FIRST-SEMESTER GENERAL CHEMISTRY CURRICULUM COMPARISON OF STUDENT SUCCESS ON ACS EXAMINATION QUESTIONS GROUPED BY TOPIC FOLLOWING AN ATOMS FIRST OR TRADITIONAL INSTRUCTIONAL APPROACH

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This study uses the ACS first-term general chemistry exam to determine if one curriculum approach is more effective in increasing student success than the other based on their performance on the ACS exam. Two chemistry curriculum approaches were evaluated in this study; the traditional curriculum (TC) and the Atoms First (AF) approach. The sample population was first-semester general chemistry students at Collin College in Frisco, TX. An independent sample *t*-test was used to determine if there were differences in overall performance between the two curriculum approaches on two different versions of the ACS exam. The results from this study show that AF approach may be a better alternative to the TC approach as they performed statistically significantly better on the 2005 exam version. Factor analysis was used to determine if there were differences between the two curriculum approaches by topic on the ACS exam. Eight different topics were chosen based on topics listed on the ACS Examinations Institute Website. The AF students performed better at a statistically significant level than the TC students on the topics of descriptive chemistry and periodicity, molecular structure, and stoichiometry. Item response theory was used to determine the chemistry content misconceptions held by the students taught under both curriculum approaches. It was determined that for both curriculum groups the same misconceptions as determined by the z_{crit} values persisted.

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CHAPTER 1

INTRODUCTION

In the fall of 2009, Collin College chemistry faculty decided to change from the traditional chemistry curriculum approach to the atoms first (AF) approach. This changed the sequence in which chemistry topics were taught to first-semester general chemistry students. The AF approach is based upon the idea of a top-down sequence in which the concepts being taught build upon each other. The curriculum begins with the discovery and structure of the atom then moves to atomic bonding, followed by the concepts of chemical reactions and stoichiometry. The traditional chemistry curriculum begins with a brief introduction to the atom, often followed by the introduction of stoichiometry before broaching the subject of chemical reactions (which are needed to do stoichiometry), then returns to the atom by discussing its electronic structure and chemical bonding. In both the traditional curriculum and the AF approach the study of gas laws is typically placed towards the end of the course.

1.1 Statement of the Problem

In September 1930 ACS Exams began as a project of the Division of Chemical Education (About Us: History, 2013). The Examinations Committee was established to begin developing and producing chemistry exams for all academic courses. Then, in 1934, the first ACS chemistry exam (for general chemistry) was released. Exams in other areas of chemistry were subsequently released. In 1984 the Examinations Committee changed its name to the Examinations Institute (Exams Institute) to better indicate the span of assessment activities carried out within the program. The Exams Institute is currently (2014) located at Iowa State University under the leadership of its director, Dr. Thomas Holme and its associate director, Dr. Kristen Murphy. In order to develop an exam for publication, a committee is chosen by the director. The members of the committee are all practicing professionals that vary in geographic location, background, and institution type. The committee decides what will be on the exam matrix, the topics and subtopics to be tested, and then are assigned specific topics which to write multiple-choice questions. An example of an ACS exam matrix is available in Appendix A. Questions from each topic vary in difficulty, ranging from Levels 1-3, Level 1 being the lowest difficulty and level 3 the highest difficulty. After all questions are submitted, the committee will review the questions and decide which ones will be pilot tested. Two exams are pilot tested by various institutions that are willing to submit all of their exam data to the Exams Institute for analysis. After thorough analysis an exam is ready to be sold for use. Once an exam is purchased by an institution for use, they are asked to report their results to the Exam Institute so the results can be normalized and national exam statistics can be produced. Great care is taken in developing each exam making the ACS exams nationally recognized as valid instruments for the knowledge assessment of chemistry content.

Some research has shown that the order in which topics are introduced affects the amount of material students can recall (Lorch & Lorch, 1985). This study used the American Chemical Society's (ACS) First-term General Chemistry exams published in two different years. The goals of this study are to (a) determine the differences in student's success on the ACS exam under the traditional curriculum (TC) and the AF approaches, (b) investigate if there is a difference in student performance by topic on a standardized ACS exam depending on the order in which the topics are taught, and (c) to identify any misconceptions held by students who have experienced either curriculum approach. Using the ACS exam allows the opportunity to use one instrument appropriate to assess first-semester general chemistry students in order to analyze their success under each curriculum approach.

1.2 Purpose and Significance of Study

The current push for curriculum reform in chemistry is an important area of research for educators. Within the past four years, several new books promoting the AF approach have been published (Burdge & Overby, 2012; McMurry & Fay, 2010; Zumdahl & Zumdahl, 2012), yet there are few published studies on the impact of the AF approach on student success (Esterling & Bartels, nd). This study determined if one curriculum approach is more effective in increasing student's understanding than the other on nationally recognized instruments for content assessment. Knowing if one curriculum approach is better for students' success on the ACS exam and being aware of the differences by topic in the course will help educators better prepare their students for success in future chemistry courses. The topics covered on the first-term general chemistry ACS exam as listed on the Exams Institute's Website are:

- Atomic and nuclear structure
- Molecular structure
- Stoichiometry
- Energetics
- States of matter/Solutions
- Redox
- Descriptive Chemistry/Periodicity
- Laboratory

1.3 Research Questions

Students were taught by either the TC approach or the AF approach. The students from both groups took the ACS first-term general chemistry exam as the final exam for their course. The raw scores from the ACS exam were used in order to determine the effect and significance of topic sequence – as presented by each curriculum approach, as well as the resulting outcome on the exam. The following research questions are posed to achieve these goals:

Q_1: What level of achievement on the ACS final exam is obtained by students who studied under the atoms first or traditional curriculum approach?

$Q_{1.1}$: What percentage of students who studied under the atoms first curriculum approach falls within one standard deviation above the national mean on the ACS First-Term General Chemistry Exam?

$Q_{1.2}$: What percentage of students who studied under the traditional curriculum approach falls within one standard deviation above the national mean on the ACS First-Term General Chemistry Exam?

$Q_{1.3}$: What percentage of students who studied under the atoms first curriculum approach falls within one standard deviation below the national mean on the ACS First-Term General Chemistry Exam?

$Q_{1.4}$: What percentage of students who studied under the traditional curriculum approach falls within one standard deviation below the national mean on the ACS First-Term General Chemistry Exam?

Q_2: What are the statistical differences at an alpha level of 0.05 in student performance by topic on the ACS exam between students taught by the traditional curriculum and students taught by the atoms first curriculum?

$Q_{2.1}$: On the topic of atomic and nuclear structure was there a statistical significant difference at an alpha level of 0.05 as determined by the average of correct responses between the students taught by the traditional curriculum and students taught by the atoms first curriculum approach?

$Q_{2.2}$: On the topic of molecular structure was there a statistical significant difference at an alpha level of 0.05 as determined by the average of correct responses between the students taught by the traditional curriculum and students taught by the atoms first curriculum approach?

$Q_{2.3}$: On the topic of stoichiometry was there a statistical significant difference at an alpha level of 0.05 as determined by the average of correct responses between the students taught by the traditional curriculum and students taught by the atoms first curriculum approach?

$Q_{2.4}$: On the topic of energetics was there a statistical significant difference at an alpha level of 0.05 as determined by the average of correct responses between the students taught by the traditional curriculum and students taught by the atoms first curriculum approach?

$Q_{2.5}$: On the topic of states of matter and solutions was there a statistical significant difference at an alpha level of 0.05 as determined by the average of correct responses between the students taught by the traditional curriculum and students taught by the atoms first curriculum approach?

$Q_{2.6}$: On the topic of oxidation-reduction (redox) was there a statistical significant difference at an alpha level of 0.05 as determined by the average of correct responses between the students taught by the traditional curriculum and students taught by the atoms first curriculum approach?

$Q_{2.7}$: On the topic of descriptive chemistry and periodicity was there a statistical significant difference at an alpha level of 0.05 as determined by the average of correct responses between the students taught by the traditional curriculum and students taught by the atoms first curriculum approach?

$Q_{2.8}$: On the topic of laboratory was there a statistical significant difference at an alpha level of 0.05 as determined by the average of correct responses between the students taught by the traditional curriculum and students taught by the atoms first curriculum approach?

Q_3: What are the content misconceptions held by students taught under traditional curriculum and atoms first approaches for questions with prevalent incorrect responses having a z-score above the z_{crit} of 1.96?

$Q_{3.1}$: What are the content misconceptions held by students taught under the traditional curriculum approach for questions with prevalent incorrect responses having a z-score above the z_{crit} of 1.96?

$Q_{3.2}$: What are the content misconceptions held by students taught under the atoms first curriculum approach for questions with prevalent incorrect responses having a z-score above the z_{crit} of 1.96?

1.4 Definition of Terms and Acronyms

This study focuses on using the American Chemical Society's standardized exam, appropriate to use as a final exam for first-term general chemistry courses, to measure student success between two different chemistry curriculum types. The following is a list of terms and acronyms that are frequently used throughout this study.

ACS – The American Chemical Society is a congressionally chartered independent membership organization that represents professionals in all fields of chemistry and at all degree levels.

AF – The atoms first approach is a chemistry curriculum that teaches chemistry topics in a different order than the usual or traditional curriculum. This approach uses a top-down method in which the topics being taught build upon each other.

DivCHED – The ACS Division of Chemical Education that is devoted to enhancing the interests and efforts of all the organizations and individuals involved in teaching and learning of chemistry.

CA Dx – The California Chemistry Diagnostic Test is a placement exam for students entering general chemistry courses.

Exams Institute – The ACS Division of Chemical Education Examinations Institute provides the nationally normalized and standardized examinations used in this research.

Exam Topics – The topics covered on the ACS exam as listed on the Exams Institute's Website.

Gen Chem I – This refers to general chemistry I, that is the first term of a two-part general chemistry course.

STEM – Science, technology, engineering, and mathematics

Successful student – Success on the ACS exam was measured by the raw exam scores. If the student scored the Exams Institute posted mean or higher than the national mean for that exam, then the student will be labeled as successful. The national mean for each exam is posted online by the ACS Division of Chemical Education (DivCHED) Examinations Institute.

TAKS test – The Texas Assessment of Knowledge and Skills test was the state mandated standardized test in Texas beginning in 2003. The exam was last given to all students who entered 9th grade before the 2011-2012 academic year.

UNT – The University of North Texas located in Denton, Texas.

1.5 Assumptions and Limitations

The nature of this research lends itself to some assumptions and limitations. The use of de-identified archival data limited the depth of information that can be obtained on a student-by-student basis and so the following assumptions are made:

- This is the first time the student has taken the course. (Approximately 12.5% of students re-take the course in a subsequent semester.)
- The sample is representative of the general population of chemistry students since data were collected from all students who completed the general chemistry I course at Collin College.
- The student had the proper prerequisites for the course completed before entering the course.

One limitation of this study is that controlling for the differences in teaching styles, instructor backgrounds, and methods between the general chemistry instructors is limited. These differences are not the focus of this research. All general chemistry I instructors are given the same syllabus to use that outlines the topics to be covered and the order in which they are to be presented to the students. The use of the same syllabus by all instructors cuts down on variation in the courses but cannot account for individual teaching styles and methods. Another limitation of this study is that it cannot account for students who have taken the class more than once. This is due to the fact that the scores reported to the investigator are anonymous. The nature of the data used in this study also leads to the last assumption that the study cannot account for external factors affecting the students' performance on the exam such as: motivation, work hours, familial obligations, and academic preparedness.

While the anonymity of the students causes several limitations in this study, the anonymity of the students along with that of the instructors are very important considerations. Great care was taken so that the researcher has no way of identifying exactly which instructor's class the scores came from and to which students the scores belong. The Institutional Review Board (IRB) approval was waived from both Collin College and the researcher's institution, the University of North Texas (UNT), because the researcher only had access to de-identified data. (Copies of UNT and Collin College IRB approvals are available in Appendix B.)

1.6 Summary

This study evaluated if one curriculum approach was more effective in increasing students' understanding on identified ACS first-term general chemistry topics and determined the misconceptions held by students taught under each curriculum approach. The remaining chapters can be summarized as follows: Chapter 2 includes a summary of supporting literature; Chapter 3 describes the research design and methodology used in this investigation; Chapter 4 presents a summary of the results found in this study; and Chapter 5 discusses the results of the study and gives suggestions for future work related to this investigation.

CHAPTER 2

LITERATURE REVIEW

The purpose of the following review is to highlight curriculum orientation and how it relates to student learning. An introduction of learning theories pertinent to this study is presented, followed by a summary of literature relevant to curriculum orientation and student learning in chemistry. A brief history of the American Chemical Society (ACS) Examinations Institute and the making of the ACS standardized exams are also included, along with literature about general chemistry student misconceptions.

2.1 Curriculum Orientation

The need for reform in chemical education is not a new concept. Chemical educators have been discussing ways of improving curriculum approaches in first-semester chemistry courses for several decades (Bodner G. M., 1992; Crosby, 1985; Johnstone, 2010; Reid, 2008; Rickard, 1992; Schroeder, Murphy, & Holme, 2012; Talanquer & Pollard, 2010; Zimmerman, 1925) and the subject content that needs to be mastered has not significantly changed over the past 15 years (Demirci, 2010). Many waves of “improvement” have been introduced into the general chemistry classroom, including the use of technology such as computer animations, classroom response systems, and online homework, increasing the amount of support material, and the use of in-class demonstrations. Johnstone (2010) points out that several projects and initiatives such as ChemCom, process oriented guided inquiry learning (POGIL), and peer-led groups have been successfully implemented in countless chemistry classrooms, yet chemistry is still perceived as a “killer” (Rowe, 1983, p. 954) course because of its difficulty and often low student success rates. Johnstone (2010) also suggests that what is missing is a failure, on the part of educators, to understand how students learn. He used several different learning theories to develop a new model of learning. Van Patten, Chao, and Reigeluth (1986) write that there are two important things to consider when designing any piece of instruction; the first is the sequencing of the instructional events, and second, the presentation of interrelationships between the topic ideas. These authors suggested that in order to construct a sequence, the elements to be sequenced need to be identified and an organizing principle needs to be chosen. Several theories about how to choose the topics to be sequenced exist, but most of them seem to fit one of two analysis techniques. Theories that utilize a behaviorist approach tend to use empirical analysis, while theories that adopt a cognitive approach tend to use rational analysis. The article goes on to describe many different theories and research of how to sequence topics and concludes that in order for sequencing effects to be consistently found, there needs to a theory based on sequencing, such as elaboration theory.

2.2 Learning Theories

Information processing theory seeks to understand cognitive development in terms of how people process information when solving difficult mental challenges (Sternberg, 1999). Information processing theorists approach learning mainly through the study of memory. According to this theory as in the unified learning model (ULM) of Shell et al. (2010), there are three types of memory: sensory registers, short-term memory, and long-term memory. The sensory registers are the part of the memory that receives all the information that a person senses. The short-term memory is where new information is temporarily held until it is lost or put into long-term memory. The long-term memory has unlimited capacity and can hold information indefinitely.

Two major theoretical ideas that build the framework for information processing theory were developed by Miller in 1956. The first idea deals with short-term memory and the concept of chunking (Miller, 1956). A chunk is a meaningful unit of information that may be composed of smaller bits of information. Miller found that short-term memory could hold 5-9 units of information as one cluster or meaningful chunk. A chunk can start out as simple as a single digit, letter, or word. Since short-term memory can hold a fixed number of chunks, it is important to group or organize the units into larger chunks.

Forming chunks is relevant to learning concepts in general chemistry. Organizing and presenting material in an efficient way will allow students to learn information well. For example, when being taught about polyatomic ions a student might make each polyatomic ion a separate chunk, which could be at least 12 separate chunks depending on how many polyatomic ions they are required to learn. Instead of presenting each polyatomic ion separately, the ions can be introduced in the following groups: those with a +1 charge, those with a -1 charge, those with a -2 charge, and those with a -3 charge. Then the students learn the polyatomic ions associated with each group as if each group is 1 chunk, reducing the number of chunks to learn from 12 to 4. The number of bits of information a chunk contains can be increased by building larger and larger chunks of information.

The second idea proposed by Miller is the concept of information processing also known as test-operate-test-exit, or TOTE. A TOTE unit is a basic unit of behavior in which a goal is tested to determine if it has been achieved. If the goal is not achieved then an operation is performed to achieve the goal before retesting. The test-operate cycle is repeated until the goal is achieved. In general chemistry this goal is met by students when they are exposed to daily quizzes, homework, and exams.

Many information-processing theorists put emphasis on developmental changes in encoding, self-monitoring, and the use of feedback (Sternberg, 1999). The ability to encode information increases with a person's age. As a person ages, they can combine encoded information in more complex ways, thereby forming more elaborate connections to their previous knowledge. In order to ensure that information is effectively encoded, the material should be meaningful and should activate prior knowledge. Strategies like chunking, rehearsal, and mnemonics can aid with encoding information. A common example of the use of mnemonics in general chemistry is OIL RIG. It is used to determine if oxidation or reduction is occurring: oxidation is losing (electrons) and reduction is gaining (electrons). Information processing involves gathering information (encoding), holding that information (retention), and getting the information when needed (retrieval). The way that information is processed will be affected by the way the information, in this case chemistry topics, are presented to the learner.

Constructivist theory is very broad and is often broken down into cognitive and social constructivism (Atherton, 2011). Cognitive constructivism is based on cognitive development and deals with how the learner understands information in terms of developmental stages; it is often linked to the work of Piaget, who demonstrated that children actively processed material. Social constructivism is based on the theories of

Vygotsky and emphasizes the social contexts of learning. Vygotsky believed that children internalize what they see in their surroundings and they build knowledge from what they observe around them (Sternberg & Williams, 2002). In constructivist theory, the learner and the teacher are actively involved in creating new meanings together (Atherton, 2011).

Constructivist theory also involves learning as an active process in which learners must build upon their own knowledge. People actively build their own knowledge based on prior experiences; in other words as stated in the ULM (Shell et. al, 2010) new ideas are built upon current and past knowledge. The theory suggests that previous experiences and the context of learning affect how people encode and recall memories, including which particular memories can be recalled (Sternberg & Williams, 2002). American psychologist, Ausubel, stated that a learner's previous knowledge is the most important factor that influences their current learning (Ausubel, Novak, & Hanesian, 1978). Bruner (1966) suggested that the learner relies on cognitive structures to transform information, construct hypotheses, and make decisions. Cognitive structures such as schemata provide organization to experiences. Schemata are cognitive frameworks for organizing connected concepts and are based on previous experiences; schemata affect how we learn and remember.

Since learners must build their own knowledge, constructivists believe that the instructor should encourage students to discover principles by themselves. This is often referred to as encouraging students to go beyond the information given. This can be accomplished by engaging students in active dialogue and translating information into an appropriate format for the learner to understand. Chemistry educator, Bodner (1992) suggested that opening a dialogue with students may give the teacher insight into what is being learned or not being learned by the students, which he refers to as “teaching by listening”. This type of cooperative learning is beneficial to the students and the teacher. Bruner provides a general framework for instruction which states that instruction should address (1) predisposition towards learning, (2) that knowledge should be structured in a format that can be easily understood by the learner, (3) effective sequences in which to present the material to the learner, and (4) the nature of rewards and punishment (Kearsley G., 2011). In other words, instruction should be concerned with the experiences that make the learner eager to learn and learning should be structured in a manner that is easily understood. Bodner suggests beginning with a topic close to the students’ experiences and then building from those experiences toward more abstract notions because no one learns from the generic to specific (Bodner, 1992).

The idea that new knowledge should be structured in a manner that is easily understood is not only important to constructivist theory, but to elaboration theory and AF approach as well. Elaboration theory is an instructional design theory originated by Reigeluth and his colleagues at Indiana University in the late 1970s. This theory is an extension of the work of Ausubel on advance organizers and of the work of Bruner on spiral curriculum (Kearsley G., 2011). The theory suggests that material to be learned should be organized in order of increasing complexity, while providing a meaningful framework in which subsequent ideas can be incorporated.

Elaborative sequencing is the most critical component of elaboration theory. It is defined as “a simple to complex sequence in which the first lesson epitomizes the ideas and skills that follow” (Kearsley G., 2011). Epitomizing should involve a single type of content and should involve learning a few fundamental ideas. Content can be conceptual, procedural, theoretical, or formative learning of pre-requisites. An effective elaboration strategy uses “epitomes” containing motivators, analogies, summaries, and syntheses. The content should be grouped into learning episodes of useful size. Through the use of the elaborative approach, the formation of more stable cognitive structures can be achieved, allowing for better retention and transfer of information along with an increase in learner motivation due to the creation of meaningful learning contexts. Bodner (1992) wrote that a significant change in the sequence of general chemistry topics would be needed if it were taught by starting with a system that has relatively few parameters and worked towards more complex systems, in other words, following a simple to complex sequencing.

In accordance with all three of the previously discussed learning theories is the unified learning model (ULM). As the name suggests, this learning model incorporates aspects of several different learning theories into one model for learning (Shell et al., 2010). The three basic principles of learning as outlined by the ULM are:

1. Learning is a product of working memory allocation.
2. Working memory’s capacity for allocation is affected by prior knowledge.
3. Working memory allocation is directed by engagement and motivation.

Motivational influences such as goals and rewards determine how much effort is put into learning and whether or not the student is engaged with what is to be learned. The ULM concentrates on motivation in the context of working memory, which is where temporary storage and processing of information happens in the brain. Similar to the information processing theory, working memory (referred to as short-term memory in information processing theory) is at the core of the ULM. Under information processing theory, information-processing involves encoding, retention, and retrieval. This goes along with the ULM, which states that learning requires attention and repetition and is about connections (Shell et al., 2010). The working memory has the capability to connect new information to prior knowledge thereby creating integrated knowledge structures. Building on previous knowledge is also important to constructivist theory. In studies conducted at UNT, a students' prior knowledge was the best predictor of chemistry success and explained nearly 68% of all the variance ($\beta = .425$, $r_s^2 = .677$) (Manrique, 2011). Another such study focused on developing the California Chemistry Diagnostic Exam (CA Dx), a general chemistry placement exam, found a positive correlation between the pre-exam measuring prior knowledge and the final grade in the course ($r = 0.42$, $n = 4{,}023$), proposing that prior knowledge accounts for approximately 18% of the final grade (Russell, 1994).

2.3 Previous Research and Applications

Lorch and Lorch (1985) conducted experiments that showed the importance of topic sequencing in memory recall. They hypothesized that people "use their representations of the topic structure to guide text recall in a top-down fashion" after reading a text (Lorch & Lorch, 1985, p. 137). The retrieval of a topic opens access to all the information incorporated under that topic in memory. Once the information is retrieved, the next topic in the topic structure is retrieved and all the information stored under it recalled. The cycle continues until all the topic structures are retrieved or until no more topics are accessible to the person. In this model, the coherence of the person's topic structure representations is integral to the recall of the text associated with the representations. One of the experiments the authors conducted examined the effects of paragraph order and advance information, such as informing readers about the topics they were about to read. The texts were approximately 1,100 words describing six attributes of two fictional countries. Three versions of the texts were written, the first ordered the paragraphs by countries, the second by attributes, and the third was randomly ordered. Each version was written with either an introductory paragraph that explained the topics that the reader was going to be reading or another with an uninformative introductory paragraph. The experiment showed that the well-organized text and the informative paragraph led to greater text recall by the subjects. While this research was limited to rather small bodies of text, the idea can be applied to an entire textbook and is one of the founding principles of the AF approach to learning.

In the article “You Can’t Get There from Here,” Johnstone (2010) proposes a new model of learning that encompasses many other learning theories. The author creates a model for learning based on information processing theory, subsumption theory, and genetic epistemology along with other common theories. The author suggests that no single learning theory is complete and that we as researchers must embrace several theories in order to get a more complete picture of how a person learns. A cognitive model that takes into account important factors of learning is proposed in Figure 2.1.

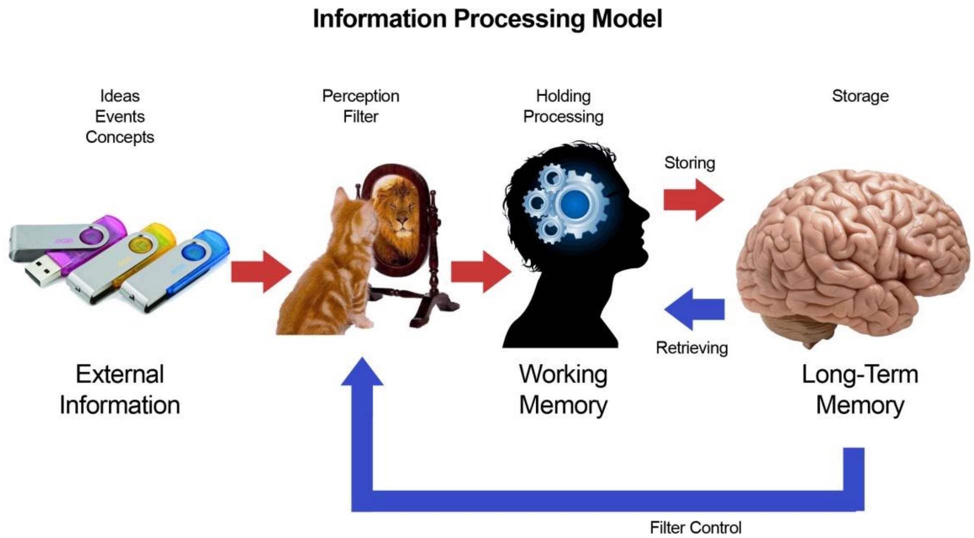

Figure 2.1. Information processing model adapted from Johnstone (2010, p. 23). This is an unofficial adaptation from an article that appeared in an ACS publication. ACS has not endorsed the content of this adaptation or the context of its use.

The researcher found the common problems with effective learning were that working memory was overloaded and students were not forming attachments in their long-term memory. As stated previously, Miller's chunking theory proposes that 5-9 chunks of information can be held in the short-term memory, also referred to as the working memory. This amount of information can only be held in the working memory if no processing is required, since the working memory not only holds information but also processes it. The proposed model suggests starting at the point of students' interests and experiences. If instruction begins by fitting into what students already know, then the working memory will not be as overloaded and attachments to long-term memory can be more easily made. The author suggests that this type of model may require a complete reordering of what is taught. The author sets out to build a model for learning based on their own research and well known learning theories. The research provided by the author and the basis of the research complement each other, leading to a good alternative learning theory. The research concluded that students were given too much information at once and that the information was disconnected. As a result, the authors sought to create a curriculum that seeks to engage students by starting with concepts already familiar to students, and then building upon that prior knowledge. This is in agreement with the learning theories the author used to form the new learning model.

Reid (2008) summarizes research conducted by himself, Johnstone, and other science educators in his articles “A Scientific Approach to the Teaching of Chemistry”. He stated that “the key message from all the research is that learners all learn in essentially the same way” (Reid, 2008, p. 56). His work showed that recall of information heavily relied on the manner in which it is stored. He agreed with Johnstone that chemistry needs to be taught in a manner that lessens the load on the working memory so that knowledge can be better stored in the long-term memory. By following the information processing model, Reid concluded that reducing the demand on the working memory will improve learning. This assertion does not mean that the content being taught needs to be changed or that difficulty needs to be avoided. The author believes that this goal can be accomplished by changing the teaching order and breaking down complex areas into smaller parts that the learner can process. It is important to reduce the amount of information presented at a particular teaching session. He concluded that if educators take a scientific approach to teaching, there will be a vast improvement in understanding and learning for the students.

In the article “Let’s Teach How We Think Instead of What We Know,” Talanquer and Pollard (2010) propose an alternative method of conceptualizing introductory chemistry curriculum. The authors point out that a considerable amount of resources have been invested in developing projects designed to change current first-year college chemistry curriculum, yet few institutions have adopted these programs. They suggested that the general chemistry curriculum is a “giant toolbox” filled with tools that students need to learn to use, but with a lack of a significant purpose. The researchers strived to: build a curriculum that promotes deeper conceptual understanding of a few fundamental ideas; connect ideas between course units; use education research about how people learn; introduce students to modern ways of thinking; and finally, involve students in decision-making and problem-solving activities in areas of interest in modern science. In order to accomplish their goal, they used a backward design model to create a new curriculum, which became their Chemistry XXI Project.

The Chemistry XXI Project developed under the assertion that it would be beneficial for the 21st century to change the focus of first-semester chemistry curriculum from mere knowledge acquisition to mastering chemical thought-processing. The art of chemical thought-processing is a transferrable skill that science majors can use in their future studies and careers. They used questions rather than topics as a guideline for their curriculum. These questions were designed to get students thinking about the concepts they were supposed to learn. The sequencing of the questions driving the curriculum was of great importance to ensure connectivity between concepts and across the modules. They built a learning progression, following what they called an “inquisitive spiral,” which begins and ends with analysis of macroscopic properties of chemical substances. Assessments of their new curriculum were conducted using assessment tools such as in-class tasks and thematic tests. The in-class tasks were designed to have students self-evaluate their performance on certain modules. The thematic tests were designed as a departure from traditional exams, which the authors feel require students to answer disconnected questions designed to test isolated knowledge. Their thematic tests require students to answer interrelated short-answer questions about relevant systems. The analysis of the assessment data was used to modify the curriculum and in-class activities. Other assessment tools were student questionnaires and in-class observations. The majority of students responded positively to the new curriculum even though they found it challenging. The ACS exam scores for students in a "traditional" course and students in the *Chemistry XXI Project* course were compared. The results showed that students in the *Chemistry XXI Project* performed at the same level as those of in the traditional course despite their lack of "training" in specific skills targeted by the exam.

In the article, "The Value of Teaching Valence Prior to Balancing Chemical Equations," the author proposes teaching valence theory before teaching balancing equations. This approach is the reverse of how these topics are traditionally taught (Zimmerman, 1925). Zimmerman states that the value of teaching valence first was satisfactorily demonstrated in the author's classroom but does not explain how it was demonstrated. The process by which the author teaches the concepts is clearly outlined and demonstrates how reversing the order of teaching forms stronger connections between the two concepts. The author used observations of student difficulties and their own prior knowledge to support the notion that teaching valence before balancing equations is useful. This is the beginning of learning theories rooted in making meaningful connections between concepts and understanding how students learn.

2.4 Standardized Exams

The use of the ACS exam as the instrument to measure student success is beneficial for many reasons. The exam is nationally standardized and normalized (i.e., norm-referenced). The exam is created by committees of educators who teach the course, hence the material on the exam is chosen by people that are intimate with and well-versed in the subject matter. The Exams Institute is actively involved in research projects devoted to the development of more helpful assessment tools. For example, one such research project investigated the factors that influenced how individual test items performed (Schroeder, Murphy, & Holme, 2012). They tested how the order of the questions and the order of the answer choices affected student performance on those particular questions. Another advantage of using the ACS exam is the fact that there is an ACS exam for each chemistry course, so studies can be done for all areas in chemistry using the same type of instrument. The ACS Exams Institute outlined a concept content map (adaptation in Figure 2.2) in order to assess content knowledge throughout an entire undergraduate chemistry career (Murphy, Holme, Zenisky, Caruthers, & Knaus, 2012).

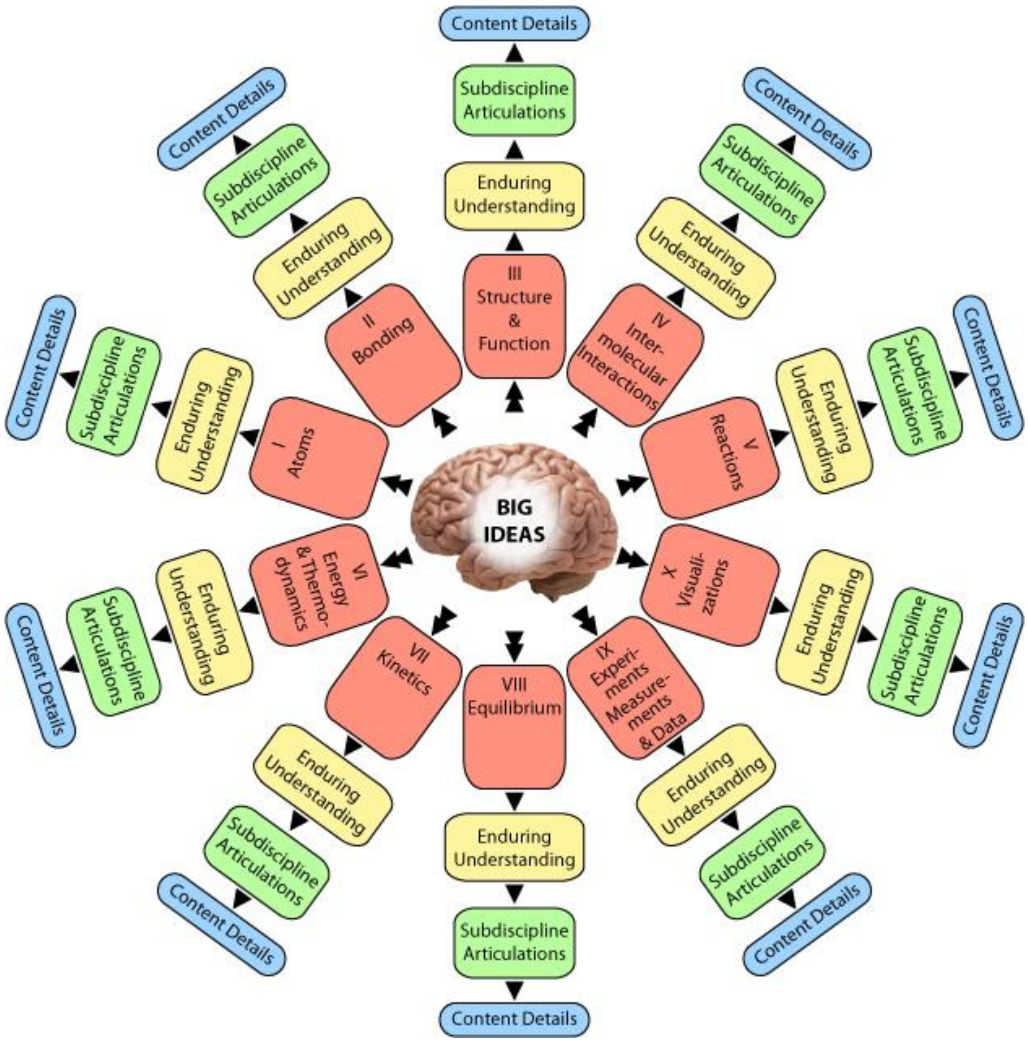

Figure 2.2. Concept map adapted from Murphy (2012, p. 717). The big ideas at the center depict the first level of chemistry knowledge, general chemistry. The subsequent levels depict higher level of chemistry with ideas becoming more focused. This is an unofficial adaptation from an article that appeared in an ACS publication. ACS has not endorsed the content of this adaptation or the context of its use.

2.5 Student Misconceptions

The learning theories discussed above support constructivism, where making connections between new material and prior knowledge is important. The process allows students to build upon previous knowledge and form more elaborate connections. While previous knowledge is a key factor in learning, it is also at the root of student misconceptions about chemistry. From a constructivist point of view, by the time a student enters a college-level course, they have accumulated years of prior content knowledge and experiences and therefore bring to the classroom a wide variety of ideas and concepts. When these concepts are inconsistent with the consensus of the scientific community they are referred to as “alternate conceptions,” which are often called misconceptions (Mulford & Robinson, 2002). Misconceptions in chemistry have been an area of interest for a long time and several articles have been published on the subject. Some chemical misconceptions include the particulate nature of matter (Gabel, Samuel, & Hunn, 1987; Yezierski & Birk, 2006), bond polarity (Furio & Calatayud, 1996; George & Mason, 2011), electrochemical cells (Ozkaya, 2002; Sanger & Greenbowe, 1997), Lewis dot structures (George & Mason, 2011), and significant figures (George & Mason, 2011). Although the existence of these misconceptions is well known, they still persist in the general chemistry classroom. Bodner (1991) revealed several misconceptions held by students by having the students answer questions and explain why they chose that answer. He concluded the following:

1. Knowledge is constructed in the mind of the learner.
2. Misconceptions are resistant to instruction.
3. Knowledge is not the same as understanding.
4. Misconceptions are often instructor-driven.

A study conducted by Azizoglu and colleagues showed that misconceptions are held by undergraduate pre-service teachers. These teachers will then pass on these misconceptions to their students. In addition to better teacher education programs, the authors suggested changes in chemical education are also needed, including chemistry curricula and textbooks (Azizoglu, Alkan, & Geban, 2006). The purpose of our study is to not only determine if student performance on the ACS exam is different for students taught using the traditional curriculum versus those taught using the atoms first approach, but also to determine if the change in curricula affects student misconceptions about chemistry. It is important to note that even though students are taught by different approaches, the end product requires that all the same topics be addressed so evaluation by one common end-of-course exam is considered valid.

A model for identifying the most notable high school chemistry concepts that were not mastered before entering general chemistry has been published (George & Mason, 2011). These researchers used the CA Dx to identify the most common misconceptions held by postsecondary students enrolled in entry-level general chemistry at one of the top four largest universities in Texas. This study noted that general chemistry students prior to instruction held misconceptions in their understanding on the following topics: bond polarity, significant figures, Lewis dot structures, nomenclature, and algebraic relationships needed to understand gas laws.

2.6 Summary

In all of the learning theories previously discussed, making connections between new material and prior knowledge is important. The process allows students to build upon prior knowledge and form more elaborate connections. These learning theories strongly suggest that teaching methods affect students' learning, retention of information, and recollection of content. As such, instructors must be strategic by periodically evaluating curriculum approaches in order to ensure that students are getting the best instructional approach to learning. However, considering that Bodner (1991) concluded that misconceptions are resistant to instruction, it will be interesting to see if the same misconceptions exist regardless of the instructional approaches evaluated in this research.

CHAPTER 3

RESEARCH METHODS

This chapter discusses the experimental design, sampling procedure, and data collection method. The academic setting and demographics of the sample population are provided. The dependent and independent variables for each research question are described. The statistical methods used for each research question in this investigation are also explained.

3.1 Design

The intent of this research is to compare student performances on the ACS exam between two curriculum approaches and to identify any differences in the misconceptions held by students who have experienced either approach. Therefore a quasi-experimental quantitative comparative research design was used. IRB exempt archival data were used to make the comparisons.

3.2 Sampling Procedures

The target population (N = 2,591) was all students enrolled in general chemistry I at Collin College in Collin County, TX. This type of sampling is one of convenience since the sample was readily available for this research. Collin College is located in the northeast region of the Dallas-Fort Worth metropolitan area. The college began offering its first classes at area high schools in 1985. Since then the college has expanded to serve about 53,000 credit and continuing education students each year. The only public college in Collin County, the college offers more than 100 degrees and certificates in a wide range of disciplines at its seven campuses and centers. The three campuses that offer general chemistry courses are Central Park, Preston Ridge, and Spring Creek. Out of the three campuses, ACS exam bubble sheets were only available for students from the Preston Ridge campus. This reduced sample population consists of students (n = 219 for TC and n = 310 for AF) that completed the course and therefore took the ACS exam as their course final exam. The sample is representative of the general chemistry student population for Collin College, since all the students completing the course are included; it may however not be representative of all students enrolled in general chemistry across the entire United States.

3.3 Sample Demographics

General chemistry students at Collin College are typically science, technology, engineering, and mathematics (STEM) majors anticipating transfer to a four-year university to further their education, or they are nursing school hopefuls. All demographic information available to the researcher of this study was formatted as percentages for each individual class section. No raw demographic data was available in accordance with the IRB approval. The age distributions for the sample population of each curriculum approach are shown in Figure 3.1. The ethnic distributions for the sample population of each curriculum approach are shown in Figure 3.2. Both figures show that although the two sample groups were taken from two different time periods (2007-2009 for TC and 2009-2011 for AF) the demographic distributions for the two sample groups are very similar.

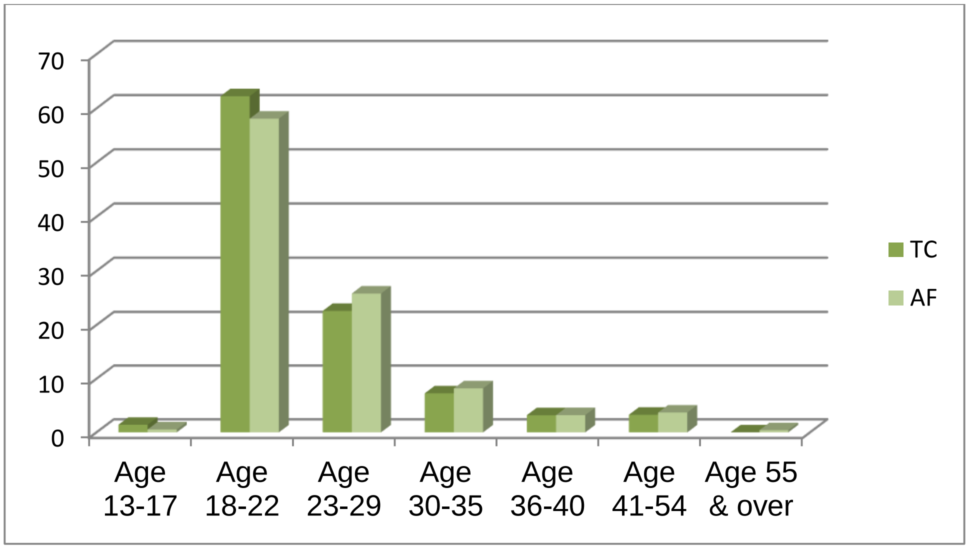

Figure 3.1. Sample population age distributions for both curriculum approaches.

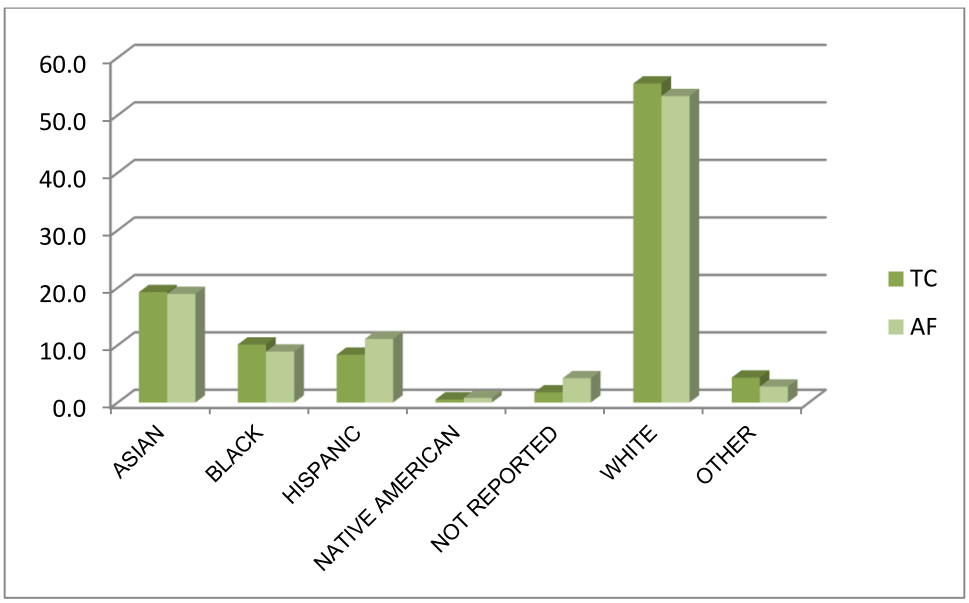

Figure 3.2. Sample population ethnicity distributions for both curriculum approaches.

Due to the nature of the data used for this research the demographics for the sample population are limited. The academic background of the students prior to entering the general chemistry course is unavailable due to the nature of the de-identified data, but approximately 96% of Collin students are Texas residents indicating that the majority of incoming students had the same high school requirements for graduation published by the Texas Education Agency and were required to complete the same end-of-course high-stakes Texas Assessment of Knowledge and Skills (TAKS) test. For the academic years 2003-2011 the minimum requirements for Texas high school graduates included algebra I, geometry, and integrated physics and chemistry (IPC) or physics and chemistry separately. The majority of the students from both sample groups were 18-22 years old, 62% and 58% for the TC and AF groups, respectively, which means that the majority of the sample population had taken high school algebra and some form of chemistry prior to enrolling in general chemistry I at Collin College. The prerequisites for all general chemistry I students at Collin College include college algebra (MATH 1314) and introductory chemistry (CHEM 1405) or at least one year of high school chemistry all completed within five years of enrollment and with a grade of C or higher.

3.4 Data Collection

ACS exam bubble sheets for the four fall and spring semesters from 2007-2009 will be used for the TC approach and ACS exam bubble sheets for the four fall and spring semesters from 2009-2011 will be used for the AF approach. The bubble sheets contain the letter answer for each question on the ACS exam chosen by each student and provide the raw exam scores for each student. The name and any other identifiable information were marked out so the scores remained anonymous. The evaluation instrument is the First-term General Chemistry Exam created and released by the ACS DivCHED. Two versions of this exam were used: exams were released in two different years and are referred to as exam 1 and exam 2. For each of those exams, two versions were used in which item position and answer choice positions are scrambled. The different versions for a given exam are each printed on different colored paper. For exam 1 the colors were blue and gray. For exam 2 the colors were gray or yellow. The exams are coded by version (1 or 2) and color (B=blue, G=gray, Y=yellow). So, exam 1 on blue paper is E1B. A copy of the answer sheet with the raw score on it was provided for the researcher and can be directly obtained from the ACS Examinations Institute by any qualifying college/university professor. The version of the exam the student took was included on the student bubble sheet. The bubble sheets were also coded as either 1 or 2, representing that the student was taught by either the TC approach or AF approach, respectively. They were also coded with an “F” for fall or an “S” for spring semesters, followed by the year. For example, a student in the TC approach group taking the exam in the fall of 2007 was coded as 1F2011. Therefore, the complete code for a student being taught by the TC approach in the fall of 2007 and taking the general chemistry I exam version 1 and printed on yellow paper would have a code of 1F2007-E1Y. A student in the AF approach group taking the course in the spring of 2011 that took the exam 2 version printed on gray paper would have a code of 2S2011-E2G.

3.5 Dependent Variables

For the comparison of the overall student performance on the ACS exam between the two groups the dependent variable was the student’s raw exam score. ACS exam bubble sheets for the four fall and spring semesters from 2007-2009 were used for the TC approach and ACS exam bubble sheets for the four fall and spring semesters from 2009-2011 were used for the AF approach. The bubble sheets contain the letter answer for each question on the ACS exam chosen by each student and provide the raw exam scores for each student. The raw exam score is simply the sum of correctly answered questions. Each correct answer counts as one point. For example, if a student answers 40 out of 70 questions correctly on the exam their raw score will be 40. The name and any other identifiable information were marked out by a member of the staff at Collin College so the scores remained anonymous to the investigator of this research.

For the comparison by topic on the ACS exam, the dependent variable was the student response to each question. Each question was put into a group depending on the topic the question pertains to. Each response was coded as correct or incorrect. The number of correct and incorrect responses for each topic was used to determine student performance on that topic for each curriculum group.

For the student misconceptions between the two groups, the dependent variable was the most frequently occurring wrong answer chosen for each question regarding a specific topic. The answer bubble sheets for each student were examined to determine what answer choice was chosen for each question. The wrong answers that were chosen at a higher probability than random guessing were considered possible student misconceptions. This process is explained further in section 3.7 of this chapter.

3.6 Independent Variables

For the comparison of the overall student performance on the ACS exam between the two groups, the independent variable was the order in which the topics were taught, either using the TC approach or the AF approach. The textbook used by the students taught under the traditional curriculum approach was the fourth edition of *Chemistry* by McMurry and Fay (2004). The textbook used by the students taught under the atoms first curriculum approach was *General Chemistry: Atoms First* by McMurry and Fay (2010). Table 3.1 provides a general outline of the topics covered in general chemistry I and the order in which they are taught under each curriculum approach. Both approaches begin by covering the topics of matter and measurement and end with gases but the material in-between those topics, the meat of the course, is where the two approaches vary.

Table 3.1

Topics Covered in Order by Each Curriculum Approach

Traditional Curriculum Approach	Atoms First Approach
Matter and Measurement	Matter and Measurement
Atoms, Molecules, and Ions	Structure and Stability of Atoms
Stoichiometry	Periodicity and the Electronic Structure of Atoms
Aqueous Reactions and Solution Stoichiometry	Ionic Bonds and Main-Group Chemistry
Thermochemistry	Covalent Bonds and Molecular Structure
Electronic Structure of Atoms	Mass Relationships in Chemical Reactions
Periodic Properties of the Elements	Reactions in Aqueous Solutions
Chemical Bonding	Thermochemistry
Molecular Geometry and Bonding Theories	Gases
Gases	

For the comparison by topic on the ACS exam and student misconceptions between the two groups, the independent variable was the exam topics themselves. The topics covered on the ACS exam as listed on the Exams Institute's Website are listed as:

- Atomic and nuclear structure
- Molecular structure
- Stoichiometry
- Energetics
- States of matter/solutions
- Redox

- Descriptive chemistry/periodicity
- Laboratory.

Table 3.2 shows how many questions there are for each topic on each exam version. When exams are purchased by an educational institution for use from the ACS Exams Institute, the purchasers agree not to disclose any information that can compromise the privacy of the exams. For this reason, only the number of the questions and topics are shown, the actual questions will not be presented. Due to the small number of questions on redox and the laboratory available on both exam versions, these topics will not be a focus of this evaluation. The topic of redox beyond a simple introduction is considered to be a topic more pertinent to the second semester of the general chemistry sequence, and the laboratory questions, even though valid to assess a complete understanding of general chemistry, are not reflective of what is taught in the lecture approach of the first-semester course.

Table 3.2

Number of Questions for Each Topic on Exam 1 and Exam 2

Topic	Exam 1	Exam 2
Atomic and nuclear structure	9	9
Molecular structure	19	16
Stoichiometry	10	15
Energetics	8	6
States of matter/solutions	9	7
Redox	1	3
Descriptive Chemistry/Periodicity	11	10
Laboratory	3	4

3.7 Statistical Methods

3.7.1 Preliminary Data Analysis

Since the statistical procedures used in this study assume that variances of the populations from which the different samples were drawn must be equal, a Levene's test was conducted to assess this assumption. IBM® SPSS® Statistics Version 14 (SPSS®) software was used to carry out the Levene’s test. R software (R Project, 2014) was used to obtain descriptive statistics of the data. The R program is an open source statistical program developed by the R Development Core Team. Box plots of the data were created to display any differences between the populations and to determine if outliers existed in the data.

3.7.2 Research Question 1: Exam Differences

The data were analyzed using R software (R Project, 2014). The percentage of successful students on the ACS exam for each treatment group was calculated to determine the level of student success on the ACS exam for each curriculum type. An independent samples *t*-test was performed using an α–level of 0.5 to compare the overall exam scores for each treatment group. The t_{crit} was compared to the t_{calc}. If the t_{calc} is greater than the t_{crit} the null hypothesis was rejected, meaning that there is a statistically significant difference between the two treatment groups. If this is the case, the averages of both groups can be obtained to determine which group performed better. Where the null hypothesis is not rejected, it is concluded that both groups perform the same, meaning there is no statistically significant difference between the two groups. The effects size, measured by Cohen’s *d*, was also reported. For this study, effect sizes of small, medium, and large are d = 0.20, 0.50, and 0.80, respectively.

These effect sizes are based on the type of statistical tests and the sample sizes used in this study in accordance with Cohen's effect size index (Cohen, 1992).

3.7.3 Research Question 2: Topic Differences

R software was used to perform a factor analysis (FA) of the data. Factor Analysis can be used to explore data for patterns and to provide information about different categories or factors. FA is able to identify groupings of variables (in this case exam questions) that can be represented by a single factor (in this case, exam topics). FA also provides information about the correlation of the variables within a factor. For this study FA was used to explore the student performance by topic on the ACS exam for the two curriculum approaches. A topic is referred to as a factor and each question is referred to as a variable. The factor score represents the correlation between the questions and the topic based on the student's response being correct or incorrect for that particular question and in turn measures student knowledge on the topic. This process identifies groupings that allow one variable to represent many, which is the case on the ACS exam, since it tests a wide range of chemistry knowledge. A *t*-test was performed on the factor scores for each topic to test for statistically significant differences between the curriculum groups and the effect sizes as measured by Cohen's *d* were reported. If the factor scores vary greatly between the two curriculum groups, they are not gaining knowledge of that topic in a similar fashion. The *t*-tests assume that the questions in each topic category, as chosen based on the ACS first-term general chemistry exam matrix, are representing one factor.

3.7.4 Research Question 3: Misconceptions

The misconception part of the study was accomplished using a model described in a study conducted by George and Mason (2011). In the George and Mason study the number of times each answer choice was chosen for a particular question on the ACS CA Dx was totaled and the *z*-score calculated. The occurrences of the most commonly chosen wrong answer and the correct answer were tested to determine if a statistically significant difference existed at a 95% significance level. The common wrong answers with a positive *z*-score above the *z*-critical value were considered answer choices chosen more frequently than if they were chosen randomly (more than 25%), and were therefore thought to be a correct answer choice or misconception. In this study, the same method was applied to determine if the prevalent incorrect answers chosen by students on the ACS first-term general chemistry exams were misconceptions.

A similar concept was applied to these data using Item Response Theory (IRT) to produce probability curves for the four possible answer choices. IRT can provide a test of item equivalence across groups. In other words, it can test whether an item (in this case, a question) is behaving differently for the two curriculum groups. IRT provides a wealth of information about an item including item difficulty across different student abilities, item discrimination (similar to correlation in classical test theory), and the probability of guessing the correct answer for the item. A nested logit nominal response model for polytomous data was used to identify distractors in the test questions (Bock, 1997; Suh & Bolt, 2010). A response to an item is considered polytomous if it is restricted to one of a fixed set of possible values, as is this case with a multiple-choice exam of the type used in this study. In other words, only one answer choice can be chosen. A nominal response model is used when the responses are not ordered and have no structure. A “nested” model incorporates the correct answer when calculating response frequencies. A nested logit nominal response model calculates the maximum-likelihood of each answer choice based on frequency response patterns in a sample of *N* respondents.

IRT was used to produce item characteristic curves (ICC) for each exam question. These curves are used to represent how each question performs across student abilities for the two curriculum groups. The curves show the probability (from 0-1) of correctly answering each question as student ability goes from low ability (-4) to high (+4) ability. There are three parameters: *a*, *b*, and *c*. The *a* parameter is called the discrimination parameter and is the counterpart of item total correlation in classical testing theory. It is the steepness of the curve at its steepest point. As the *a* parameter decreases, the curve gets flatter until there is virtually no change in probability across the ability continuum. Items with very low *a* values are not useful for distinguishing among people, just like items with very low item total correlations. The *b* parameter is called the difficulty parameter. It sets the location of the inflection point of the curve on the horizontal axis. As an item becomes more difficult it shifts from left to right on the horizontal axis. The *c* parameter is known as the guessing parameter. The *c* parameter is a lower asymptote and gives the probability of guessing the item correctly.

CHAPTER 4

RESULTS

The purpose of this study was to investigate if one curriculum approach is more effective in increasing students' understanding on special topics than the other on the American Chemical Society (ACS) exam and to determine the chemistry misconceptions held by students taught under both curricula. Accordingly, answered bubble sheets for the ACS first-term general chemistry exam were obtained and the scores and answer choices were examined. The subsequent sections provide the results of the analysis for each research question.

4.1 Preliminary Analysis

Descriptive statistics for the two curriculum groups were obtained using R software (R Core, 2014). The dependent variable, the raw ACS exam score, was measured on a continuous scale from 0-70. The score is based on how many correct responses were answered by the student. The two categorical independent variables are the different curriculum approaches, traditional curriculum (TC) or atoms first (AF). The box plot of the data in Figure 4.1 showed no outliers for either curriculum group.

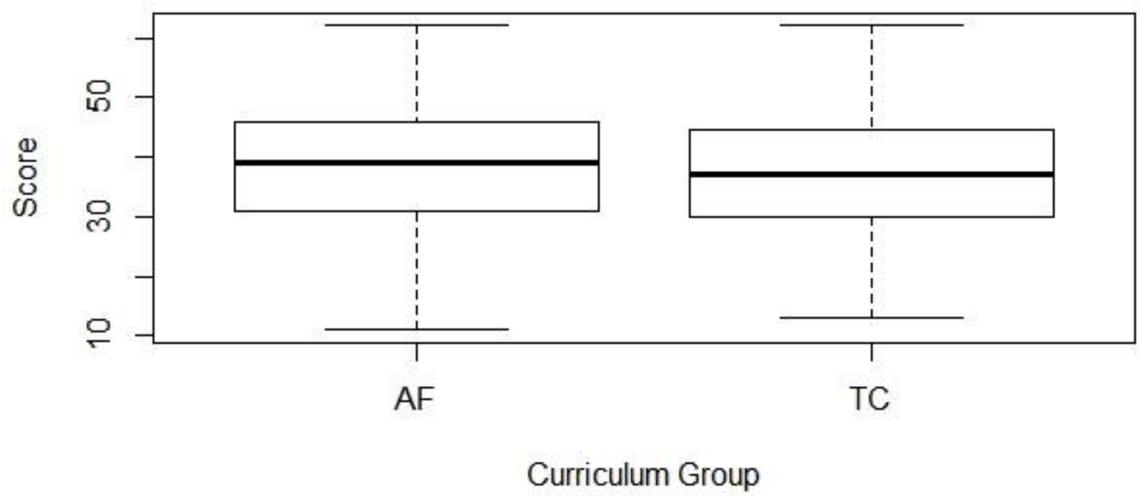

Figure 4.1. Box plot for the two curriculum groups, AF and TC.

The values for the skewness and kurtosis of the TC group were 0.17 and -0.7, respectively. The values for the skewness and kurtosis of the AF group were -0.05 and -0.53, respectively. The AF group is slightly skewed to the left. Both groups are slightly flat near the mean.

The mean ACS exam score and standard deviation (*SD*) for the entire sample (*n* = 529) was 38.33 (10.52) with a range of 11-62. Table 4.1 shows the means and standard deviations for each curriculum group. The mean (SD) for the TC group (*n* = 219) was 37.68 (10.39) with a range of 13-62 and for the AF group (*n* = 310) was 38.79 (10.60) with a range of 11-62. There was no exam data for the TC for the gray exam 2, only for the AF group, so that exam's data were excluded from the sample.

Table 4.1

Descriptive Statistics for the Two Curriculum Approaches

Curriculum Group	*n* (sample size)	Mean	Standard Deviation	Standard Error on the Mean
TC	219	37.68	10.39	0.70
AF	310	38.79	10.60	0.60

A Levene's test for homogeneity between the two curriculum groups showed that the variability between the groups was not significant because the significant value of 0.859 was greater than the critical value of 0.05.

An independent samples *t*-test of the raw scores on the ACS exam between the two curriculum groups showed no significant difference between the two curriculum groups at a 95% confidence interval ($t = -1.195$, $df = 475$, $p = 0.233$). The effect size as measured by Cohen's *d* was 0.11 that shows very little effect and corresponds to there being no statistically significant difference between the two groups (Coladarci, Cobb, Minium, & Clarke, 2008).

4.2 Research Question 1

Research Question 1 (Q_1) of this study is: What level of achievement on the ACS final exam is obtained by students who studied under the atoms first or traditional curriculum approach? In order to investigate this question, the ACS exams scores for each curriculum group were compared to the national mean for each version of the exam. The national means are listed by exam type and version on the ACS Exams Institute's Website. Table 4.2 shows the national means and standard deviations for the two exams used in this study. The national mean (*SD*) for the general chemistry first-term exam 1 and exam 2 are 42.24 (12.33) and 40.35 (12.26), respectively.

Table 4.2

National Norms for the ACS General Chemistry First-term Exams

Exam Version	National Mean	Standard Deviation
Exam 1	42.24	12.33
Exam 2	40.35	12.26

For the general chemistry first-term exam 1, the mean (*SD*) for the TC group (*n* = 162) was 38.96 (10.82) and for the AF group (*n* = 96) it was 39.89 (10.16). For the general chemistry first-term exam 2, the mean (*SD*) for the TC group (*n* = 57) was 34.07 (8.13) and for the AF group (*n* = 214) it was 38.30 (10.78). Table 4.3 shows the percentage of student scores that are equal to or above the national mean.

Table 4.3

Student Achievement on the ACS Exam

Exam Version	Curriculum Group	*n* (sample size)	Mean	Standard Deviation	≥ National Mean (%)	< National Mean (%)
Exam 1	TC	162	38.96	10.82	39.5	60.5
	AF	96	39.89	10.16	41.7	58.3
Exam 2	TC	57	34.07	8.13	24.6	75.4
	AF	214	38.30	10.78	48.1	51.9

A student is successful on the ACS exam if their score is equal to or above the national mean. Both groups follow the national trend of having higher means on exam 1 than exam 2, and the experimental means in all cases are below the national reported means. The AF group however, has a higher mean than the TC group for both exams. Although the AF mean is higher than the TC mean on exam 1, a *t*-test at a 95% confidence interval showed no statistical significance between the two groups (t = 0.693, df = 209.6, p = 0.489). The effect size as measured by Cohen's *d* was 0.09. This is not the case for exam 2 where a *t*-test at a 95% confidence interval showed a statistically significance between the two groups (t = 3.24, df = 114, p = 0.002). The effect size as measured by Cohen's *d* was 0.48, which is a medium effect size.

Research Question 1 was broken down into more specific sub-questions ($Q_{1.1}$-$Q_{1.4}$) that are described in Table 4.4. The sub-questions are as follows:

$Q_{1.1}$: What percentage of students who studied under the atoms first curriculum approach falls within one standard deviation above the national mean on the ACS First-Term General Chemistry Exam?

$Q_{1.2}$: What percentage of students who studied under the traditional curriculum approach falls within one standard deviation above the national mean on the ACS First-Term General Chemistry Exam?

$Q_{1.3}$: What percentage of students who studied under the atoms first curriculum approach falls within one standard deviation below the national mean on the ACS First-Term General Chemistry Exam?

$Q_{1.4}$: What percentage of students who studied under the traditional curriculum approach falls within one standard deviation below the national mean on the ACS First-Term General Chemistry Exam?

Table 4.4

ACS Exam Scores within 1 SD Above and Below the National Average

Exam Version	Curriculum Group	Percentage of Students Within 1 Standard Deviation Above the National Mean	Percentage of Students Within 1 Standard Deviation Below the National Mean
Exam 1	TC	32.1	38.3
	AF	33.3	39.6
Exam 2	TC	24.6	50.9
	AF	39.7	35.0

4.3 Research Question 2

Research Question 2 (Q_2) of this study is: What are the statistical differences at an alpha level of 0.05 in student performance by topic on the ACS exam between students taught by the traditional curriculum and students taught by the atoms first curriculum? This question was broken down into the following sub-questions:

$Q_{2.1}$: On the topic of atomic and nuclear structure was there a statistical significant difference at an alpha level of 0.05 as determined by a *t*-test on the factor scores between the students taught by the traditional curriculum and students taught by the atoms first curriculum approach?

$Q_{2.2}$: On the topic of molecular structure was there a statistical significant difference at an alpha level of 0.05 as determined by a *t*-test on the factor scores between the students taught by the traditional curriculum and students taught by the atoms first curriculum approach?

$Q_{2.3}$: On the topic of stoichiometry was there a statistical significant difference at an alpha level of 0.05 as determined by a *t*-test on the factor scores between the students taught by the traditional curriculum and students taught by the atoms first curriculum approach?

$Q_{2.4}$: On the topic of energetics was there a statistical significant difference at an alpha level of 0.05 as determined by a *t*-test on the factor scores between the students taught by the traditional curriculum and students taught by the atoms first curriculum approach?

$Q_{2.5}$: On the topic of states of matter and solutions was there a statistical significant difference at an alpha level of 0.05 as determined by a *t*-test on the factor scores between the students taught by the traditional curriculum and students taught by the atoms first curriculum approach?

$Q_{2.6}$: On the topic of oxidation-reduction (redox) was there a statistical significant difference at an alpha level of 0.05 as determined by a *t*-test on the factor scores between the students taught by the traditional curriculum and students taught by the atoms first curriculum approach?

$Q_{2.7}$: On the topic of descriptive chemistry and periodicity was there a statistical significant difference at an alpha level of 0.05 as determined by a *t*-test on the factor scores between the students taught by the traditional curriculum and students taught by the atoms first curriculum approach?

$Q_{2.8}$: On the topic of laboratory was there a statistical significant difference at an alpha level of 0.05 as determined by a *t*-test on the factor scores between the students taught by the traditional curriculum and students taught by the atoms first curriculum approach?

Three versions on the ACS first-term general chemistry exam were examined. The blue version of exam 1 is E1B, the gray version of exam 1 is E1G, and the yellow version of exam 2 is E2Y. Table 4.5 shows the sample sizes, means, and standard deviations for both curriculum approaches for each exam version. The E1B exam showed no statistically significant differences at an alpha level of 0.05 between the curriculum groups. Due to the small sample size of the AF group ($n = 17$), the chance of committing a Type II error is increased so the probability of concluding “no effect” when there is one is high (Coladarci et al., 2008).

Table 4.5

Sample Sizes, Means, and Standard Deviations by ACS Exam Version for the Two Curriculum Approach Groups

Exam Version*	AF Sample Size	AF Mean	AF Standard Deviation	TC Sample Size	TC Mean	TC Standard Deviation
E1B	17	39.3	9.7	79	36.9	10.9
E1G	79	40.0	10.3	83	40.9	10.4
E2Y	214	38.3	10.8	57	34.1	8.1

*Note: E1 = general chemistry exam version 1; E2 = general chemistry exam version 2; color of exam: B = blue, G = gray, Y = yellow.

Although the *p*-statistic ($p = 0.081$) showed no statistically significant difference between the two groups for all topics, Figure 4.2 shows that the effect size ($d = 0.48$) for the topic of descriptive chemistry and periodicity medium-high based on the sample size. The AF students had a higher factor score mean than the TC students for this topic. The E1G exam showed a statistically significant difference ($t = 4.42$, $df = 146.87$, $p = 0.00002$) at an alpha level of 0.05 between the two groups for the topic of descriptive chemistry and periodicity. The effect size as measured by Cohen's *d* was 0.69. The AF students had a higher factor score mean than the TC students for this topic.

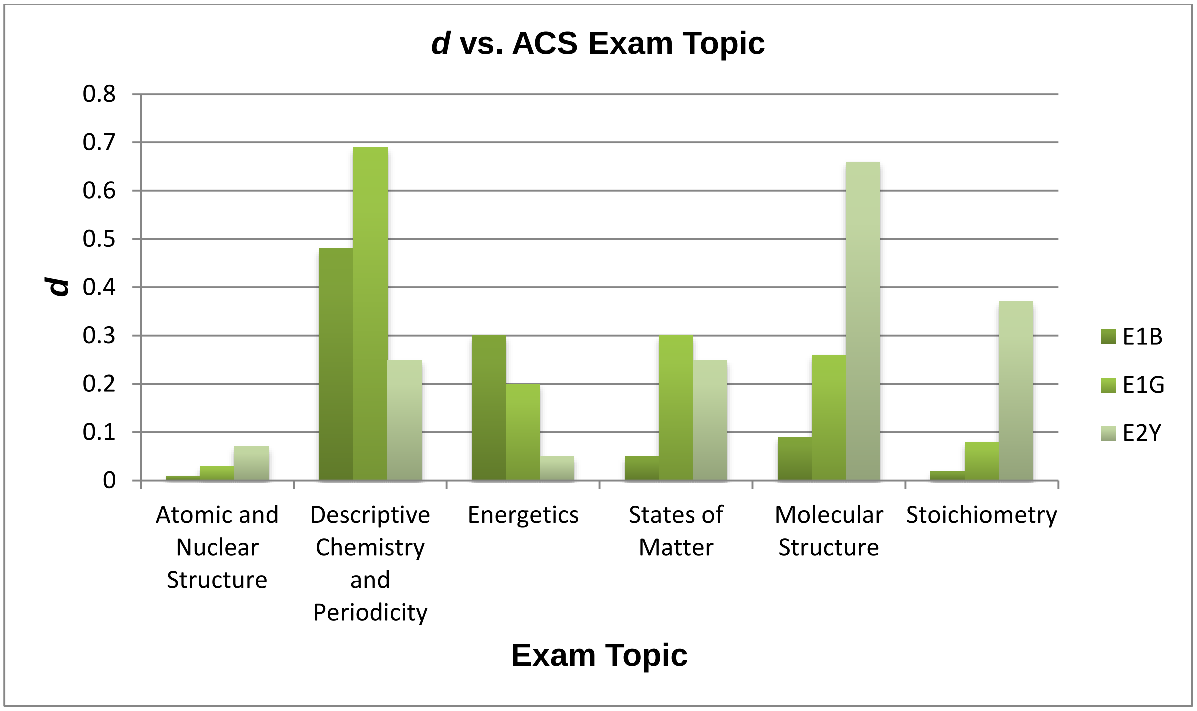

Figure 4.2. Effects sizes for all ACS exams shown by topic.

The E2Y exam showed a statistically significant difference for two different topics. The topic of molecular structure showed a statistically significant difference (t = 4.44, df = 75.87, p = 0.00003) at an alpha level of 0.05 between the two groups. The effect size as measured by Cohen's d was 0.66. The same exam showed a statistically significant difference (t = 2.46, df = 75.87, p = 0.00003) at an alpha level of 0.05 between the two groups for the topic of stoichiometry. The effect size as measured by Cohen's d was 0.37. The AF students had a higher factor score mean than the TC students for both of those topics. The redox and laboratory topics were excluded because there were not enough exam questions in each category for this type of analysis. Redox is a subtopic of electrochemistry. Electrochemistry is covered in general chemistry II, not general chemistry I. The few questions covering redox on this exam pertain to very simple aspects of electrochemistry covered in general chemistry I and are therefore few in number. The main purpose of this evaluation is to explain differences in lecture approaches and not evaluate laboratory topics, so omitting these few questions (4 from the TC; 7 from the AF) from 70 on each ACS exam is justified (refer to Table 3.2).

4.4 Research Question 3

Research Question 3 (Q_3) of this study is: What are the content misconceptions held by students taught under traditional curriculum and atoms first approaches for questions with prevalent incorrect responses having a *z*-score above the z_{crit} of 1.96? This question was broken down into the following sub-questions:

$Q_{3.1}$: What are the content misconceptions held by students taught under the traditional curriculum approach for questions with prevalent incorrect responses having a *z*-score above the z_{crit} of 1.96?

$Q_{3.2}$: What are the five most prevalent student misconceptions held by students taught under the atoms first curriculum approach for questions with prevalent incorrect responses having a *z*-score above the z_{crit} of 1.96?

Due to the small sample size of the AF group for the E1B version of the exam, it was excluded from this part of the study. The two versions of the ACS first-term general chemistry exam that were examined were the E1G and the E2Y exams. For each question, a *z*-score was calculated for the incorrect answer chosen the most and compared to the *z*-critical at an alpha level of 0.05. The top misconceptions on the E1G exam for the TC group are in Table 4.6 below.

Table 4.6

The Top Misconceptions on the E1G Exam for the TC Group

Question	Topic	Subtopic
35	Atomic and nuclear structure	Electron configurations
16	Redox	Oxidation numbers
18	States of matter	Solubility
34	Energetics	Enthalpy stoichiometry
54	States of matter	Boiling points of solutions
63	States of matter	Gas laws

The top misconceptions on the E1G exam for the AF group are shown in Table 4.7. Note that four out of the six questions are misconceptions held by students in both curriculum groups.

Table 4.7

The Top Misconceptions on the E1G Exam for the AF Group

Question	Topic	Subtopic
35	Atomic and nuclear structure	Electron configurations
54	States of matter	Boiling points of solutions
63	States of matter	Gas laws
56	Molecular structure	Bond polarity
34	Energetics	Enthalpy stoichiometry
8	Laboratory	Accuracy and precision

The item response curves for the top misconception held by each curriculum group are in Figures 4.3-4.10. The data were re-coded so that the correct answer is always category P1 as not to reveal what the actual answers to the questions are and maintain the confidentiality required by the ACS Exams Institute in accordance with the

ACS privacy agreement. The response curves for Question 35 are very similar for both groups and clearly show that answer choice P3 is a distractor as it has a higher probability of being chosen than the correct answer, P1.

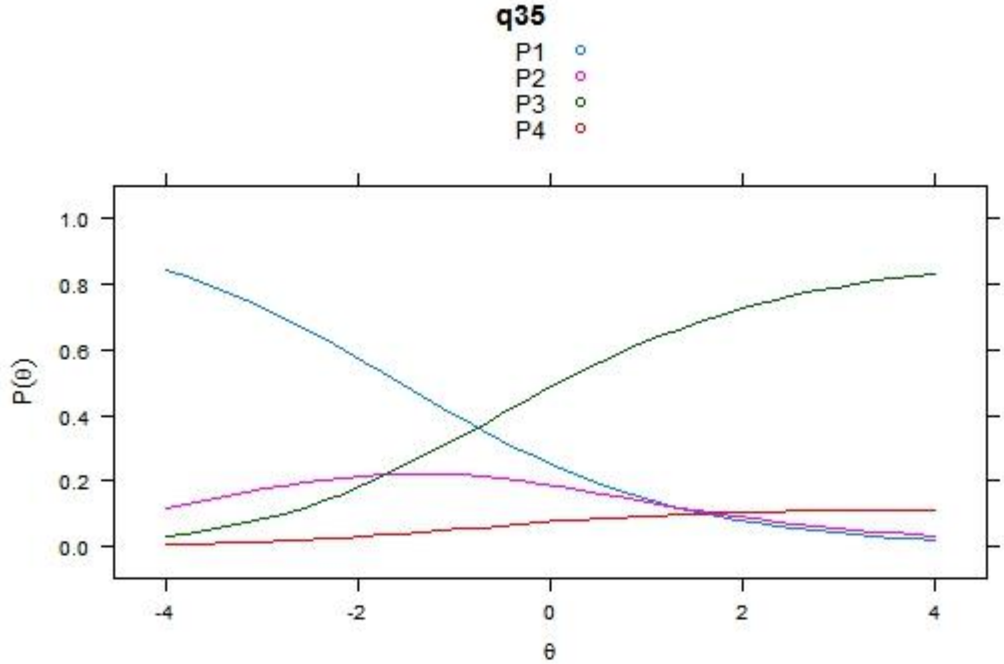

Figure 4.3. Item response curve for Question 35 on the E1G exam for the TC group. The correct answer is P1.

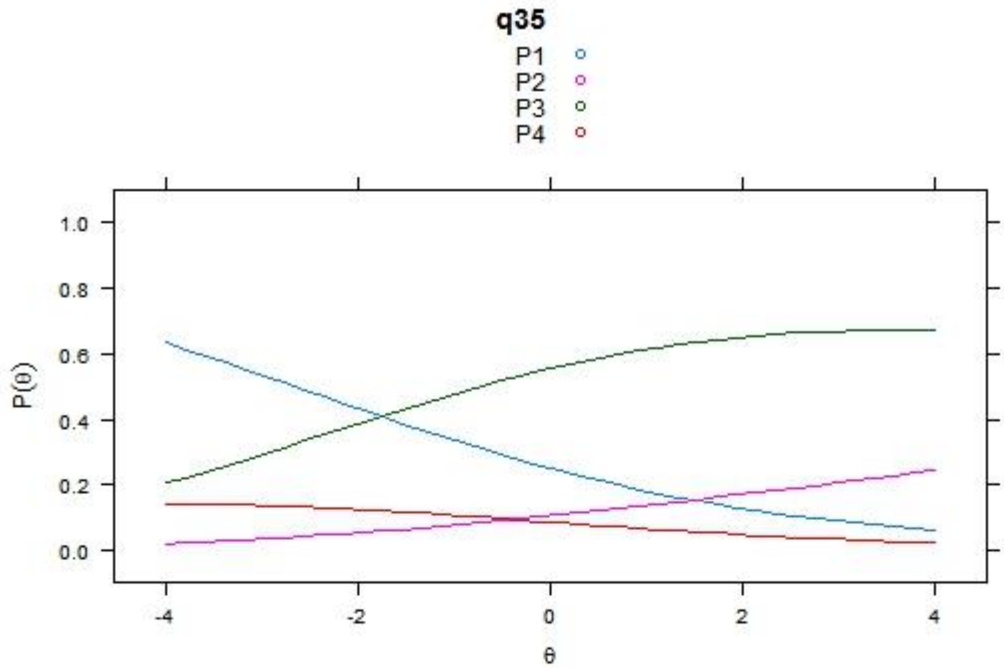

Figure 4.4. Item response curve for Question 35 on the E1G exam for the AF group. The correct answer is P1.

The item response curves for Question 34 are in Figures 4.5 and 4.6. The correct answer, P1, is only being answered correctly for high ability students in both groups. Distractor P2 is being chosen by low ability students and P4 is being chosen by mid-level ability students for both curriculum groups.

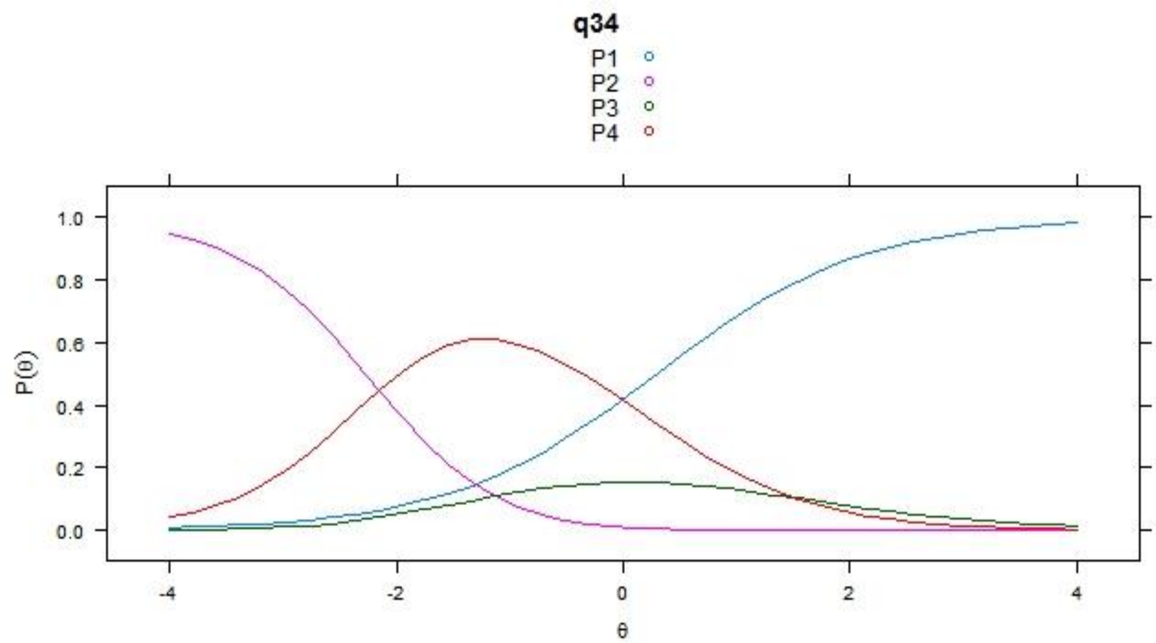

Figure 4.5. Item response curve for Question 34 on the E1G exam for the TC group. The correct answer is P1.

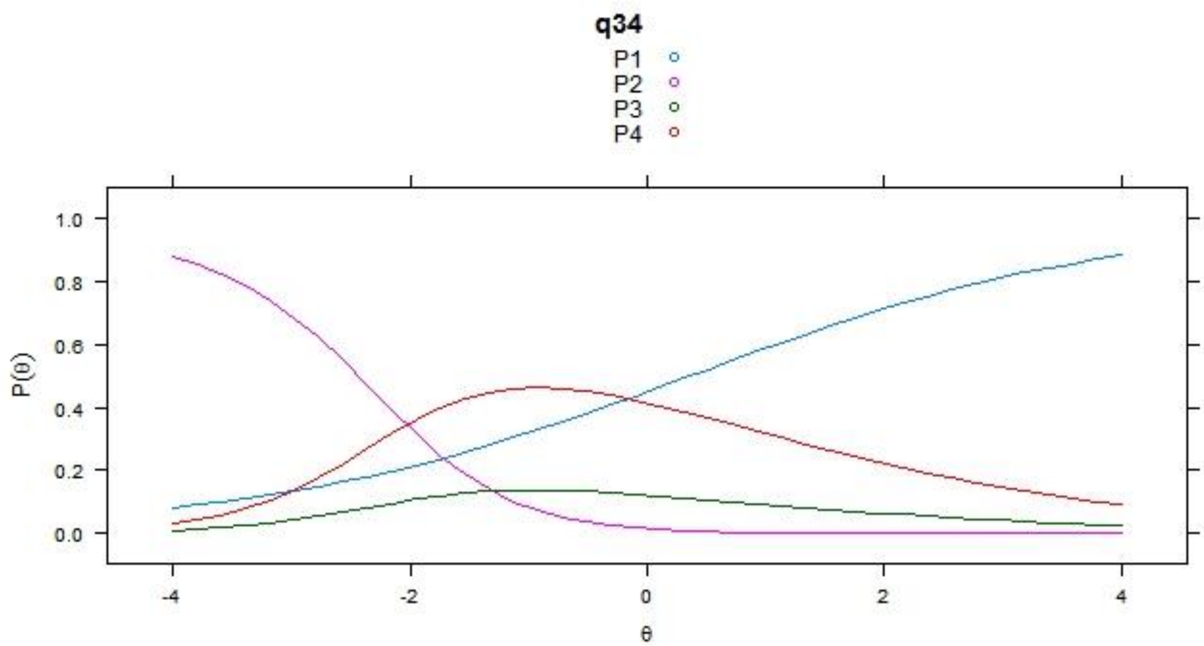

Figure 4.6. Item response curve for Question 34 on the E1G exam for the AF group. The correct answer is P1.

The item response curves for Question 54 are in Figures 4.7 and 4.8. The probability of choosing the correct answer, P1, for Question 54 is very low for all ability students in the TC group. Distractor P2 is being chosen by low-middle ability TC students and P3 is being chosen by middle-high ability TC student. The probability of choosing the correct answer, P1, for Question 54 for the high ability AF students is higher than the TC students but is still low compared to the distractors. In the AF group, all three distracters are being chosen at different ability levels.

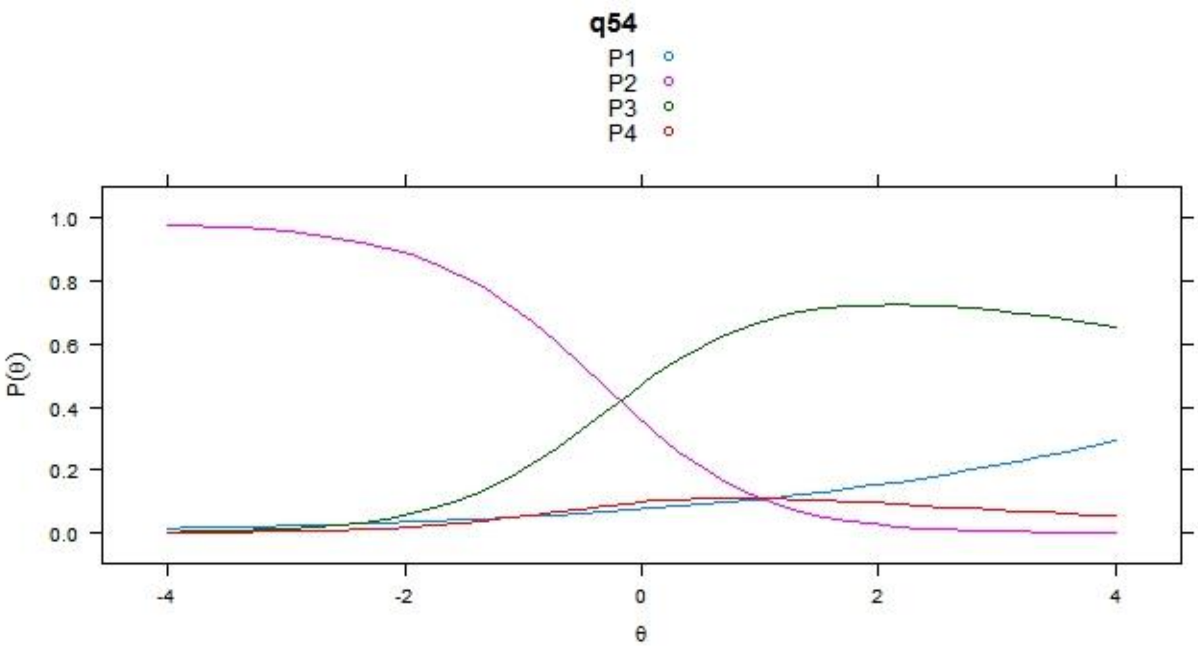

Figure 4.7. Item response curve for Question 54 on the E1G exam for the TC group. The correct answer is P1.

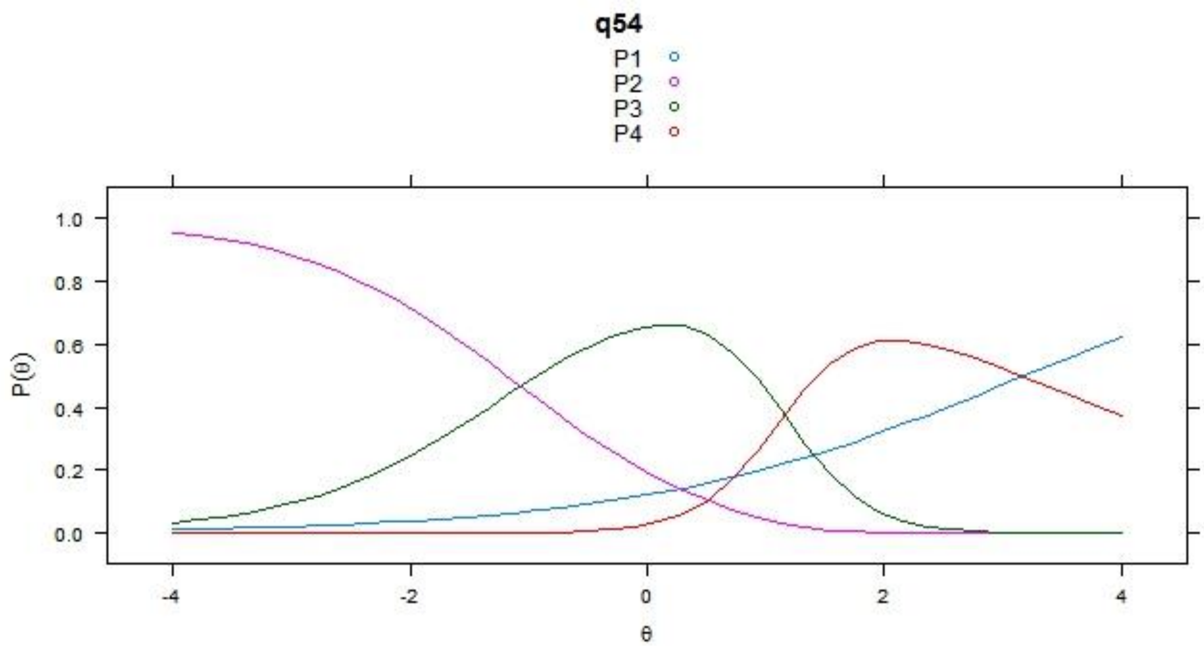

Figure 4.8. Item response curve for Question 54 on the E1G exam for the AF group. The correct answer is P1.

The item response curves for Question 63 for both groups are in Figures 4.9 and 4.10 below. For the TC students, only high ability students are choosing the correct answer, P1. Distractors P2 and P4 are being chosen at higher probabilities across most of the student ability levels. For the AF group, the correct answer has a very low probability (about 0.1) of being chosen across all ability levels. As with the TC group, distractors P2 and P4 are being chosen at higher probabilities than the correct answer.

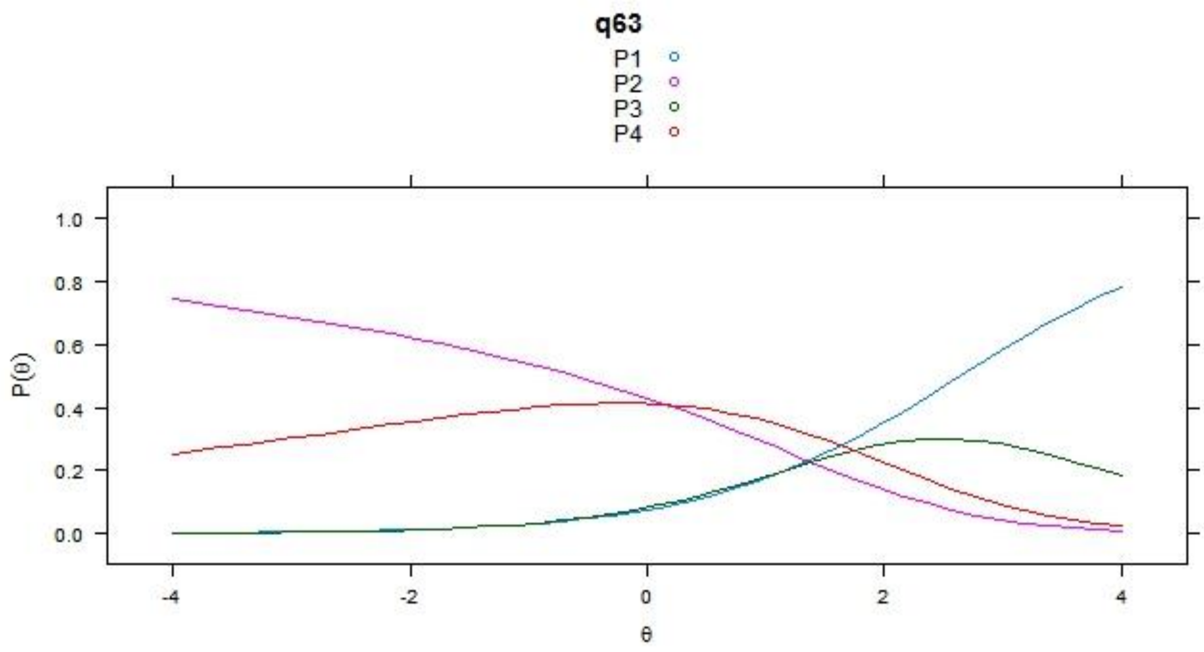

Figure 4.9. Item response curve for Question 63 on the E1G exam for the TC group. The correct answer is P1.

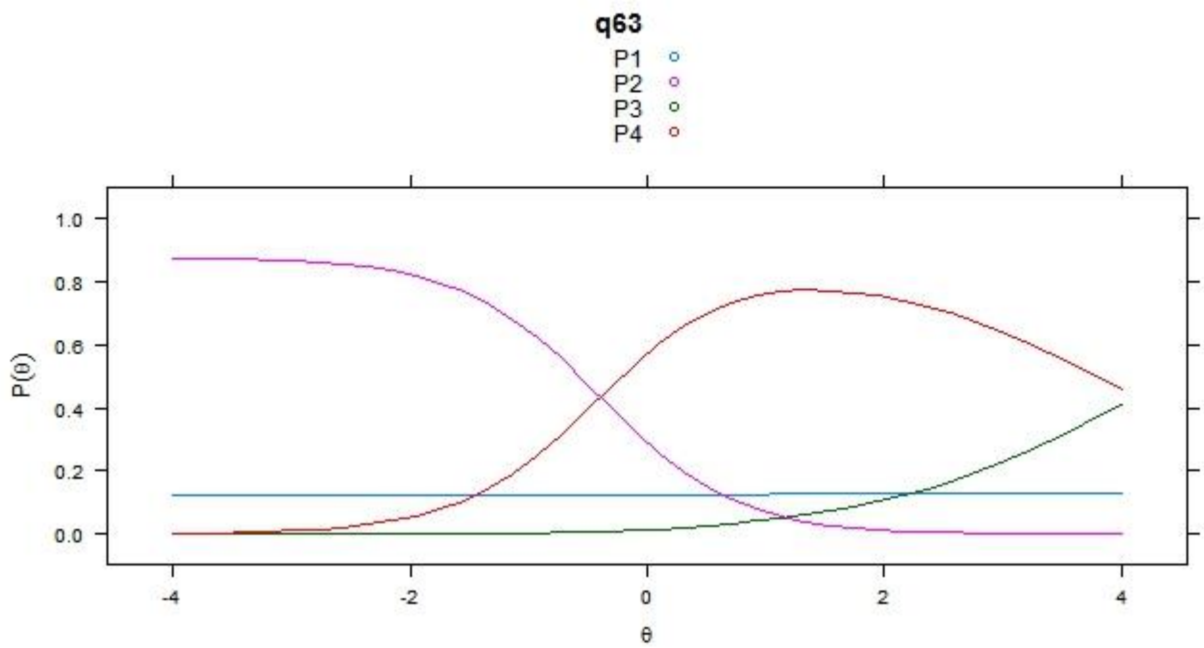

Figure 4.10. Item response curve for Question 63 on the E1G exam for the AF group. The correct answer is P1.

The top misconceptions on the E2Y exam for TC group are displayed in Table 4.8 and for the AF group in Table 4.9. In this case the evaluation of the topic of Laboratory was conducted due to the nature of the subtopic (significant figures) being also very relevant to the lecture part of the course.

Table 4.8

The Top Misconceptions on the E2Y Exam for the TC Group

Question	Topic	Subtopic
61	Molecular structure	Valence bond theory
40	Energetics	Enthalpy concept
6	Laboratory	Significant figures
9	Molecular structure	Naming
3	Descriptive chemistry	Properties of elements
21	Stoichiometry	Stoichiometry calculation

Table 4.9

The Top Misconceptions on the E2Y Exam for the AF Group

Question	Topic	Subtopic
6	Laboratory	Significant figures
3	Descriptive chemistry	Properties of elements
9	Molecular structure	Naming
40	Energetics	Enthalpy concept
54	Descriptive chemistry	Periodic trends

As for the E1G exam, four of the top misconceptions for the two groups are the same. For the E2Y exam, four out of the top misconceptions appear to persist regardless of curriculum approach. The item response curves for the top misconceptions held by both curriculum groups are in Figures 4.11-4.16. As previously mentioned, the topic of laboratory was excluded from IRT analysis due to the small sample size of items associated with this topic but Question 6 was evaluated due to the nature of the subtopic being relevant to standard lecture information from both approaches.

The item response curves for Question 3 for both groups are in Figures 4.11 and 4.12. The probability of choosing the correct answer, P1, is increasing as student ability increases for both groups. However, for low-middle ability students, the probability of choosing a distractor is higher than that of the correct answer for both groups.

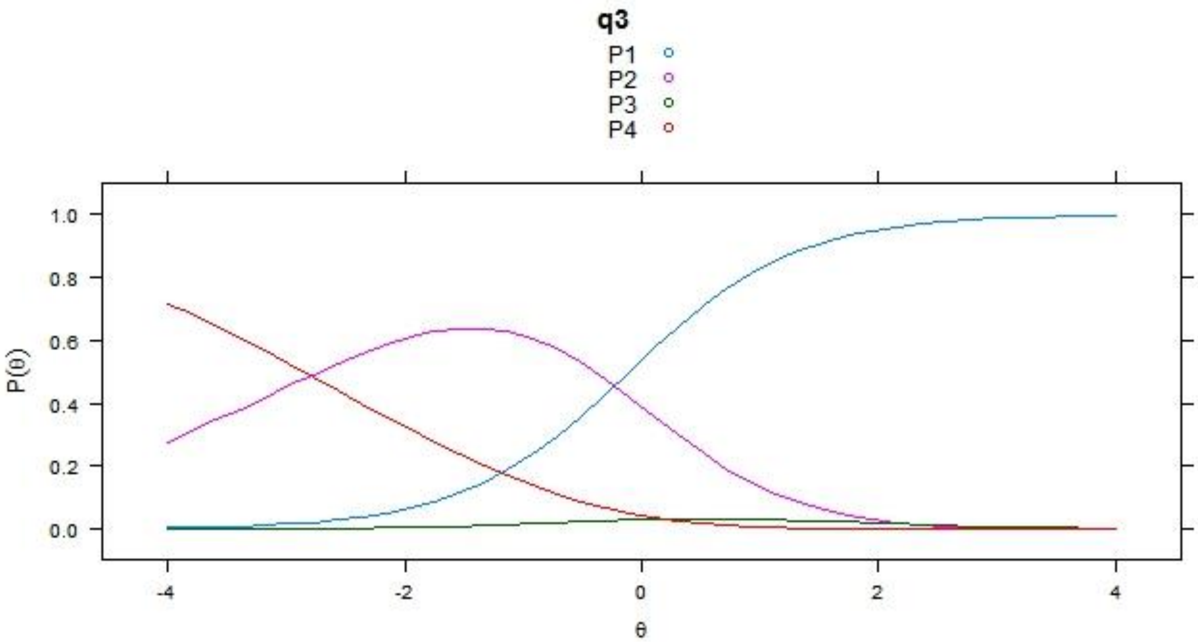

Figure 4.11. Item response curve for Question 3 on the E2Y exam for the TC group. The correct answer is P1.

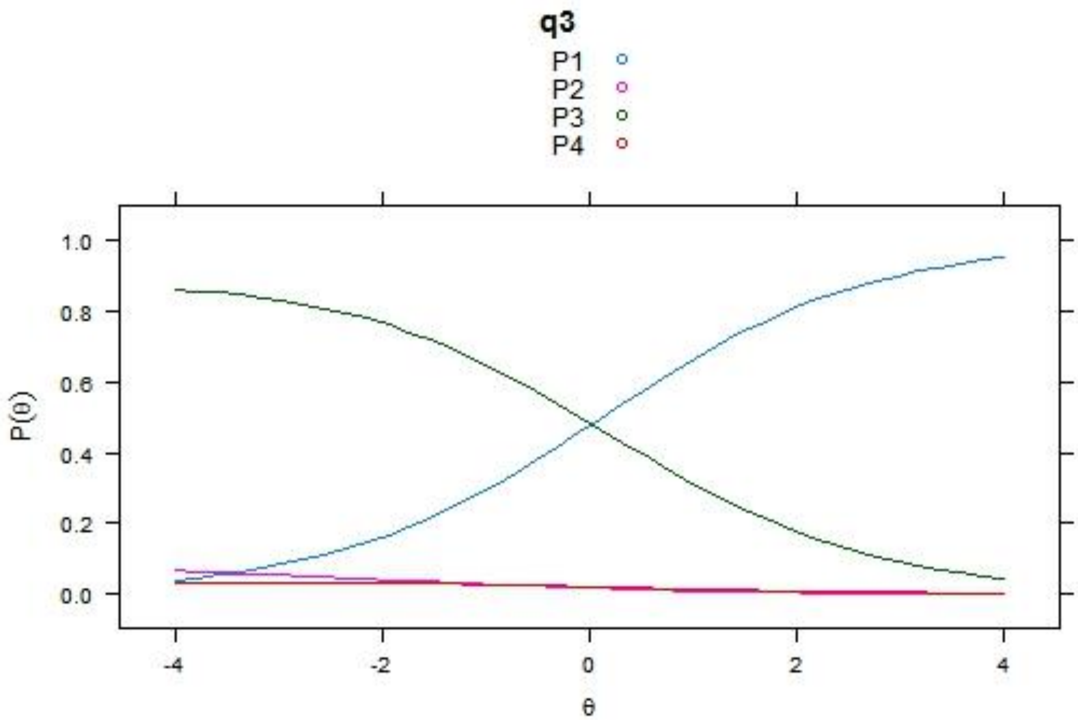

Figure 4.12. Item response curve for Question 3 on the E2Y exam for the AF group. The correct answer is P1.

The item response curves for Question 9 are in Figures 4.13 and 4.14 for the TC and AF groups, respectively. As in Question 3, the higher ability students for both groups have a higher probability of choosing the correct answer, q1, while low-middle ability students are choosing distracters at higher possibilities. TC students are choosing from all three distractors while AF students are mainly choosing distracters P2 and P4.

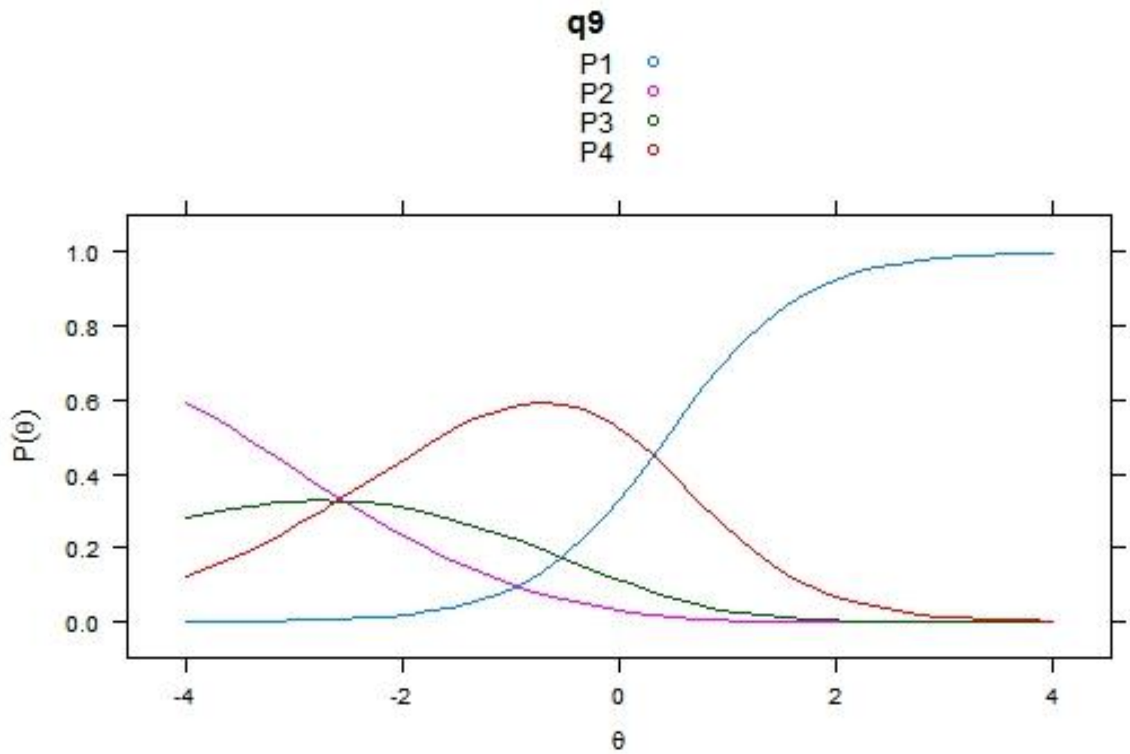

Figure 4.13. Item response curve for Question 9 on the E2Y exam for the TC group. The correct answer is P1.

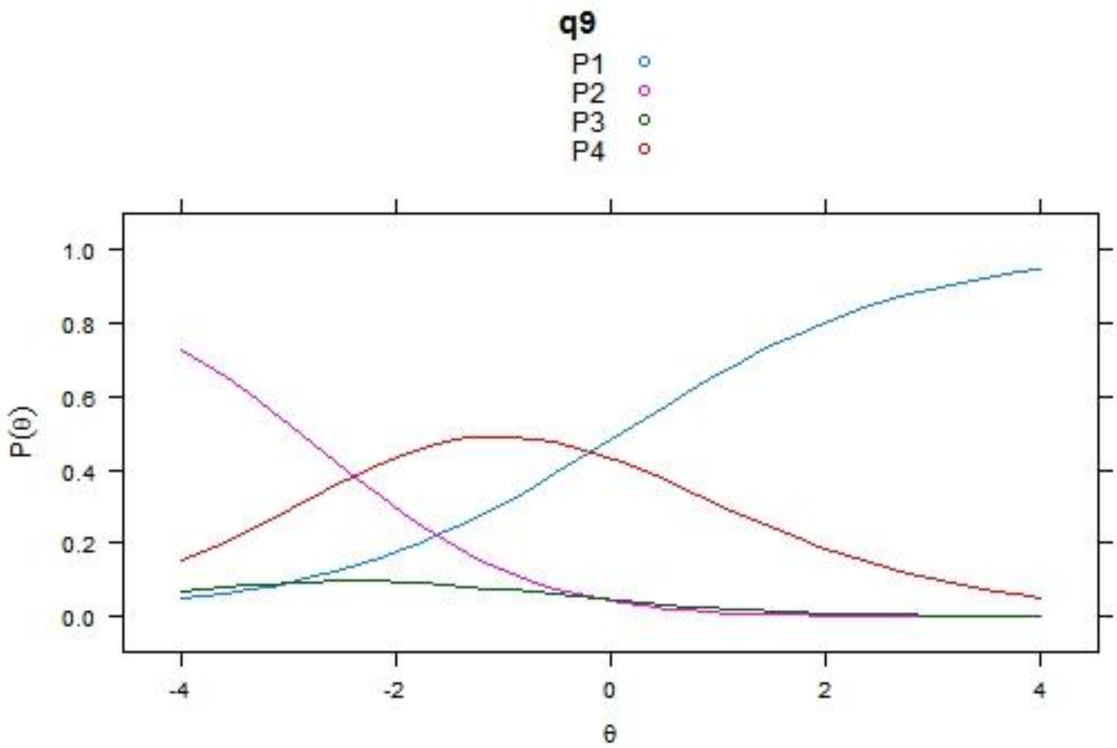

Figure 4.14. Item response curve for Question 9 on the E2Y exam for the AF group. The correct answer is P1.

Item response curves for Question 40 Figures 4.15 and 4.16 for the TC and AF groups, respectively. Both groups show low probability of answering the correct answer, P1, across all student abilities. Both groups appear to be choosing distractor category P3 at higher probabilities.

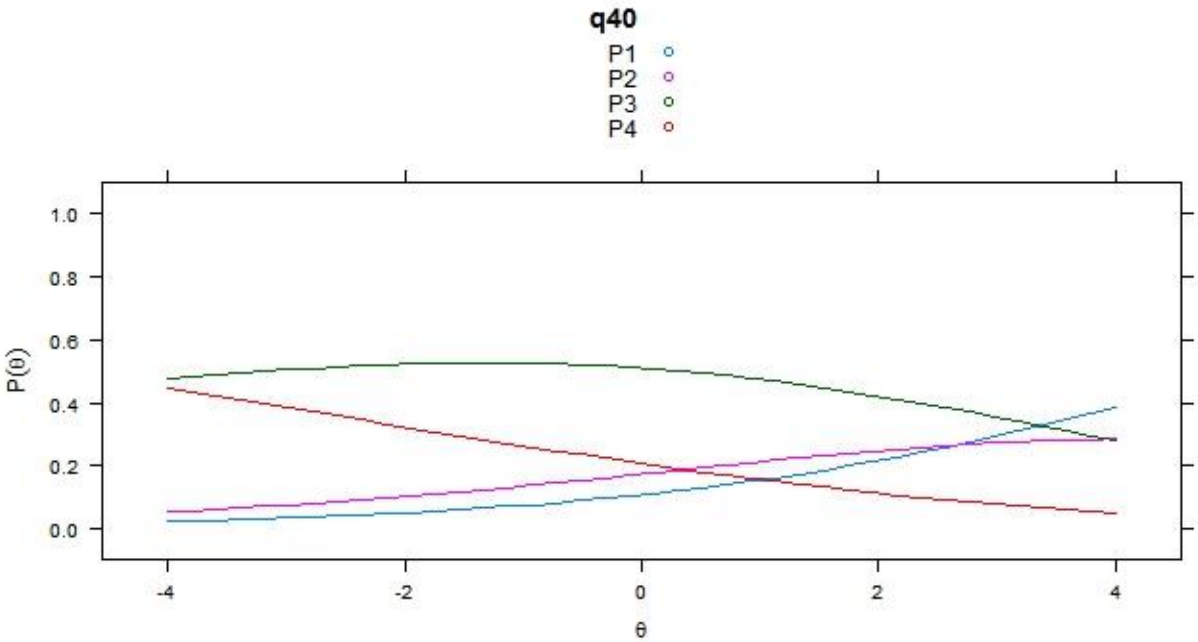

Figure 4.15. Item response curve for Question 40 on the E2Y exam for the TC group. The correct answer is P1.

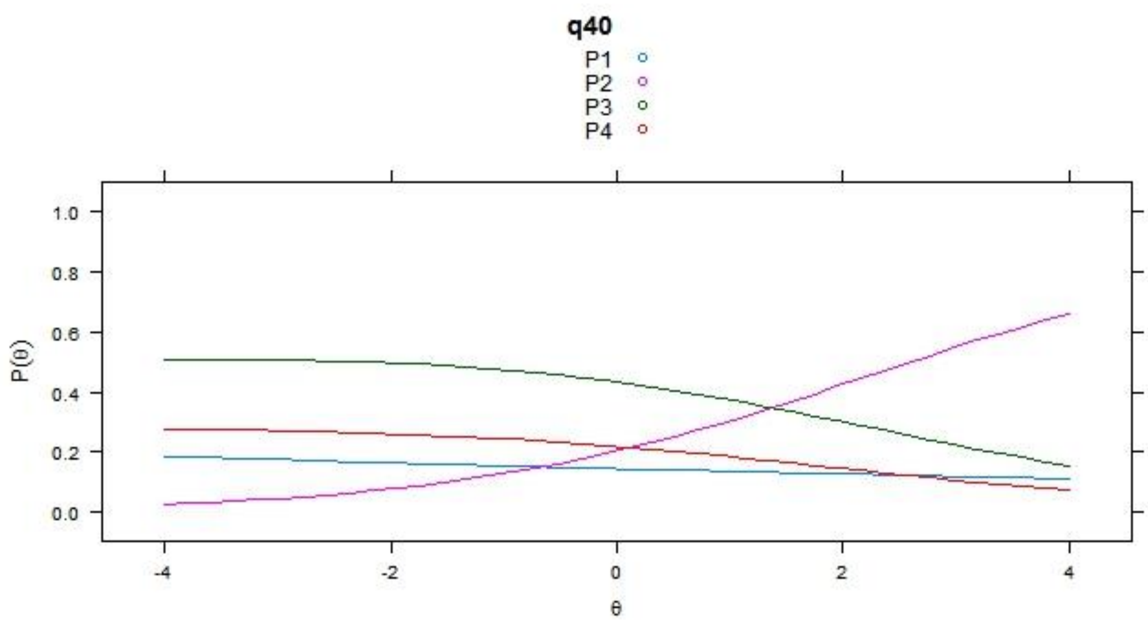

Figure 4.16. Item response curve for Question 40 on the E2Y exam for the AF group. The correct answer is P1.

Although Question 6 was included in the misconception study due to the subtopic of significant figures being taught in lecture, an item response curve could not be generated.

4.5 Summary

This study showed that students taught under the atoms first approach performed better at a statistically significant level on the yellow exam 2 version of the ACS exam than students taught under the traditional curriculum. The AF students are performing better at a statistically significant level than the TC students on the topics of descriptive chemistry and periodicity, molecular structure, and stoichiometry. Although they are performing better on the aforementioned topics, those same subtopics appear as misconceptions for both curriculum groups (e.g., significant figures, properties of elements, naming, electron configuration, enthalpy, physical properties of solutions, and gas laws). For each exam version, four out of the top misconceptions for both groups are the same. A discussion of these findings and recommendations for future studies follows in chapter 5.

CHAPTER 5

DISCUSSION

The goal of this study was to investigate if one curriculum approach is more effective in increasing student success than the other on the ACS exam deemed appropriate for first-semester general chemistry and to determine the chemistry misconceptions held by students taught under both curricula. This chapter contains a discussion of the results for each research question posed in this study including recommendations for future study.

5.1 Research Question 1 Discussion of Results

Research Question 1 of this study is: What level of achievement on the ACS final exam is obtained by students who studied under the atoms first or traditional curriculum approach? Both of the curriculum approaches followed the national trend of having a higher mean on exam 1 than exam 2. There was no statistically significant difference between the two groups on exam 1 but there was a statistically significant difference on the exam 2. The AF group performed better on exam 2 than the TC group.

Research Question 2 showed statistically significant differences on the topics of molecular structure and stoichiometry. The means on the factor scores showed that the AF students performed better on both of those topics than the TC students. There are more stoichiometry questions on the exam 2 than on the exam 1, so this could be a possible reason why the AF mean is significantly higher on the exam 2 than the TC mean. The smaller sample size of the TC group could also be contributing to the observed differences. Another possible reason could be due to when stoichiometry is taught during both of the curriculum sequences. Under the traditional curriculum stoichiometry is taught early in the chemistry sequence, typically chapters 3 or 4 (Brown, LeMay, Bursten, & Burdge, 2003; McMurray & Fay, 2004; Moore, Stanitski, & Jurs., 2006; Petrucci & Harwood, 1997; Silberberg, 2010; Zumdahl & Zumdahl, 2003). Under the atoms first curriculum stoichiometry comes much later in the sequence, as early as chapter 6 and as late as chapter 9 (Burdge & Overby, 2012; Gilbert, Kirss, Foster, & Davies, 2014; McMurry & Fay, 2010; Tro, 2015; Zumdahl & Zumdahl, 2012). The AF students may be able to recall stoichiometry better than the TC students because the topic was presented to them closer to the final exam and therefore they had less time for knowledge decay (forgetting what has been learned).

5.2 Research Question 2 Discussion of Results

Research Question 2 of this study is: What are the statistical differences at an alpha level of 0.05 in student performance by topic on the ACS exam between students taught by the traditional curriculum and students taught by the atoms first curriculum? On the E1B exam the two curriculum groups had an effect size of 0.48 on the topic of descriptive chemistry and periodicity. The ICC plots in Figure 5.1 depict how each exam question under the descriptive chemistry and periodicity topic tested under the two curriculum groups.

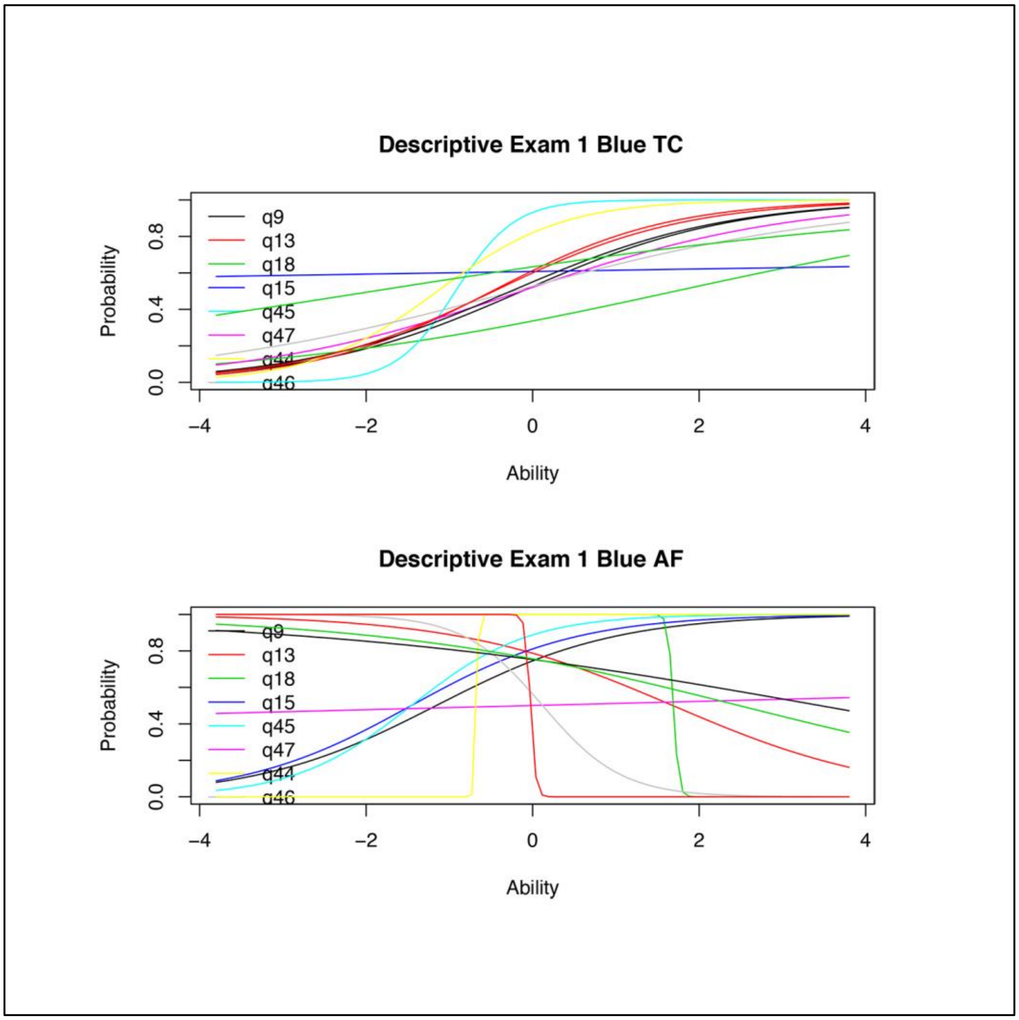

Figure 5.1. Comparison of the TC and AF ICC plots for the descriptive chemistry and periodicity blue exam 1 questions. (The legend to identify each question is on the far left inside the plot.)

The plots show that several of the questions have a very high probability, greater than 0.7, of being answered correctly for low-medium abilities for the AF group. The topic of descriptive chemistry and periodicity is early in the AF sequence and late in the TC sequence but knowledge decay does not seem to be affecting the AF students on this topic as it did the TC students on the topic of stoichiometry.

The same topic showed a statistically significant difference between groups, with the AF group performing better, on the E1G exam as well. This makes sense since the exams have the same questions just presented in a different order. The ICC plots in Figure 5.2 depicts how each exam (E1G) question under the descriptive chemistry and periodicity topic tested under the two curriculum groups.

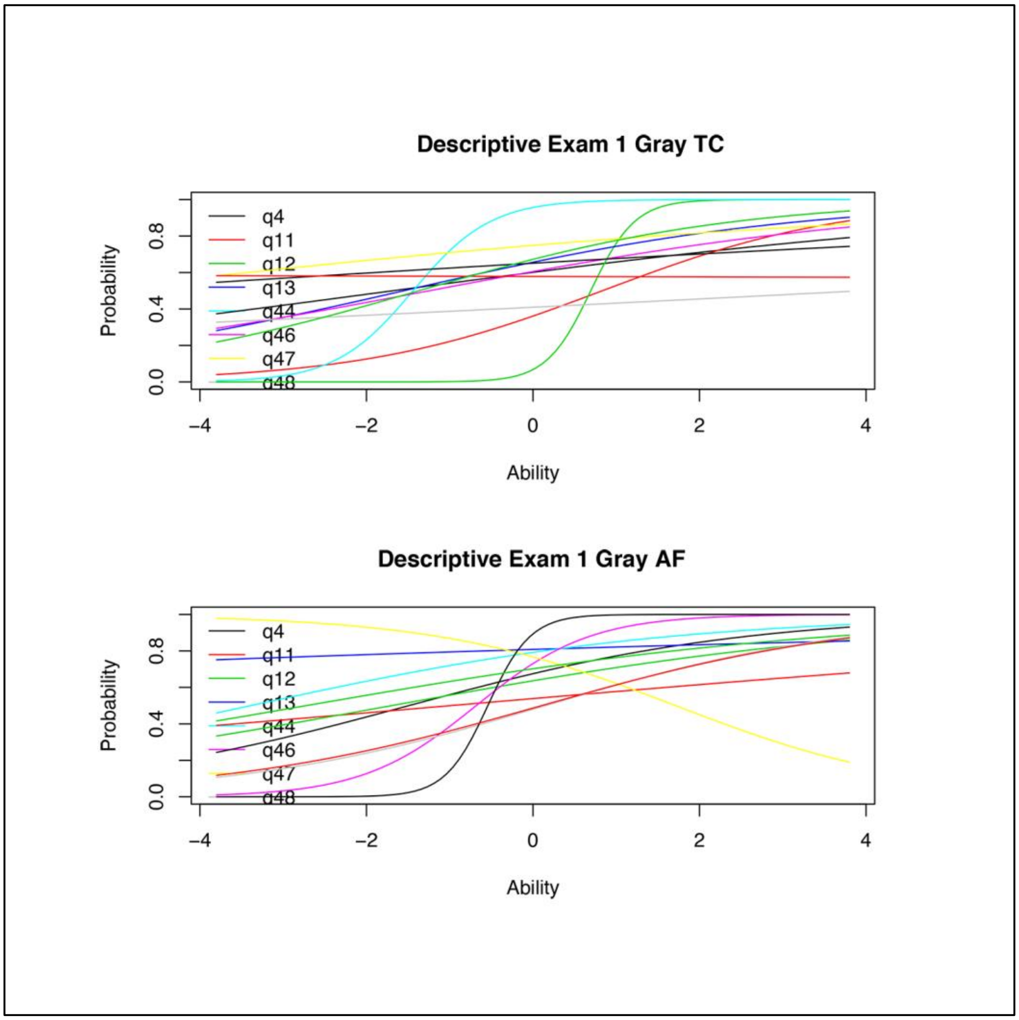

Figure 5.2. Comparison of the TC and AF ICC plots for the descriptive chemistry and periodicity gray exam 1 questions. (The legend to identify each question is on the far left inside the plot.)

The ICC plots in Figure 5.3 depict how each exam (E2Y) question under the molecular structure topic tested under the two curriculum groups. The TC group does not show very much discrimination across student ability and could be the reason why the AF group had a higher factor score mean for this topic. Research Question 3 showed that for the TC group, two of the top five misconceptions were on the topic of molecular structure for this exam version. Meanwhile, the AF group only had one of the top five misconceptions related to the topic of molecular structure.

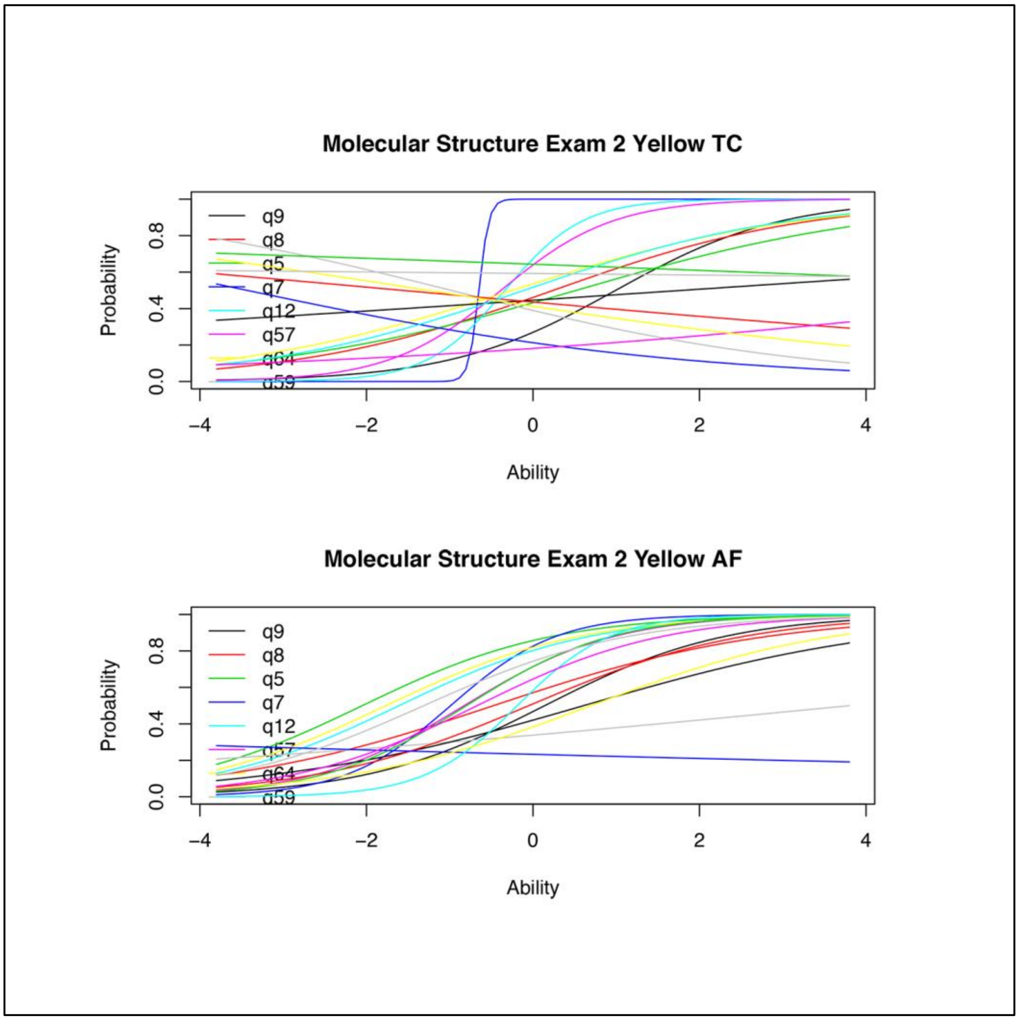

Figure 5.3. Comparison of the TC and AF ICC plots for the molecular structure yellow exam 2 questions. (The legend to identify each question is on the far left inside the plot.)

Molecular structure is near the beginning of the AF sequence and almost last in the TC sequence. Often times, material near the end of the semester is rushed through due to time constraints. This could be a contributing factor to the difference in performance between the two groups. Another possible reason could be that for the AF students, more meaningful connections were made due to the order that the topics were presented in, which led to better recall of molecular structure knowledge.

The ICC curves in Figure 5.4 depict how each exam (E2Y) question for the topic of stoichiometry tested under the two curriculum groups.

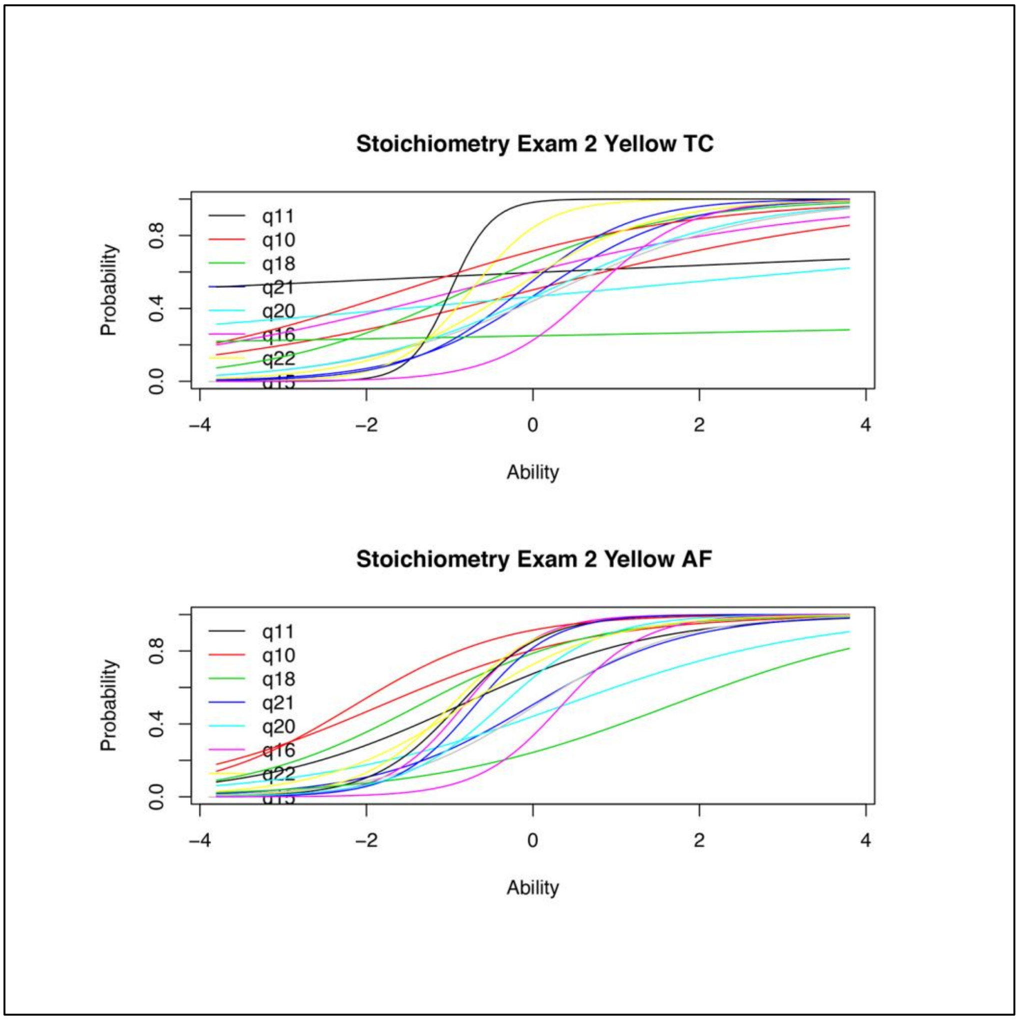

Figure 5.4. Comparison of the TC and AF ICC plots for the topic of stoichiometry on the E2Y ACS exam. (The legend to identify each question is on the far left inside the plot.)

As previously discussed in section 5.1, stoichiometry is near the end of the AF sequence and the beginning in the TC sequence. The better performance by the AF group could be due to less knowledge decay of the material or as with the topic molecular structure if could be the effect of topic sequence. ICC curves for the other topics are in Appendix C.

5.3 Research Question 3 Discussion of Results

Research Question 3 (Q_3) of this study is: What are the content misconceptions held by students taught under traditional curriculum and atoms first approaches for questions with prevalent incorrect responses having a *z*-score above the z_{crit} of 1.96? This part of the study used the *z*-scores of the most chosen incorrect answer choice to determine which questions could be considered misconceptions. Incorrect answer choices with a *z*-score higher than the z_{crit} (1.96) were considered misconceptions. The students from both curriculum approaches hold several of the same misconceptions. Bond polarity (Furio & Calatayud, 1996; George & Mason, 2011) and significant figures, nomenclature, and gas laws (George & Mason, 2011) are some misconceptions that also appear in previous research. While the two curriculum approaches seem to have an effect on overall student performance on the ACS exam, they do not seem to have an effect on student misconceptions. These results go along with Bodner's (1991) conclusion that misconceptions are persistent and resistant to instruction. The results also add validity to the ULM, supporting that prior knowledge is one of the most important attributes that students bring with them to the next course.

5.4 Conclusions

The current push for curriculum reform in chemistry has led to the publishing of several new books using the AF approach. This study set out to determine if one curriculum approach is more effective in increasing student success than the other on the ACS exam. The results from this study show that atoms first *may* be a better alternative to the traditional chemistry curriculum. The AF students performed better on both (statistically significantly better) versions of the ACS exams. The AF students are performing better at a statistically significant level than the TC students on the topics of descriptive chemistry and periodicity, molecular structure, and stoichiometry. The AF approach does appear to be helping students retain chemistry knowledge better than the TC approach. In this study, as well as in the previously discussed study conducted by Lorch and Lorch (1985), the coherence of the students' topic structure representations was important to the recall of the knowledge associated with those representations. This is an important finding that can lead to better preparation of students, through the use of the AF approach, so that they can be more successful in their chemistry careers.

5.5 Recommendations for Future Study

The amount of information obtained from the FA and IRT analyses of these data was vast but further study with a more diverse population from different locations is required to substantiate the findings of this study. The FA provided important information on how the items in each category are correlated and groups of subtopics could be seen from correlation plots used to determine the number of factors in each topic group. Further study by subtopic would give more information on how the students are performing on each topic. There might be a particular subtopic that is causing the differences in the groups.

The IRT analysis provided a wealth of information about each individual item on the exam. The ICC curves for each item, rather than a group of items, can be more closely examined for group differences. The distractor curves also need to be more closely examined. Knowing what incorrect answers our students think are correct can help us as educators better prepare our students.

The misconceptions need to be more closely examined. These same misconceptions have been held by students for many years and may stem from prior academic exposure. Curriculum change is not changing these misconceptions so a study into what other factors may be contributing to these misconceptions is needed.

This study should be extended to a larger sample group to see if the findings still hold. A comparison of student success on the ACS exam to student success in the course would also be beneficial. Due to the use of archival de-identified data it was not possible in this study.

APPENDIX A

EXAMPLE ACS EXAM MATRIX

	Number of Questions		
Topic I Atomic & Nuclear Structure	Level 1 Understanding	Level 2 Analysis	Level 3 Generalization
1. Experimental Basis/History	1	1	
2. Atomic Symbols/Isotopes	2	2	
3. Atomic Mass	2	2	
4. Atomic Spectra/Bohr Theory	2	2	1
5. Quantum Theory	3	1	1
6. Orbital Shapes and Energies	3	1	1
7. Electron Configurations	2	2	1
8. Nuclear Reactions/Balancing/Types	2	1	
9. Nuclear Stability/Decay	2	2	
10. Mass-energy Relations	1	1	
Total	20	15	5

	Number of Questions		
Topic II Molecular Structure	Level 1 Understanding	Level 2 Analysis	Level 3 Generalization
1. Nomenclature	2	2	
2. Lewis Structures	3	2	
3. Molecular Geometry/VSEPR	3	2	
4. Ionic Bonding/Structures	2	2	1
5. Covalent Bonding/Hybrid Orbitals	2	3	1
6. Electronegativity/Polarity of Bonds and Molecules	2	3	1
7. Bond Order/Strength	2	1	1
Total	16	15	5

	Number of Questions		
Topic III Stoichiometry	Level 1 Understanding	Level 2 Analysis	Level 3 Generalization
1. Mole Concept	2	1	1
2. Mass/Mole/Formula Unit	2	2	
3. Empirical/Molecular Formula	2	1	1
4. Balancing Equations (not redox)	2	2	
5. Net Ionic Equations	2	2	
6. Limiting/Excess Reagent	2	1	1
7. Theoretical/Percent Yield	2	1	1
8. Solution Stoichiometry/Titration	2	1	1
9. Stoichiometry and Enthalpy	2	2	
10. Stoichiometry and Gases	2	2	
Total	20	15	5

APPENDIX B

IRB APPROVAL NOTICES

From: Harmon, Jordan [Jordan.Harmon@unt.edu]
Sent: Tuesday, September 11, 2012 2:36 PM
To: Diana Mason (dmason@unt.edu) (dmason@unt.edu)
Subject: IRB 12-434 "Analysis of ACS Examination..."

Dr. Mason,

The UNT Institutional Review Board has jurisdiction to review proposed "research" with "human subjects" as those terms are defined in the federal IRB regulations. The phrase "human subjects" is defined as "a living individual about whom an investigator (whether professional or student) conducting research obtains (1) Data through intervention or interaction with the individual, or (2) Identifiable private information.

Since the data you will be obtaining from Collin College has been totally de-identified, then your use of that data falls outside the scope of the "human subjects" definition and UNT IRB review and approval is not required.

We appreciate your efforts, however, to comply with the federal regulations and sincerely thank you for your IRB application submission!

Jordan Harmon
Research Compliance Analyst
Office of Research Integrity and Compliance
Hurley Administration Building 185A
University of North Texas
P: 940-565-4258 F: 940-565-4277
Jordan.Harmon@unt.edu

6/7/2014 4:29 AM

Institutional Review Board

Collin College

January 28, 2013

To : Cathy Molina
Re : Notice of Collin College IRB
Study Title : *Analysis of ACS Examination Questions Collected by Topic Following the Use of the Atom's First Approach Curriculum*
Category : Exempt
Study # : 2013-03

Dear Cathy:

This letter and attached form is to inform you that the Collin College IRB has reviewed the project "*Analysis of ACS Examination Questions Collected by Topic Following the Use of the Atom's First Approach Curriculum*". It has been determined that the risk involved in this project is no more than minimal. In accordance with 45 CFR Section 46.101(b)(1,2), this study represents a minimal risk, and all efforts are put into place such that data cannot be identified to any particular human subject. Furthermore, being a graduate student at UNT, this project already received IRB approval (exempt status) from UNT. This IRB concurs and this project is therefore exempt from further review. We thank you for complying with the requested documentation and wish you good luck in your project. Please be advised that any changes in protocol need to be communicated with the IRB and that this approval is valid until two (2) years from this date. If this project is to continue, a renewal must be requested from the IRB.

Sincerely

Chris Doumen

Dr. Chris Doumen
Collin College IRB Chair
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