathematical conversions within the first month of the course. However, in the “atoms first” approach the students do not see any complex mathematical manipulations until later in the semester. This difference in the timing of mathematical concepts is related to the drop date of the course. It was previously mentioned that mathematics ability is one of the primary indicators of
chemistry success. The “traditional” approach introduces math concepts early enough for
the weaker math students to drop the course. However, the “atoms first” approach does
not introduce the math concepts until the drop date has passed. This causes those students
who are not well-prepared mathematically to have to stay in the course. Whereas, in the
“traditional” approach these students are able to drop the course and take it when they are
better prepared. This causes the two curricular approaches to potentially have different
types of students taking the course. The less prepared students are able to drop the course
in time for the “traditional” approach, which causes the mathematical ability of the class
to be higher compared to those students in the “atoms first” approach. As stated, these
students who are better prepared for the math concepts will most likely perform better in
the chemistry course. With this correlation in mind, this could be one possible
explanation for the “traditional” approach having higher student achievement compared
to the “atoms first”. The “traditional” approach retained the better prepared students in
the course and thus had higher final exam and letter grade averages.

**Future Work**

There are two areas for future work following the results of this research study.
The first area involves extending the research project to include more semesters of data, a
qualitative analysis of the delivery of each curricula, and additional statistical analyses to
determine the validity and extent of generalizability of the results. The second area
involves the development and implementation of professional development training for
chemistry faculty who are implementing the “atoms first” curriculum.
Extend the Research Project

Extending the research project involves three different aspects: additional “atoms first” data, a delivery of curricula analysis, and additional statistical analyses. In this research study, the “atoms first” approach was analyzed using data from the first three semesters of implementation. It has been previously noted that there is an adjustment period when transitioning to a new curriculum (Esterling & Bartles, 2013). Esterling and Bartles (2013) found that student achievement is remarkably lower during the first year of implementation and that the “true” effects of the curriculum are not seen until after this period. The semesters studied using the “atoms first” curriculum

Specific to this research study in the final letter grade results for research question 2, it was seen that the averages per academic semester for the “atoms first” approach were increasing and either equaling or overtaking the averages for the “traditional” approach. When the two approaches were divided into on and off sequences, there was only one semester available for the “atoms first” off sequence comparison. By extending the number of semesters included in the study, the question of whether the “atoms first” approach leads to high student achievement compared to the “traditional” approach after the transition period could be answered. The recommendation would be that the last three years of the “traditional” approach and the first three years of implementing the “atoms first” approach be used in analysis. This extension would allow for the following benefits: 1) confirmation of the transition period theory, 2) determination of its length for the specific research environment, 3) two years of data after the transition period, and 4) enough data to analyze when divided into on- and off-sequence semesters.
In regards to the second segment of the extended research study, the delivery of each curricula was not known. This was partially due to the data being collected from previous semesters of instruction. The extension of this research study would involve the researcher interviewing and observing the instructors for the “atoms first” general chemistry I and II courses. The researcher would observe the instructors to determine if the “atoms first” curriculum is being implemented as it was designed. Specifically, focusing on the usage of the history of science, nature of science, and the scientific method in their lectures, because these areas were found to be either new or significantly improved on in the “atoms first” curriculum. The interviews with instructors would determine how the teachers prepared for the new curriculum and in what ways they adjusted their teaching materials and teaching style. Determining if the “atoms first” curriculum is delivered as intended would show if the success measures are actually the result of the new curriculum or an altered “traditional” approach. If the “atoms first” curriculum is only being implemented by using a different ordering in the PowerPoint slides and a different textbook, then this would clarify the results found in this research study that the “traditional” approach leads to higher performance.

The third segment included in the extended research project would be the addition of statistical analyses focused on the generalizability of the results. The researcher would perform a factor analysis to determine the larger relationships between the multiple sub-factors and to bring out any strong patterns in the dataset. Factor analysis would be used to explain student performance patterns based on the variables included in this research study, but do so using a smaller collection of factors. This will help us to determine the underlying patterns and structure to student performance in the general chemistry course.
and how the curricular approach is related. For example, the seven subfactors and curricular approach may all relate to a specific factor that can be generalized to other student populations.

**Professional Development Training**

The second area involves the development and implementation of professional development training for chemistry faculty who are implementing the “atoms first” curriculum. The primary goal of this professional development would be to diminish the transition period time when implementing the new curriculum. This would allow for student achievement to occur quicker and more efficiently.

Researchers have long asserted that the effectiveness of curriculum implementation depends on implementation fidelity: the degree to which teachers and administrators implement curricula as intended by the curriculum developers (Kennedy, 2004). However, many curricular innovations are seldom implemented perfectly, and several studies have revealed the extent to which implementation fidelity occurs and how various factors of implementation fidelity affect curriculum outcomes (Fullan & Pomfret, 1977). The success or failure of a curriculum may ultimately rest with its teachers. Teachers may be freely adapting classroom curricula by removing, modifying, or adding to the curricular content. Thus, it is important that teachers are fully aware of the underlying intentions of the curriculum change.

Research by Snyder, Bolin, and Zumwalt (1992) found fifteen research based interactive factors thought to affect curriculum implementation. Three of these factors, need, clarity, and complexity, are directly related to the teacher’s views of the new curriculum. The first factor relates to the teacher recognizing the need for the new
curriculum. The second factor deals with the teacher being able to identify the essential features of the innovation. The teacher needs to be able to understand the major differences between the currently used curriculum and the new curriculum. Lastly, the extent or difficulty of implementing or changing to the new curriculum will have a negative impact on the teacher’s view of the new curriculum. These three factors must be addressed in order to ensure curriculum fidelity and one such way is through professional development.

Several studies have demonstrated the relationship between teacher training and greater implementation fidelity (LaChausse, Clark, & Chapple, 2014). Factors associated with implementation fidelity include in-depth training for teachers, strong support from administration, the characteristics of the curriculum itself, and the provision of ongoing technical assistance. Teacher workshops are critical for success because they provide the background justification, knowledge, and skills needed to implement the curriculum, foster support and commitment to the curriculum, and communicate the importance of curriculum fidelity (Fors & Doster, 1985). As seen, targeted professional development can address several factors negatively impacting teacher’s views regarding curriculum change and can increase implementation fidelity.

In regards to this research study, the “atoms first” approach focuses more on the essential elements for science instruction and the guidelines for chemistry curricula compared to the “traditional” approach. Additionally, the chemistry content has been reordered for the first semester general chemistry course. These two major curricular changes and the previously mentioned factors affecting teacher’s willingness to change show the importance of targeted professional development.
The professional development would first bring the need for a new curriculum to the professors’ attention and provide opportunities for questions and answers. This would allow for the professors to understand why the change is occurring, since not all lecturers are involved in the curriculum selection decisions. Secondly, the professional development would provide clarity regarding the changes made in the curriculum compare to the “traditional” approach. This may be very important since some of the changes may be pedagogical in nature and not as noticeable for some. Thirdly, the professional development would provide strategies on how to teach these new elements and guidelines. For example, one of the guidelines is “to meet the needs of all learners”, which may be challenging to professors who have taught only the advanced chemistry courses or who are new to teaching. The professional development would provide examples of how specific topics could be explained and demonstrated to students interested in becoming benchtop chemists and to those who the introduction to chemistry course will be the only science class they take in college. Lastly, the professional development would explain that PowerPoint lecture slides cannot just be rearranged into the new curricular order, but that the reasoning behind the new order needs to be taken into consideration in how the material is presented. The new ordering may require the creation or deletion of old slides, changes in the material presented on specific slides, and the adjustment of any demonstrations or laboratory experiments. Overall, the professional development will assist chemistry professors to implement the new curriculum using the curricular strategies and pedagogical techniques necessary to fully implement the curriculum. This would decrease the transition period and the number of students affected.
by the change. Thus, allowing the new curriculum to impact students in its intended format.
REFERENCES


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APPENDIX A

IRB PERSONNEL MODIFICATION
The following sections include the personnel modifications to the previously established and approved IRB study 14-373. The two personnel modifications include the addition of committee members and the removal of one professor who retired.

**Personnel Modification: Addition of Individuals**

![Personnel Modification Form: Addition of Committee Members](image)

**Figure A1.** Personnel Modification: Addition of Committee Members

Addition of committee members to the previously approved IRB study.
Addition of committee members to the previously approved IRB study.
Yes, all data has been de-identified and only the principal investigator will be using and have access to the de-identified collected under the original approved IRB.

Name of Principal Investigator / Researcher:
Signature: Christina Hillesheim Date: Apr 28, 2016

Name of Advisor (if applicable):
Signature: Ryan Walker Date: Apr 28, 2016

*Note: You must receive written notification of approval from the IRB before implementing any changes (except when necessary to eliminate apparent immediate hazards to the subject).

Figure A1 (continued)

Addition of committee members to the previously approved IRB study.
Personnel Modification: Removal of Retired Professor

Removal of retired professor to the previously approved IRB study.

Figure A2. Personnel Modification: Removal of Retired Professor

(Complete page with details from the form, not shown here.)
Removal of retired professor to the previously approved IRB study.

Figure A2 (continued)