ABSTRACT

A CHANGE IN STRUCTURE:
MEANINGFUL LEARNING AND COGNITIVE DEVELOPMENT
IN A SPIRAL ORGANIC CHEMISTRY CURRICULUM

by Nathaniel P. Grove

Many students have described organic chemistry as a “killer course” – its purpose to prevent only but the most worthy students from continuing to professional school. To decrease high attrition rates and update course content, the Department of Chemistry and Biochemistry at Miami University developed and implemented an innovative, spiral curriculum for use in the year-long organic chemistry course for pre-professional students. This dissertation sought to better understand the difficulties students encountered in this spiral, organic chemistry curriculum and explored the strategies students developed to address such problems. A qualitative, case-study approach using interviews and reflective essays documented the experiences of 18 students as they progressed through the updated curriculum. The results of this inquiry revealed that many students made the decision not to utilize meaningful learning techniques and instead used rote memorization techniques as a proxy for learning. The factors that influenced these decisions were complex, but included such concerns as time-management problems, the perceived lack of relevance of organic chemistry, and decreased motivation. Furthermore, this inquiry discovered a dramatic gap between the level of cognitive development most students brought to the organic chemistry classroom and the level the subject required them to utilize.
A CHANGE IN STRUCTURE:
MEANINGFUL LEARNING AND COGNITIVE DEVELOPMENT
IN A SPIRAL ORGANIC CHEMISTRY CURRICULUM

A DISSERTATION

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by

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DEDICATION

This dedication is split in two. First, to the role models and the unconditional supporters; to those who taught me the value of hard work and the meaning of dedication. Secondly, to the architect and inspiration; to the person who continually challenged my conception of the world and settled for nothing but my best. This work is dually dedicated to my parents, Colleen and James, and to my research advisor, Dr. Stacey Lowery Bretz.
Introduction

A recent report from the National Research Council\(^1\) examining the global competitiveness of the United States’ chemical research programs stated:

Organic chemistry deals with all aspects of the chemistry of carbon compounds. Since carbon compounds, including fats, sugars, proteins, and nucleic acids, are the building blocks of all living organisms, there is a strong linkage between organic chemistry and the chemistry of the life processes. Organic chemists design and synthesize drugs to improve human health, agricultural chemicals to safeguard the food supply, commodity chemicals for use as personal care products, and polymers for use as structural materials or fibers for clothing. Organic chemists design processes to convert petroleum, coal, and biomass to fuels for transportation and a myriad of materials that enhance our daily lives (pp. 60-61).

Such a description rightfully gives the impression that modern organic chemistry is a rich, vibrant, and diverse field situated at the very heart of the global economy. However, for students pursuing degrees in science or pre-professional fields, organic chemistry is often not the vibrant discipline described in the NRC report, but rather, a course with a difficult reputation. As students struggle, the myth that organic chemistry is an impossible, unforgiving subject is regrettably passed on to the next generation of students. Much of organic chemistry’s relevance and vitality are stripped away during its transition from the real world to the typical sophomore course.

For many students pursuing degrees in the science or medical fields, organic chemistry is a course approached with dread. Over the years, this course, perhaps more than any other, has garnered a reputation for being the gatekeeper – the portal through which only the most worthy students may pass. In the Department of Chemistry and Biochemistry at Miami University, attrition rates in CHM 241/242, the year-long organic chemistry sequence most frequently taken by students planning on attending
professional school, can range from 30-50%. Unfortunately, this high attrition rate is not uncommon at other colleges and universities across the country.

Purpose of the Study and Research Questions

In the Fall of 2006, the Department of Chemistry and Biochemistry at Miami University instituted a curricular change (described more fully in Chapter 2) in CHM 241/242 to address the following problems:

1. As referenced above, the attrition rates in the year-long, organic course sequence are high, typically ranging from 30-50%.

2. Most students who drop before completing the second semester course in the year-long sequence ultimately decide to change their majors as well. Often, these students do not decide to leave science altogether, but rather choose to pursue careers in dietetics or exercise science. Both of these majors also have an organic chemistry requirement; however, the requirement is for a one-semester, survey course. While the survey course ensures breadth of exposure to topics, students who change majors must now enroll in the one semester survey and repeat material already covered in the dropped two semester sequence.

3. Because the content of the courses had not been substantially updated for several years, some faculty believed that students were not learning up-to-date, synthetically relevant reactions. For example, the past two decades have witnessed an explosion in the use of transition metal catalysts, particularly for use in carbon-carbon bond formation reactions. Inexplicably, most textbooks have been slow to incorporate these advances. As such, many students are left
with the erroneous belief that organic chemistry is a stagnant body of knowledge instead of the dynamic subject it truly is.

The study reported herein is an attempt to describe the experiences of, and to document the challenges faced by, 18 students as they progressed through a CHM 241/242 course sequence restructured to address these challenges. This study has been guided by the following research questions:

1. What are the biggest problems students have in understanding organic chemistry?
2. How do these perceptions change as students progress through the revised organic chemistry curriculum?
3. What strategies do students employ to address the problems that they face in learning organic chemistry?

**Boundary Conditions**

It was not the purpose of this inquiry to compare the experiences of students in the spiral curriculum to those in a more traditional organic chemistry course sequence. Instead, as outlined above, and expanded upon in subsequent chapters of this document, this research inquiry was an attempt to better understand the difficulties students encountered in understanding organic chemistry and the strategies they developed to address those difficulties. Although the answers to such questions will not in and of themselves solve the myriad problems that students face in their learning of organic chemistry, they will hopefully provide both teachers and learners of the subject with common ground upon which solutions can be mutually developed and refined.
Introduction

This chapter reviews the relevant literature as it pertains to how students learn organic chemistry and highlights previous attempts to better understand the difficulties students have in the process of doing so. In addition, the theoretical frameworks that underlie this inquiry are outlined.

Constructivism and Meaningful Learning

How do humans learn? This has been a question of interest for millennia and is of fundamental importance to those who deal in the commodity of knowledge. Until recently, many educators believed that learning was a passive process and subscribed to the Aristotelian notion expounded by the English philosopher John Locke that the learner is nothing more than a “tabula rasa”, or “clean slate”, upon which the teacher can impress new information.4 Such a simplistic model does not adequately explain the difficulties that students frequently experience in the educational environment, and indeed, ignores the central role of the learner in the learning process. In recent decades, more student-active models of learning have emerged – the most prevalent of which is constructivism.

According to constructivist theory, knowledge is an active construct of the individual learner.5 For this construction process to be meaningful, it necessitates three key components as pictured in the concept map in Figure 1.6–8 Students must first possess relevant prior knowledge with which to situate and anchor the new knowledge to be learned. Secondly, this knowledge in and of itself must be perceived by the student as “relevant to other knowledge and must contain significant concepts and propositions”.8 Finally, the learner must choose to learn meaningfully. That is, the learner must “consciously and deliberately choose to relate new knowledge to knowledge the learner already knows in some nontrivial way”.8 In cases where one or more of these conditions have not been met, students may feel compelled to utilize rote
learning techniques, i.e., the new knowledge is not connected in any substantive manner to the pre-existing cognitive structure, but is simply memorized, and more likely than not, quickly forgotten. Novak has suggested that new knowledge must also possess elements of the cognitive, affective, and psychomotor domains – in other words, elements of thinking, feeling, and doing. Although the constructivist theory of learning is useful in elucidating the requirements for meaningful learning experiences, it does not address the more fundamental questions that pertain to how knowledge is perceived nor how it eventually is incorporated into the learner’s existing cognitive structure.

Figure 1. Concept map detailing requirements for meaningful learning.

While many of these processes remain unknown, cognitive neuroscience has been useful in creating a model to explain how the mind processes information. The Information Processing Model begins with the perception of external stimuli from the
environment (see Figure 2). Initially collected by the senses, the brain is bombarded by immense amounts of information every second of every day. This information is sent to the thalamus which within a few milliseconds uses the learner’s previous experiences as a guide to determine the relative importance of each sensory impulse, all within just a few milliseconds. In essence, this “perception filter” as it is referred to in the diagram in Figure 2, acts as a set of window blinds, filtering out stimuli deemed unimportant. For information that is deemed worthy of perception, it passes into short term memory which is generally described as having two phases: immediate memory and working memory. Perceived information first moves into immediate memory, housed in the sensory processing areas of the cortex. Again, the individual’s prior experiences are used to assess the importance of this sensory information, and based on that assessment, the information is either dropped out of the system or passed into the working memory.

![Information Processing Model](image)

**Figure 2.** Information Processing Model (modified from reference 9)

While information is in working memory, it begins to be perceived by the conscious mind and the storage process can begin as the new information interacts with pre-existing knowledge retrieved from the long term memory; however, even at this

8
point, the decision must be made whether the new knowledge should be encoded for future recall or removed from the system. Again, the brain turns to prior knowledge to help make this decision as the learner considers whether the new knowledge makes sense and whether it has meaning. In other words, is there a sufficient pre-existing knowledge base within which to situate and anchor the new knowledge and is the new knowledge perceived to be meaningful to the learner? These very concerns also sit at the heart of meaningful learning as Ausubel and Novak described it some 40 years ago.5-8

Such concerns are of vital importance to educators of organic chemistry given the central role the subject occupies in the chemistry curriculum. After finishing organic chemistry, many students continue on to take biochemistry. While a distinct discipline with a long and storied past, many fundamental biochemical principles have their roots in concepts first presented in organic chemistry. Without a meaningful understanding of organic chemistry, such concepts may not be available for future use when required.

**Intellectual and Ethical Development**

For many students, the college years are a time associated with intense periods of intellectual and ethical development that can forever change the learner’s perception of knowledge and the view of the world around them. It was with the intent of better understanding these changes that William Perry began his study of students at Harvard and Radcliffe in the 1950’s and 1960’s.11 The Perry Scheme of Intellectual and Ethical Development, as pictured in Figure 3,12 emerged from this work.
Figure 3. The Perry Scheme of Intellectual and Ethical Development.12

As can be seen in the depiction of the Perry Scheme in Figure 3, students can be categorized into one of nine positions based upon their conception of knowledge. These nine positions can be further grouped into four broader categories: dualism, multiplism, relativism, and commitment in relativism. To illustrate the differences among these levels, consider the following scenario of three different students studying for an exam in general chemistry12:

A chemistry teacher has just finished a unit on bonding in her General Chemistry course. The lectures have included an introduction to Valence Bond Theory, Molecular Orbital Theory, and the advantages/disadvantages in using each. While studying for the exam, three students are discussing this portion of their notes.

Student 1: “The teacher usually seems to know what she is talking about but I am still a bit confused about this Valence Bond and MO Theory stuff. Why didn’t she just tell us which one is the right one to use?”

Student 2: “I also was a bit confused by that part. Although it looks like both theories work, she seemed to talk more about the Valence Bond approach so that is the one I am going to use on the exam.”

Student 3: “I thought that was a great lecture! It is so interesting to see how scientists can have two competing theories for the same
thing and how one theory seems to better explain certain aspects of a model. It all depends on what you are trying to explain.”

Looking at the students’ descriptions of the lectures on valence bond theory and molecular orbital theory, one would almost believe that these students attended different lectures or had been taught by different professors, and yet, this was certainly not the case. In considering the response from student 1, it is important to note that he is desperately trying to figure out which approach is the correct one to use. According to William Perry, student 1 would be categorized as a dualistic learner because of his inability to see beyond the artificial dichotomy he believes exists in the world around him. Student 2 would be categorized as a multiplistic learner as she recognizes that “both theories work.” Multiplistic thinkers recognize that multiple perspectives can, and do, exist but ultimately believe that all perspectives are equally viable. In this example, student 2 settles on the use of valence bond theory, but only because she believes the teacher talked about it more than the other.

Finally, student 3 recognizes that whether to use either valence bond theory or molecular orbital theory depends upon the situation. Indeed, it is this view that the professor was trying to advocate, and more likely than not, was assuming that the students would take away from the lecture. In terms of the Perry Scheme, student 3 would be described as a relativistic learner. Although there is an additional – and higher level – position on the Perry Scheme, it is most frequently associated with ethical development and is not usually of immediate concern to students enrolled in introductory chemistry courses.

Cast in the light of the scenario above, it is easy to see why a teacher’s knowledge of a students’ level of intellectual development is so important. When planning the content of a course, it is important that activities challenge the students to grow and to mature in their understanding of the nature of chemistry knowledge; however, care
must be taken not to challenge the students so much as for the activity to seem impossible. This fine line separating challenge from impossibility is a difficult one for many professors to judge, and therefore, in a subject like organic chemistry that frequently requires the use of more complex cognitive schemes, it is not unlikely that many of the problems students encounter may stem from such discrepancies in cognitive levels.

**Attracting and Retaining Students in the Sciences**

In the mid 1980’s, an alarming trend began to emerge: it was projected that by 2005 there would be a shortfall of as many as 700,000 BS and BA recipients in the science, technology, engineering, and mathematics (STEM) fields. Given the political context of the era – it would still be several years until the fall of the iron curtain – it became imperative to find ways of attracting students to, and retaining more students in, the STEM majors as such shortfalls would dramatically decrease the United State’s ability to compete with the Soviet Union. In order to actively attract more students to the STEM disciplines, Sheila Tobias argued that any long-term solution required looking beyond “the usual suspects” and learning more about the factors that influenced students’ decisions to stay away from the sciences. In particular, she was interested in learning more about those students that she termed as “second-tier” – students who had, she believed, the mental capacities and abilities to succeed in science, but who ultimately decided to pursue career options outside of STEM.

In order to explore such issues, Tobias asked seven, second-tier stand-ins to seriously audit introductory physics and chemistry courses, paying particular attention to inherent characteristics of the courses that might discourage individuals like themselves from choosing careers in those fields. These second-tier stand-ins represented a small but diverse sample of postgraduate students. All seven were successful in their own fields and had avoided taking science courses during college.
Many science professors would predict that such students decide not to take science courses simply because many do not possess the knowledge and skills to do so. Contrary to those beliefs, however, most second-tier students excelled in the introductory science courses they were auditing, many times earning among the highest grades in the course.14

So, if it is not the students’ innate abilities that generally dissuade them from entering scientific fields, what factors do weigh upon those decisions? Although these second-tier students did exceptionally well academically, many found the culture they encountered in the sciences to be foreign. A majority were amazed by the lack of communication between not only the professor and the students, but among the students themselves. They also noted what they perceived to be an almost exclusive focus on problem solving, whereas they craved to know more about the *whys* of science and less of the *hows*. They knew that cutting edge science was being done every day; yet, no mention of it was made in their courses. These sentiments were summarized well by Tom, a professor of classical languages who was auditing a general chemistry course14:

> I would much rather be asked to attend a formal, inspirational lecture once every week or two and spend the rest of my time with a TA or Macintosh [computer] solving sample problems. There would be at least some degree of interaction with a machine. We spend too much time gaining technical knowledge of chemistry, necessary to be sure, but there is formal and even informal information which could be presented to us without numbers and details whereby we might learn what chemistry is doing on the cutting edge, what are its various subfields, and more of its history. (p. 47)

Amazingly, Tom felt that he would receive more attention from a machine than from the professor! In the end, many of the second-tier stand-ins felt that the culture of
science did not value the skills and perspectives that they possessed, and as such, they were convinced that other fields would better appreciate their talents.

Although Tobias’ research provided great insight into the factors that initially dissuade students from entering the sciences, it did not shed much light on the factors that weigh upon students as they determine whether to leave the sciences once they enter. To better understand such influences, Seymour and Hewitt\(^5\) began a project that eventually led them to talk with almost 500 students about “their decisions to enter, continue in, or leave their original [STEM] majors” (p. 24). _Talking About Leaving_ gave voice to many of these talented individuals as they struggled with the decisions that would ultimately determine their career paths, and in so doing, called into question many of the conventional beliefs held by STEM faculty:

Another common assumption encountered among faculty and challenged by our data is that switching involves the discovery of errors in student choices, judgments or self-perceptions, and represents logical action to correct these ... [the] view of students as either 'scientists' or 'not scientists' obscures the loss of many students with the ability to do science - including some who could have done it very well. The nature of the switching process revealed in students' accounts is very different from that imagined by [STEM] faculty. We found the decision to leave [a STEM] major was always the culmination of a dialogue with self and others over time, in which students were drawn back and forth between the options that seemed open to them. Typically, the process began with poor experiences in [STEM] classes in their first year... It was deepened by a series of academic crises and disappointments that provoked anger towards particular faculty, advisors or teaching assistants. Students began to experience self-doubt and lowered confidence in their ability to do science. They became disillusioned with science and the science-based careers to which they had aspired, and questioned whether getting the degree would be worth the effort and distress involved. Only then did they begin to consider a switch to those non-[STEM] classes where they had experienced better teaching and/or more satisfaction with their academic work. (p. 393)
More than anything, the works of Tobias, Seymour, and Hewitt, call into question the commonly held belief among many faculty that students who decide not to enter the STEM fields (or leave prematurely once they do enter) do so because they are not capable of succeeding. On the contrary, the experiences of the students involved in these research studies show a group of students who are intelligent and hard working. Frequently, these students only leave the sciences as a last resort because they believe that the discipline does not value their unique skills and perspectives.

Although the students in organic chemistry cannot be described as belonging to the second-tier, many only take organic chemistry because it is a requirement for their major or for professional school. Without such compulsions, the unfortunate truth is that most would elect not to take organic chemistry. As such, the students involved in the current inquiry have a great deal in common with Tobias’ second-tier stand-ins and may cite similar issues when talking about their experiences in organic chemistry.

Motivation and Learning Chemistry

As stated previously, and depicted in the concept map in Figure 1, one of the key requirements for meaningful learning is for the learner to consciously choose to utilize meaningful learning techniques; however, it is not clear from the information in Figure 1 what factors influence that decision. While the decision is a complex one, the importance of student motivation cannot be ignored.

Traditionally, motivation has been described as either intrinsic (task-oriented) or extrinsic (ego-oriented).\textsuperscript{16-18} In other words, is the student driven to succeed because she is interested in learning the subject for its own sake, or is she driven to succeed for some external reward such as grades or praise from family and friends?\textsuperscript{19} More recent models of motivation\textsuperscript{20} have attempted to convey a broader scope of motivation and the myriad factors that fall under its purview. For the purpose of this inquiry, four factors –
self-efficacy beliefs, task value beliefs, goal orientation, and affect – are particularly significant.

Self-efficacy can be defined as a student’s own assessment of how capable they are at doing something. For example, a student with high self-efficacy in organic chemistry believes that he is highly capable at performing well in the subject. Not surprisingly, students who are more confident in their abilities tend to perform better and more frequently engage in behaviors that promote learning. The second motivational component, task value beliefs, lies at the very core of the notion of meaningful material. In short, task value speaks to the students’ beliefs about the relevance or importance of a course. In other words, do students believe organic chemistry is important because the material will be inherently useful in their future endeavors or is it merely a hurdle to jump over in the process of moving forward in their academic careers?

Goal orientation describes the students’ “purposes when approaching, engaging in, and responding to achievement situations”. It is within this component that the older motivational dichotomy of intrinsic versus extrinsic fits. Are students interested in learning organic chemistry for mastery of underlying concepts or for performance as evidenced by grades or MCAT scores? Although this may seem a trivial question to many, research has shown that these issues are directly related to a student’s open-mindedness, thoughtfulness, and tolerance for ambiguity. Finally, consideration must be given to those issues surrounding affect (a student’s interest in, or anxiety toward, a subject). Previous research has shown that there is a great deal of anxiety generally associated with chemistry as a discipline, so much so, in fact, that researchers have taken to using the word “chemophobia” to describe such fears.
Problems with Learning Organic Chemistry

A 2002 study appearing in the journal *Academic Medicine* reported that 78% of students who decided to drop a pre-medical major cited problems with organic chemistry as a major factor in that choice.27 Because of this unique position that organic chemistry holds for many students, there have been a number of research studies initiated to explore the problems that students face in learning the subject. It is important to note that the vast majority of these studies began as a result of informal observations made by the professor and are typically confined to exploring one problem in-depth – most frequently focusing on issues surrounding organic reactions and synthesis28,29, reaction mechanisms30,31, or visualization.32-35

Organic synthesis has always been an activity that students have struggled with. Not only are students responsible for keeping track of a large number of organic reactions, but they are required to put these reactions together in a way that will rationally lead to the desired product. In a study comparing how students and organic chemists plan synthetic schemes28, Bhattacharyya, Calimsiz, and Bodner noted some stark differences between the two groups.

While professional organic chemists tightly linked the synthetic schemes they wrote on paper to the actual reactions they would perform in the laboratory setting, most students were oblivious to the actual procedures they would perform to carry out the transformations listed on their papers. The students frequently focused so much on individual reactions that they had difficulty connecting the pieces together to form a rational synthetic scheme. When they did find ways of connecting the pieces, they usually could only do so one way – even when they knew that that way would not work or would be incredibly inefficient. Finally, while professional synthetic chemists frequently worked together in groups, it was almost unheard of for their undergraduate equivalents to do the same. Because such differences existed between the two groups,
the authors concluded that organic syntheses were frequently more difficult for students than perhaps they needed to be.28

In an effort to better understand how students approached the process of solving mechanisms, Bhattacharyya and Bodner studied fourteen graduate students who were enrolled in the first semester of a graduate-level organic chemistry course.30 Students were interviewed as they used the curved-arrow convention to predict the mechanism of an organic transformation. Interestingly, the researchers concluded that the curved arrows held no symbolic meaning for the graduate students despite the fact that they all had at least a full year of organic chemistry as undergraduates. Much like the more general reaction arrows used in more simplistic reactions, the arrows were simply a means of getting from reactant to product. Given this focus, many students developed a “connect the dots” strategy “as a conduit between intermediates in the pursuit of the target molecule.”30 Although this study was performed with graduate students, it is not hard to imagine that such problems exist among many undergraduate organic students as well.

At its core, organic chemistry is a visual science using two-dimensional representations to portray synthetic schemes, mechanistic processes, and spectroscopic data. Students are continually asked to transform two-dimensional structures to three-dimensional representations and mentally manipulate those three-dimensional representations in their minds.33 Unfortunately, many students struggle with these activities not only because these representations attempt to convey an incredible amount of information, but also because students generally have little experience with such transformations.34,35
Curriculum Reform in Organic Chemistry

Given the problems that students have encountered with organic chemistry and the gateway that it serves to further study in many STEM disciplines, researchers have experimented with a large number of curricular reforms. These organic reforms include the use of context-based materials, an emphasis on the development of visualization and writing skills, the use of cooperative and collaborative learning groups, and varying the sequence of chemistry courses taken.

Improvements in student achievement and retention have been reported for many of these curriculum reforms; however, on average, 25% - 50% of the students were still earning grades lower than a C-. Although these reforms vary widely in their approach, it is interesting to note that the vast majority leave the traditional organic “canon” intact without consideration as to how achievement and retention could be improved with an update and restructuring of the curriculum. Some have suggested such curriculum reforms will have limited impact because the difficulties students encounter in organic chemistry may stem from the sequence and fundamental structure of the traditional course. One attempt to resequence and restructure the organic chemistry curriculum is known as the spiral approach.

The Spiral Approach in Organic Chemistry

The beginnings of the spiral approach are rooted in an observation made by educational psychologist Jerome Bruner in his 1960 work, *The Process of Education*:

I was struck by the fact that successful efforts to teach highly structured bodies of knowledge like mathematics, physical sciences, and even the field of history often took the form of a metamorphic spiral in which at some simple level a set of ideas or operations were introduced in a rather intuitive way and, once mastered in that spirit, were then revisited and reconstrued in a more formal or operational way, then being connected with other knowledge, the mastery at this stage then being carried one step
higher to a new level of abstraction and comprehensiveness. The end state of this process was eventual mastery of the connexity and structure of the large body of knowledge...

Within a few years, examples of curricula designed to utilize Bruner’s spiral structure began to appear in the literature, starting first in the humanities and social sciences\(^60-62\) and eventually working its way into mathematics\(^63,64\) and the physical sciences.\(^65-70\) Such spiral curricula typically exhibit three defining characteristics\(^71\):

1. **Topics are revisited in greater detail.** Throughout the course or the sequence of courses, students revisit topics, subjects, or themes on a number of occasions.

2. **As students move through content loops, the difficulty increases.** By carefully controlling the material introduced in the first loop of the spiral, the likelihood of students initially becoming overwhelmed is lessened; however, each subsequent iteration of the content adds new knowledge or skills, more advanced applications, and increased proficiency or expertise because of the additional experience. As such, the difficulty frequently increases as well.

3. **New Learning is related to previous learning.** New knowledge, skills, or applications introduced in subsequent loops of the spiral naturally build off of information learned previously. In essence, the spiral approach provides students with a common prior knowledge base upon which to situate and anchor the new information.

Figure 4 illustrates the salient features of the spiral, organic chemistry curriculum implemented in CHM 241/242 at Miami University and contrasts it with a more traditional approach. Unlike the traditional organic chemistry curriculum that works its way sequentially through the material, the first semester of spiral organic chemistry
is taught as a survey of fundamental organic principles, covering most of the concepts taught in a two-semester organic course, albeit in less detail.

During the first semester survey, students learn how to name organic compounds, discuss defining physical and chemical properties of each organic functional group, and explore some basic mechanistic processes. As the second semester progresses, students revisit material learned in the previous semester, focusing this time on more advanced mechanisms and current reactions. It was expected that such an approach would address the problems identified by the organic faculty in the traditional curriculum as outlined previously in chapter 1.

![Figure 4](image-url)

**Figure 4.** Comparison of traditional organic curriculum vs. spiral organic curriculum.

**Directions for Current Research**

The spiral approach in organic chemistry is not new; however, its use as a means to positively impact student attrition is novel. Although much research has been conducted regarding the problems that students face in learning organic chemistry,
most studies were initiated as a result of informal observations made by the professor and typically focus on one problem in-depth. Certainly, such studies are of great use to instructors; however, few studies seek to gain a more holistic picture of the problems that students encounter as they learn organic chemistry. Further, all investigations – whether specific or more holistic in nature – were conducted in the context of traditional organic curricula. Thus, the current investigation capitalized upon an opportunity to better understand the difficulties that students face as they learn organic chemistry in the context of the spiral curriculum.
Chapter 3

Methodology
The Scientific Method and the Positivist Approach

On May 8, 1794, the man now heralded as the father of modern chemistry was beheaded before a packed crowd in Paris, France. In reflecting upon his execution, the Italian-born mathematician, Joseph Lagrange, commented that “[i]t took them only an instant to cut off his head, but France may not produce his like in a century.” Indeed, the impact that Antoine Lavoisier had on chemistry can still be felt some 200 years after his death.

Lavoisier’s interests in chemistry were far-reaching, ranging from studying gases and stoichiometry, to disproving of the theory of phlogiston. Although his research varied widely, the one commonality uniting it all was the systematic approach he employed to study all phenomena:

I have tried...to arrive at the truth by linking up facts; to suppress as much as possible the use of reasoning, which is often an unreliable instrument which deceives us, in order to follow as much as possible the torch of observation and of experiment.

In the decades and centuries to come, this systematic approach would be further refined and would eventually come to infuse all scientific thought as the scientific method. The scientific method is cyclic in nature, usually beginning by defining the research questions based upon formal or informal observations. Using the research questions as guides, hypotheses are stated and experiments are designed and conducted that will allow researchers to hopefully gain a better understanding of the phenomena of interest. By analyzing and interpreting the results, the researchers can further refine their initial hypotheses – thus, beginning the process anew.

Historically, the rise of the scientific method has been linked with the ascension of the positivist era in the nineteenth and twentieth centuries. The three most important tenets of the positivist framework are the assumptions of naïve realism, universal scientific language, and the correspondence theory of truth:
These three assumptions between them constitute a picture of science and the world somewhat as follows: there is an external world which can in principle be exhaustively described in scientific language. The scientist, as both observer and language-user, can capture the external facts of the world in propositions that are true if they correspond to the facts and false if they do not. Science is ideally a linguistic system in which true propositions are in one-to-one relation to facts, including facts that are not directly observed because they involve hidden entities or properties, or past events or far distant events. These hidden events are described as theories, and theories can be inferred from observations, that is, the hidden explanatory mechanism of the world can be discovered from what is open to observation. Man as scientist is regarded as standing apart from the world and able to experiment and theorize about it objectively and dispassionately.77

Over the course of the last two hundred years, tremendous scientific advances were achieved using both the scientific method and the positivist framework to which it is so closely linked. As the true complexity of the physical universe began to be revealed, however, a critical re-examination of such a framework was required as positivism stood in stark opposition to some of the most important scientific breakthroughs of the twentieth century.

Einstein, Heisenberg, and the Beginning of the End of the Positivist Era

By the turn of the twentieth century, scientific evidence was mounting that called into question several of the central tenets of the positivist framework. The positivist researcher believed that an external world existed and no matter which vantage point chosen, the results should be the same. In 1905, Einstein proposed his Theory of Relativity to address an apparent contradiction between the work of Newton and Maxwell.78 At the most fundamental level, Einstein’s Theory of Relativity called into question the existence of single, external Truth and required its replacement with
multiple perspectives which, dependent upon the observer’s relation to the world around, were all equally valid.

Beyond the philosophical debates surrounding the existence of external Truth, most positivist researchers still clung to their belief that they could be impartial and objective observers of reality. Unfortunately for supporters of the positivist framework, even this vaunted tenet began to crumble in the light of the research conducted by German physicist Werner Heisenberg. In trying to study the properties of subatomic particles such as electrons, Heisenberg found that the momentum and the position of such a particle could only be defined in terms of a probability function – not a definitive answer. Inherent within these observations is what is generally referred to as the Heisenberg Uncertainty Principle, which, briefly stated, says that as the observer’s certainty in the position of an electron increases, the observer’s certainty in the momentum of the electron decreases.

The Heisenberg Uncertainty Principle is one of the earliest and most dramatic, scientific examples of what is commonly referred to as the observer effect – the idea that the very act of studying a phenomenon can inherently alter it. Such effects seriously undermine the positivist belief that the researcher can be a dispassionate observer of reality. Indeed, what Heisenberg’s work so clearly illustrates is that the researcher is an active and integral participant in the research process, working together with the research participants to make meaning of the experiences under investigation. As Heisenberg stated in his 1958 work *Physics and Philosophy: The Revolution of Modern Science*, “[w]e have to remember that what we observe is not nature herself, but nature exposed to our method of questioning.”

**Looking beyond the Positivist Era: The Rise of Interpretivism**

Given the mounting scientific evident to suggest the inadequacies associated with the positivist framework, researchers began to look for a more appropriate
paradigm to guide their work. For many, such a paradigm was found in interpretivism, a more naturalistic form of inquiry.\textsuperscript{76} The differences between the two frameworks are dramatic:

Where positivism is concerned with surface events or appearances, the new paradigm takes a deeper look. Where positivism is atomistic, the new paradigm is structural. Where positivism establishes meaning \textit{operationally}, the new paradigm establishes meaning \textit{inferentially}. Where positivism sees its central purpose to be \textit{prediction}, the new paradigm is concerned with \textit{understanding}. Finally, where positivism is deterministic and bent on certainty, the new paradigm is probabilistic and speculative.\textsuperscript{76} (italics own)

Lincoln and Guba suggest that research guided by the interpretivist framework has fourteen key characteristics\textsuperscript{76}: natural setting, human instrument, utilization of tacit knowledge, qualitative methods, purposeful sampling, inductive data analysis, grounded theory, emergent design, negotiated outcomes, case study reporting mode, idiographic interpretation, tentative application, focus-determined boundaries, and special criteria for trustworthiness. The remainder of this chapter shall highlight these characteristics as they apply to the current research.

\textbf{The Natural Setting: The Spiral, Organic Curriculum}

One of the more fundamental differences between qualitative research and the bench research conducted by most chemists is the issue of transferability of results. Traditional chemists strive to produce results that are generalizable and transferable to a wide variety of research settings; however, since each educational environment is unique, such broad-ranging results are frequently not appropriate for qualitative education research. As such, it is essential that this researcher provide a “rich description” of the educational environment so that readers of this study can decide for
themselves how transferable and generalizable the results are, both to their classrooms and to their students.80

CHM 241/242 is the two-semester organic chemistry sequence most frequently taken by students who plan on attending medical school. Each lecture course is three credit hours with an accompanying two credit hour laboratory course. More than 75% of students enrolled in the course are sophomores; all have had at least one year of college-level general chemistry or advanced placement credit.

The organic chemistry curriculum at Miami has changed little over the last four decades. Although the textbook has changed on several occasions during that time period – most recently from Carey81 to Bruice82 – the structure and content of the course has remained remarkably constant. One organic chemistry professor described the organic sequence:

...as a “traditional setup.” In essence, we find a satisfactory textbook and pretty much follow it rather faithfully... [W]e start off with a very rapid review of the most important general chemistry concepts, go through some generalities of structure and conformation, and then begin reactions and pretty much follow through that on a functional group basis with problems assigned concerning synthesis and...analysis...and reactions.

One key difference between Miami’s organic sequence and other universities’ is that at Miami, spectroscopy is taught exclusively in the laboratory portion of the course. In so doing, the laboratory professors are able to not only teach spectroscopy in the context of the experiments their students are conducting, but also to provide the lecture professors several weeks at the end of the second semester to teach special topics such as the chemistry of biomolecules, i.e., topics the students are likely to encounter in biochemistry the subsequent year.

Over the last several years, however, faculty in the organic division at Miami began to recognize that this “traditional setup” was no longer serving students as well as it perhaps could. Organic faculty cited three main concerns as outlined in chapter 1.
In response to these concerns, the organic faculty at Miami decided to update and reform the two-semester course sequence by the use of a spiral, organic chemistry curriculum. In this manner, Miami students gained a broad overview of functional groups (alkanes and cycloalkanes, alkenes, alkynes, chirality, haloalkanes, alcohols, benzene and benzene derivatives, amines, aldehydes, ketones, and carboxylic acids and their derivatives) during the course of the first semester. Students began the second semester with a study of aromaticity and molecular orbital theory and then revisited the organic functional groups highlighted above.

Although the structure of the content changed dramatically in the implementation of the spiral curriculum, the method of presentation remained constant – that of the traditional lecture. The course professor utilized overhead transparencies that were placed online for the students to download and print prior to coming to class. During lecture, the professor expanded upon what had been posted online and provided additional examples for the students’ consideration. In the course of both the fall and spring semesters, students were assessed based upon their performance on four, one hour exams (worth 66% of the course grade), a comprehensive final (worth 17% of the course grade), and online homework assignments that students were required to complete outside of class (worth 17% of the course grade). The hour long exams for both the fall and spring semesters and the comprehensive final given in CHM 241 were composed of short answer questions; the comprehensive final in CHM 242 was a standardized, multiple choice exam published by the American Chemical Society’s Division of Chemical Education Examinations Institute.83

The Human Instrument: Presence of Self in the Inquiry

The primary data-gathering instrument in most interpretivist inquiries is the human instrument. In many cases, the phenomena under investigation are not well understood, making the choice of a more traditional pen-and-paper instrument
problematic since the researchers frequently do not know what important constructs to quantify.

Given the importance that the researcher plays in shaping the research and in building meaning with the research subjects, it is incumbent upon this researcher to provide readers of this inquiry with some notion of the life experiences that have informed and shaped this research.

Up until the time I started high school, I had aspirations of being a zoologist. I have always found the natural world fascinating and wanted to study the diversity of life on earth. It was during my 9th grade biology class that I was introduced to the beauty that is the cell. I was absolutely enthralled by how such an incredibly tiny entity could function so precisely and with such purpose. It was also at this point that I began to realize how much I enjoyed helping other people learn science. As it came time to truly begin to think about what I wanted to do with the rest of my life, I came to the decision that I wanted to be a high school biology teacher. It was with such a goal in mind that I began my undergraduate studies at the University of Pittsburgh in August of 1998.

My freshman year was quite the learning experience and it ultimately set me upon my present day course. The first college class I ever had was my 8 am general chemistry class. I remember walking into it feeling anxious – not knowing what would become of me once I entered the lion’s den. To my great surprise, I found that the professor was actually a nice person and greatly concerned about how we learned chemistry. She was quite the maverick in the department, and insisted that we work in small groups throughout the course. Although she did lecture at times, for much of the class we were working on activities in our groups. Because of these experiences, I came to appreciate early in my academic career just how collaborative science is. Over the course of the next year and a half, I slowly came to realize that what I found most fascinating about biology is what I would now describe as biochemistry. Further, unlike many of my friends who struggled with organic chemistry, I found that I excelled at the subject and considered it one of the more interesting and fulfilling courses I
had taken up until that point – indeed, much more fulfilling than my biology classes. As such, by the time I finished the first semester of organic chemistry, I was ready to change my major to chemistry and secondary education. It is important to note that even at this point in my career, I recognized that content and pedagogy could not exist in isolation of each other (hence the double major), and as I began to take more courses in both chemistry and education, I began to wonder why there wasn’t more communication between the professors who were teaching my science classes and those teaching my education classes. Thus, my formal interest in the field of chemistry education began.

During the course of the next several years, I participated in undergraduate research at the University of Pittsburgh that involved the creation of new NMR laboratory experiments for use in the organic chemistry labs. Before graduating, I also began work on attempts to integrate new technology into the organic lecture. These research experiences – in addition to the more formal organic course experiences during my sophomore and senior years – are what fueled my desire to understand more about how students learn organic chemistry and the unique challenges they face in doing so.

After graduating from the University of Pittsburgh in December of 2003, I began work on my master’s degree in chemistry with a concentration in chemistry education at Youngstown State University. At that point, I intended to return to Pennsylvania and teach high school chemistry when I finished with my master’s degree; however, as I became more involved in my work, things began to change. I realized that I enjoyed teaching college students as much as high school and that conducting chemistry education research was quite fulfilling. As such, I began to work on my PhD in chemistry at Miami University after finishing my degree at Youngstown State.

My involvement in the current inquiry began quite by accident. During the spring of 2006, I was taking a physical organic course as part of my organic chemistry cognate area requirements; this course was taught by Dr. Jim Hershberger. Dr. Hershberger was similar to the professor I had for general chemistry at the University of Pittsburgh – a bit of a maverick who was greatly
Dr. Hershberger had evidence to suggest that the first semester course worked well; indeed, it would end up being exactly the same as the one-semester survey course (CHM 231) that he had been teaching each fall for the last several years. For an organic chemistry course, CHM 231 had tremendously low attrition rates – in most years averaging less than 2-3%. The second semester course, however, would be entirely new, both to him and to the students of Miami University. After hearing him speak about the proposed structure of the new courses, I was immediately drawn to the research possibilities inherent in such a curricular change. The division, with Dr. Hershberger leading the charge, was attempting to positively impact the high attrition rates, yet there were few studies (and certainly none conducted in the context of a spiral curriculum) providing a holistic chronicle of the problems students encounter in organic chemistry. As such, the success of any curricular change might be tempered since it might not address the significant problems that students actually face. Furthermore, given the realities associated with the spiral approach, the problems that students experience in the fall semester could be very different from those they encounter in the spring. I found these potential research ideas fascinating and used them to shape the current inquiry.

**Research Questions Revisited**

Before proceeding with a more detailed description of the methodology utilized in this inquiry, it would be beneficial to remind the reader of the goals of this research. This research sought to better understand the challenges that students faced in learning
organic chemistry in the context of the spiral curriculum. Specifically, the following research questions guided this inquiry:

1. What are the biggest problems students face in understanding organic chemistry?

2. How do these perceptions change as students progress through the revised organic chemistry curriculum?

3. What strategies do students employ to address the problems that they face in learning organic chemistry?

Structure of the Inquiry: Interviews, Essays, and the Case Study Approach

These research questions were explored with the use of case studies. The use of case studies can be traced back as far as the early part of the nineteenth century to the work of French sociologist Frédéric Le Play. In order to investigate issues surrounding socioeconomic transitions, Le Play devised a system whereby he studied a single family unit (referred to as the case) for an extended period of time. By studying a single case in great detail, he was able to provide insights into the familial workings that few other researchers knew existed.

As the case study approach has matured over the course of the last two centuries, researchers have come to appreciate its versatility:

Case study is not a methodological choice but a choice of what is to be studied...We could study it analytically or holistically, entirely by repeated measures or hermeneutically, organizationally or culturally, and by mixed methods – but we concentrate, at least for the time being, on the case.
Given the flexibility of the case study approach, it affords the researcher with a wealth of information about the experiences of the cases involved in the work. As such, this approach was adopted for use in the current inquiry.

Unlike most quantitative studies which typically utilize a random sampling protocol for the selection of research participants, the case study approach requires a more purposeful selection process. Given that the average qualitative inquiry focuses on the experiences of a relatively small number of cases (at least compared to the several hundred or even several thousand that may participate in a quantitative project), the researcher must be selective in the cases chosen. Such cases must be “information-rich,” and therefore, the selection process must be purposeful, i.e., must yield cases from which “one can learn a great deal about issues of central importance to the purpose of the inquiry...”\textsuperscript{86}

On the first day of the fall semester, Dr. Hershberger provided this researcher with several minutes at the beginning of class to explain to students the purpose of the inquiry and to solicit volunteers who might be interested in participating in it. Students were then provided with a short demographics questionnaire designed to ascertain their interest in participating in the project and asking those students who were interested to provide specific information about themselves. A copy of this questionnaire is included in Appendix A.

Unlike the atoms and molecules that most traditional chemists research, human subjects have rights protected under federal law. To ensure that all human subjects research is of minimal risk to potential participants and in accordance with federal, state, and local laws, most colleges and universities have an institutional review board (IRB) to review and approve all human subjects research. Such is the case at Miami University.

The primary issue of importance in any human subjects research is that informed consent is obtained from all participants. In other words, it is the responsibility of the
researcher to ensure that all participants are fully aware of the potential risks and benefits associated with the work and have voluntarily agreed to participate in the research. All phases of the current inquiry were reviewed and approved by Miami University’s IRB. All research participants were provided with information regarding their rights as human subjects; informed consent was obtained from all of the participants. A copy of the consent form used is included in Appendix B of this document.

Of the 298 students initially enrolled in CHM 241 at the beginning of the fall semester, 114 indicated that they would be interested in participating in the study. For the purpose of this inquiry, 18 students were purposefully selected from that pool of volunteers to provide diversity in gender (10 females, 8 males), ethnicity (10 white/Caucasian, 8 minority), academic level (1 freshman, 11 sophomores, 3 juniors, 3 seniors), and academic performance in general chemistry (8 high performing, 5 average performing, 5 low performing). For each semester students participated in the inquiry, they were provided with a $25 gift certificate to the Miami University Bookstore. Specific information for each student is included in Table 1. (Note that the names listed throughout the dissertation are pseudonyms and not the students’ real names.)

Data regarding students’ experiences was collected from two sources: reflective essays and interviews. The students involved in the inquiry were asked to complete three sets of essay questions (see Appendix C) exploring their goals and expectations for organic chemistry and eventually having them reflect upon their experiences in the courses after completing them. These essay questions were provided to the students via email and administered in late August, late December (after the students had completed the first semester of organic chemistry), and mid-May (after the students had completed the second semester of organic chemistry). Responses were collected using a secure online form.
Students were interviewed twice during the study – once in October, the second time in March. The interviews, which utilized a semi-structured format, focused on (1) exploring topics from the reflective essays in more detail and (2) gaining a better understanding of the day-to-day workings of the courses. (The semi-structured interview guides are included in Appendix D.) Interviews were recorded using a digital voice recorder and subsequently transcribed to provide a textual record of the conversations.

Table 1. Demographic information for the 18 cases.

<table>
<thead>
<tr>
<th>Name</th>
<th>Gender</th>
<th>Ethnicity</th>
<th>Academic Level</th>
<th>Performance in General Chemistry</th>
</tr>
</thead>
<tbody>
<tr>
<td>Angelina*</td>
<td>Female</td>
<td>African American</td>
<td>Sophomore</td>
<td>Low</td>
</tr>
<tr>
<td>Bill*</td>
<td>Male</td>
<td>White/Caucasian</td>
<td>Senior</td>
<td>High</td>
</tr>
<tr>
<td>Charlie</td>
<td>Male</td>
<td>White/Caucasian</td>
<td>Junior</td>
<td>High</td>
</tr>
<tr>
<td>Ernie</td>
<td>Male</td>
<td>American Indian</td>
<td>Sophomore</td>
<td>Average</td>
</tr>
<tr>
<td>Fred</td>
<td>Male</td>
<td>White/Caucasian</td>
<td>Sophomore</td>
<td>Low</td>
</tr>
<tr>
<td>George</td>
<td>Male</td>
<td>White/Caucasian</td>
<td>Senior</td>
<td>Average</td>
</tr>
<tr>
<td>Ginny</td>
<td>Female</td>
<td>White/Caucasian</td>
<td>Sophomore</td>
<td>High</td>
</tr>
<tr>
<td>Hannah*</td>
<td>Female</td>
<td>White/Caucasian</td>
<td>Junior</td>
<td>Low</td>
</tr>
<tr>
<td>Katie</td>
<td>Female</td>
<td>White/Caucasian</td>
<td>Freshman</td>
<td>High</td>
</tr>
<tr>
<td>Lily*</td>
<td>Female</td>
<td>White/Caucasian</td>
<td>Sophomore</td>
<td>High</td>
</tr>
<tr>
<td>Luna</td>
<td>Female</td>
<td>Asian</td>
<td>Sophomore</td>
<td>High</td>
</tr>
<tr>
<td>Marietta</td>
<td>Female</td>
<td>White/Caucasian</td>
<td>Sophomore</td>
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</tr>
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<td>Neville</td>
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<td>Asian</td>
<td>Sophomore</td>
<td>High</td>
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<tr>
<td>Parvati</td>
<td>Female</td>
<td>Indian</td>
<td>Junior</td>
<td>Average</td>
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<tr>
<td>Penelope*</td>
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<td>White/Caucasian</td>
<td>Senior</td>
<td>Low</td>
</tr>
<tr>
<td>Percy*</td>
<td>Male</td>
<td>Indian</td>
<td>Sophomore</td>
<td>Average</td>
</tr>
<tr>
<td>Ron</td>
<td>Male</td>
<td>Hispanic</td>
<td>Sophomore</td>
<td>High</td>
</tr>
<tr>
<td>Susan</td>
<td>Female</td>
<td>Hispanic</td>
<td>Sophomore</td>
<td>Low</td>
</tr>
</tbody>
</table>

* Indicates students who only completed the first semester of organic chemistry.
Data Analysis: Grounded Theory, Emergent Themes, and the Utilization of Tacit Knowledge

Despite the fact that the present study had a well defined set of goals and questions to guide the research, it was not possible for this researcher to fully anticipate all of the possible directions the research results were likely to lead. A more flexible and iterative analysis scheme was required. As Lincoln and Guba concluded,76 “the design of a naturalistic inquiry (whether research, evaluation, or policy analysis) cannot be given in advance; it must emerge, develop, unfold…” Such a design framework was found in the work of Corbin and Strauss – that of grounded theory.89 Using grounded theory as a guide, analysis of the results in a qualitative study is an iterative process that makes use of “cycles of research activity” whereby the results are used to continually refine not only the overall research model but also the next phase of the research project.90 In such a cyclic environment, emerging theory is fundamentally grounded in the data collected, and continually refined as more data becomes available.

Theory development typically begins with the analysis of preliminary results for emergent themes, i.e., commonalities that begin to develop within the data and appear to be significant in gaining a better understanding of the research at hand. To begin the process of fleshing out these emergent themes, subsequent data collection is modified in order to explore such themes in greater detail.88 Furthermore, such an approach allowed this researcher to begin to set the boundaries of the research and to focus in on those themes he perceived to be most significant.76 In the context of the present inquiry, the questions included in the semi-structured interview guides were critically reexamined after each interview to gauge their effectiveness and to make additions that this researcher believed would allow him to better understand the patterns in the data that appeared to be emerging. This process continued to encompass the questions contained within the reflective essays as well.
The process described above was informed not only by the data collected from the interviews and reflective essays, but also from the researcher’s firsthand experiences with the professor and students in the course. During the fall semester, this researcher observed the classroom setting at least once a week and assisted the course professor in grading the hour-long exams. In his capacity as teaching assistant, this researcher taught three sections of the laboratory portion of the course during the spring semester. The utilization of such tacit knowledge was vital in shaping the collection and analysis of data.

Once all of the raw data was collected, a case record was compiled for each student who participated in the inquiry. The case records included copies of responses to each set of reflective essays, transcripts from both interviews, and the notes taken during those interviews. This information was then used to generate the rough drafts of the case studies that appear in chapter 4 and the emergent themes in chapter 5. Such emergent themes were defined ideographically, i.e., in terms of the words and experiences of the cases.

Establishing Trustworthiness: Reliability and Validity of the Inquiry

Issues surrounding the trustworthiness of the results of an inquiry are of paramount importance to all research; however, the conventional trustworthiness criteria of reliability and validity are not appropriate for most qualitative research. Rather, Lincoln and Guba argue that the criteria of transferability, credibility, dependability, and confirmability be used as alternative measures of trustworthiness.

As stated previously, one of the more significant differences between traditional chemistry research and most qualitative research center on the issue of transferability. While the former is expected to make well defined statements surrounding transferability of results, the latter can only make tentative applications because every research environment is unique. It is, however, the responsibility of the qualitative
researcher to provide a sufficiently detailed description of the research environment so that the reader can make an informed decision as to how applicable the results are in the local environment of the reader. Such a thick description was provided earlier in this chapter.

The second criteria of trustworthiness focuses on the **credibility** of the results generated. One of the major limitations in conducting qualitative research is that language is an imperfect vehicle for conveying ideas as the researcher and participant may have differing conceptions of the meaning of a word or phrase, thus, it is imperative that this researcher make every possible effort to ensure that his understanding of events match those of the participants. One common way of testing this understanding is the use of the member check. During the course of the member check, the researcher summarizes what the participant said during the interview and tests for understanding. The use of such negotiated outcomes enabled this researcher to test his constructions of the realities described by the participants. Member checks were performed during all interview conducted during this inquiry.

The last two tenets of trustworthiness, **dependability** and **confirmability**, sit at the very heart of the reliability and validity of the research. Although there are several methods for determining the dependability and confirmability of qualitative research, this inquiry used triangulation, i.e., an overlapping approach. There are four different types of triangulation: sources, methods, investigators, and theories. As will be seen in the case studies included in chapter 4, and the emergent themes and conclusions discussed in chapters 5 and 6, triangulation of sources, methods, and theories were utilized. Many of the problems that students encountered in their journeys through organic chemistry were not unique to them alone, but extended to multiple sources. This data was gathered by also relying upon multiple methods, most importantly interviews and reflective essays. Finally, multiple educational and psychological theories have guided this research and have served to anchor the results.
Chapter 4

Results
Introduction

The results of this inquiry are presented below as case studies. These cases studies document the experiences of 10 of the 18 students originally selected for the inquiry, and are purposefully presented here due to their importance generating the conclusions and recommendations of the inquiry.

The Case Studies: Charlie

Some would call him an overachiever; others, perhaps, would describe him as a glutton for punishment. Whatever words one may use to describe Charlie, the fact remained that he was an exceptional student pursuing two exceptionally difficult majors. Not content to pursue a career as an electrical engineer, he was also taking the courses required for entry into medical school. He explained his desire to become a doctor as a desire to work with and assist people:

The number one reason [I want to be a doctor], is that…well, I guess it’s a combination of after getting involved in the engineering program, I realized that’s something I couldn’t do the rest of my life…it wasn’t enough interaction with people…talking with people and the idea of being a doctor and being able to serve other people as your profession, that was really appealing to me – just the opportunity to help others out and do that on a daily basis. I guess I saw that more as something I would enjoy doing every day of my life than being an engineer.

Although there were other professions that would have provided Charlie with the interaction with people that he craved, he felt that these other professions, such as social work, would not be challenging enough for him: “I wanted something that would stretch me and make me try new things…maybe a little bit more than the average major.”
Charlie believed that organic chemistry was required of students intending to go to medical school for two reasons. He felt it was important for future doctors to learn more about:

...the natural functions of life... at a very basic level. I mean – organic chemistry – those sorts of reactions are played out every second in your life, you know... within your body different sorts of reactions and so understanding those at a basic, molecular level...I’m assuming you can build on that sort of understand, like more complex things that your body does that you might actually use as a doctor. If you, if there’s some disease that causes certain proteins not to synthesize, is that because of some chemical reaction that isn’t occurring?

Secondly, Charlie considered organic chemistry to be “a great field to be able to test someone’s ability to learn material and then apply it to multiple, different situations.”

Charlie had expected organic chemistry to be much like general chemistry “just applied to different aspects, to organic molecules as opposed to inorganic molecules but the same thing about learning how they interact with each other, how they interact on their own, what their specific characteristics are.” In his mind, the reality he encountered was similar to what he had anticipated:

I’d say it was pretty close [to what I was expecting]. Basically, we learn about certain groups like...alcohols, esters, alkenes, alkynes, like you learn about different groups and then you learn how they interact with different molecules and how those reactions take place is basically what we’ve been doing so far – we just go from group to group and then learn how they interact...and now we’re starting to get into like multiple step synthesis where you have to...you’re given a beginning and an end and you have to go through multiple steps so you’re combining the different things that you learn to get your end product.

In speaking about his experiences during the first half of the fall semester, Charlie believed that the material he encountered in organic chemistry was
“straightforward” and not too fast paced. Indeed, he reported that his grade in organic chemistry was probably the highest of all of the classes he was taking during the fall semester as some of his engineering courses were “ridiculously difficult.” Charlie felt that his engineering courses were more difficult for him because they were very different from the other courses he had taken. This was not the case with organic chemistry:

...like my engineering classes – [for example], electronic and signals and systems – and the thing that makes those really difficult is I’ve never seen the material before. I’ve never seen anything like it before where I think organic chemistry it’s like...from general chemistry like you’ve seen reactions. You kind of know how reactions work. You know the difference between acids and bases. Like, there are a lot of general things you know with organic chemistry that you learn from general chemistry. So, it’s not all completely new – you kind of have, like, a foundation you build off of.

He did admit, however, that organic chemistry was only straightforward provided that he spent the needed time studying and preparing for class. To help him prepare for class, Charlie liked to read ahead in the chapter so that when it came time to attend lecture, it wasn’t the first time he was encountering the material. Although he tried to take notes in class, Charlie realized as the semester progressed that he was not using them as much as he had originally thought he would, and instead, found it more useful to try to understand what he was being told in lecture instead of frantically trying to copy down what was said. Charlie typically generated his own set of notes based upon his reading of the book chapters. When it came time to study for an exam, he used these notes as a resource in creating a study guide which typically included the general form of all of the reactions he had learned about since the previous exam and the general reaction conditions under which they would occur. In addition to studying his guide, Charlie also liked to complete the problems at the end of the chapter so he
was “familiar with how different problems are worded.” These strategies worked well for Charlie, and during the course of the semester, he missed only 15 points on tests and homework assignments, earning one of the highest grades in the class.

In reflecting upon his experiences during the fall semester, Charlie felt that the biggest challenge he faced was staying motivated to go to class since he found his private studying of the course material to be of greater benefit to him. In fact, he admitted that he did not attend class during most of the last month of the semester, and yet, continued to do well in the course. Overall, he found the fall semester to be

... a fairly easy class. There was not a lot of work outside of class, minus, you know, preparing for tests, but even that wasn’t too extensive. The material conceptually was never too difficult, but there was a lot of memorization involved in the class... for the most part, the teacher does a pretty good job of explaining anything that conceptually might be difficult to understand.

Although he was expecting the spring semester to be more difficult – he had heard such from friends – he found the material only slightly so. He attributed this increased difficulty not to the new material he was learning, but rather to having to remember all of the material he had learned in the fall semester. He also commented on what he perceived to be an increase in the pace of the material covered. Finally, he felt that the professor was not “spoon feeding” the material as much as he had done the previous semester: “I think he’s kind of expected the second semester being that everyone’s gone through their first semester [and] maybe to figure some things out on their own and not be so blatantly obvious to like tell the students everything…”

The biggest difference Charlie perceived between the two semesters was in the structure of the course and the content itself:

... I would say that... second semester has been more general as opposed to like working with specific, you know, functional groups or whatever – studying one and moving on to the next. This is kind of take them all and apply those together; being able to synthesize
different things; combining all of the different functional groups as opposed to looking at them individually…we’ve seen a lot of the same stuff second semester that we did first semester. [It’s] just kind of going into a little more detail or learning a few [ways of doing something]. Rather than learning one way to do something, we’ll learn three or four different ways to do something. [For example], if we’re trying to make a ketone, we’ll learn how to make it from a carboxylic acid, and ester…you know, rather than just learning one way to do it.

He thought that the spiral approach was a good one “in the sense that it doesn’t overwhelm people when they start taking organic chemistry because you’re kind of just getting a broader overview of everything.” The only disadvantage he could see to the approach was the fact that if you did not do well on something during the first semester, it would be doubly hard for you when you came back to it the second time around and tried to add to it.

Despite the slight increase in difficulty, Charlie’s preparation for the course actually diminished. As he put it during our interview in April: “...in all honesty, I very rarely go to class...maybe once every two weeks on average...I’ve found personally that’s a more effective use of my time to not go to the lecture and then when it comes time for the test, just learn the material on my own.” He reported that when he did study for the exam, his study habits remained unchanged from the previous semester. In particular, he found his study guides, and his subsequent review of those, to be most beneficial:

Coming up with my own study guides [is the most beneficial thing I do to study for an exam] – that helps a lot because it requires me to go through, not only go through and read all of his notes, but then dictate it myself, you know, and write it down myself so it’s almost like having gone through it twice right away and that usually helps me a lot...I usually do that, go through until I feel pretty confident and then once I feel pretty confident and I feel like looking at it even more – I’m just glazing over it, not taking in new
information – at that point...I’ll stop studying and then when I wake up in the morning, then I’ll go over it again, say, “Ok, what did I keep? What did I retain from my studying yesterday and what type of material do I need to keep going over?” Usually I just reach a point where I’ve seen my notes enough that I’m just…I’m not taking anything in and when I reach that point, it’s time for me to take a break. If I don’t have...the benefit of having a night before to take a break, you know, I’ll just take an hour and go work out or something. You know, watch TV for an hour and then come back to it and say, “Ok…this is the stuff I haven’t retained as well as I would have liked to.”

Since Charlie’s performance on the tests and homework assignments had remained high – in fact, Charlie had received bonus points on the second exam because of his exceptional answer to one of the test questions – he felt no need to do more than what he was. Again, he reported that the biggest problem he faced was staying motivated. This was an even bigger problem for him during the spring semester since he was attending class less frequently than he had the previous semester. Regardless of his more relaxed attitude towards organic chemistry, Charlie still earned an A in the course. For Charlie, success in organic chemistry was defined not only by the grade – he considered an A to be very successful – but also the ability to remember and apply the material he had learned in new situations. On both counts, Charlie considered himself successful.

Ernie

Ernie’s previous performance in chemistry was what science professors would describe as average. Although he was very driven to succeed, he had only been marginally successful in his chemistry courses in the past – earning a B and C in general chemistry 1 and general chemistry 2, respectively. Ernie was a sophomore business major with aspirations of going to medical school. In January of 2004, he had been
involved in a serious accident that left his leg broken in more than 20 different places. This experience, more than any other, catalyzed and solidified his desire to become a doctor:

All the help and assurance that everything would be alright made me realize that I want to give others who have terrible accidents the peace of mind that I will help to return them to as close to 100% as I possibly can – in the same way my doctors did for me.

At first glance it would appear that medicine and business were not associated in a meaningful way, but Ernie later explained that also majoring in business would “facilitate…running my own practice when I become an established radiologist.”

Ernie had high expectations for what he hoped to learn in organic chemistry. He believed that such a course would allow him to not only “understand the pieces that go into the everyday medical advances that [doctors] use,” but also viewed organic chemistry as an opportunity “to learn the value of hard work.” Beyond merely learning the value of hard work, however, Ernie believed organic chemistry was the true test of whether he, and indeed all pre-medical students, had the motivation, drive, and skills to be successful in medical school:

If we put in a constant, dedicated effort, we, as students, will have the satisfaction of knowing that when we really put our mind to something, we can accomplish anything. I think this mentality is a great advantage in the entrance to, and our education in, medical school.

To say that Ernie had a great deal riding on his performance in organic chemistry was an understatement. Although he understood that this performance would be judged using grades, Ernie recognized that grades – whether good or bad – did not necessarily correlate with understanding. “I don’t feel that grades are always a good measuring stick on how well the materials and the concepts are understood,” he wrote near the beginning of the fall semester. This discrepancy
would set up an uncomfortable tension within not only Ernie but many of the other students involved in the study.

Ernie was initially apprehensive about organic chemistry; he felt that it was going to “be the hardest class [he had] ever taken.” He attributed this anxiety to not only the complexity and density of the material in his organic lecture course, but also to his unfamiliarity with organic-specific laboratory techniques, equipment, and instrumentation. Like many other students that semester, Ernie found that the demands of lab far outweighed those of the lecture itself:

I hate going to lab and all that crap…[H]onestly, our lab course…you cannot get an A in. I try to pay attention and listen but I don’t understand a thing…[T]he material on Blackboard – I read that – and I still don’t understand where it comes from or what relevance it has to anything. It’s kinda flipped from last year [general chemistry]…I just thought last year the lab was put together better… (emphasis original).

On the other hand, as the fall semester progressed, Ernie was pleasantly surprised to find that the lecture course was not nearly as difficult as he had expected. He found the pacing of the material to be appropriate and the difficulty was only marginally higher than the business courses he was taking that semester. The professor, he admitted, was

…the best professor I’ve had here at Miami. I mean he makes the material understandable and…he doesn’t try to go over our heads with teaching it to us…[H]e makes going to class fun. I haven’t missed an organic chemistry class yet. One, because I don’t want to fall behind but he also makes class interesting.

Ernie did acknowledge that organic chemistry was a time-intensive course, but he was quite adamant that for those students having difficulties, it was because they were not spending enough time working with the material or were not seeking out the extra help they required:
I don’t think that it’s that hard. I mean it’s…it’s just a matter of kids applying themselves and like taking the time to study the material. I don’t think the course material is difficult and I don’t believe that it’s impossible. It’s not impossible to get an A.

[Interviewer: So, a lot of people don’t do that well and a lot of people say it’s very difficult. What do you think is the biggest problem for them?] They just don’t take the time to…like study, do the problems, and go to the review sessions. I mean, it’s their own [expletive deleted] fault!

During the first few weeks of the semester, Ernie developed a system for preparing for class and studying for exams. Ernie insisted that success in organic chemistry could only be achieved by staying on top of the material and by “do[ing] something a little bit each day.” As such, he started his routine by first reading the textbook before lecture to give him a better understanding of what would be covered that day. After lecture, he would review the material again to keep it fresh in his mind and to ensure that he understood it. In the time leading up to the exams, Ernie would continually work practice problems from the book and would even make up his own. He felt that this latter activity was extremely helpful as it increased not only the number of problems he was working, but also the diversity of problems as well. As he explained, “If you only see one example, then you’re automatically going to just think back to that, whereas if you have multiple, you’ll be like, well, this structure was like this or this structure was like this and this is what it ended up looking like.”

When it came time to study for the exams themselves, Ernie applied his “something everyday” mantra to that process as well:

If the exam is on a Wednesday and there are three chapters covered, I’ll start the questions for the first chapter on Sunday and then the next day, the next chapter…and so on…and then I’ll just study my notes and the practice problems. If there’s SI [Supplemental Instruction] or the review session, I’ll go to those.
By keeping on top of the material and doing a little bit of organic chemistry each day, Ernie was able to perform exceptionally well on the first two exams (he scored a 92 and 96). After the third exam, he indicated that the exams had “gotten progressively harder” during the semester. In addition, he admitted that he had not spent as much time preparing for the exam as he probably should have. Indeed, his last two test scores reflected less preparation. Although he still scored approximately 5% higher than the class average on the third and fourth exams, his results were lower than they had been on the previous two. He was still convinced, however, that he would get an A in the course. Ultimately, he did not reach this goal (he earned a B for the course), but overall, Ernie was pleased with his efforts during the first semester of organic chemistry and was confident that he could continue that success in the second semester.

It was with great optimism, then, that Ernie approached second semester organic chemistry. Almost immediately, however, he recognized how much he had forgotten from the previous semester, and how very different the new textbook was from the old:

[CHM] 242 is a little bit more difficult. I guess at the beginning, I thought it was a lot more difficult because I didn’t remember anything after winter break…I’d say it’s a little more difficult switching textbooks and a completely different style of reading in how the textbook’s done…the way the questions were worded in the last book compared to the end of the [chapter] questions in the back of this new book…I mean it’s a little different and…the way that they explain the material in the chapter – it’s a little more difficult reading.

Problems surrounding the new textbook became a common theme for Ernie as he described his experiences, and most notably his difficulties, during the second semester. Not only did Ernie find the textbook harder to read – and therefore many times he didn’t – but also because he knew that it was originally written for students taking a graduate-level organic chemistry course, he had constructed a mental barrier that he never overcame:
I think that definitely is part of it [knowing that the book was originally intended for graduate-level courses] – a mental barrier for some people. I know at the beginning of the year, it was for me because I was like, “why are we using a graduate-level textbook?” Like, why would he [Professor Hershberger] do this? I think that the fact that he told us probably didn’t help any. Had he not have told us, I don’t think people would have responded in the way they are now…

Because of the problems he encountered with the textbook and his difficulty remembering material from the previous semester, Ernie’s score on the first exam of the second semester was the lowest of his entire organic chemistry experience and pushed him to the point where he seriously considered dropping the course. In the end, he decided to stick with it – at least until after the second exam:

I went and talked with Professor Hershberger about it and doing so well last semester, he was like “well, you know, you’ll probably do better [on subsequent exams] because we’re basically reviewing old material and as long as you keep studying and, you know…” We set up a couple visits a couple times a week to go talk about things that I didn’t understand. So, that helped and my test grades have been slowly going back up.

Because of this steady improvement, Ernie did not find it necessary to drop the course; however, this constant struggle to remember what he had forgotten from the previous semester, and at the same time trying to make up for his poor performance on the first exam, came to define his experiences the rest of the spring semester.

By and large, Ernie noted that the second semester was similar to the first in structure and how it was taught although he did feel as if the course was more difficult and moved at a slightly faster pace. He also noticed that, unlike the more cursory coverage of the material during the first semester, the class was now looking at chemical reactions in more detail; overall, he liked this approach:
I think it’s definitely a good approach, especially for organic chemistry, because it is a very difficult subject for some people and...I remember when I was deciding whether or not I wanted to do pre-med, people told me that this would be the hardest course I’d take and I think once I got here, I was really nervous for a little while and then once we got into the course, the book and the way Professor Hershberger taught, you know...definitely it didn’t seem as difficult as it was made out to be.

Despite the fact that Ernie was not performing as well as he had first semester (nor as well as he would have liked), he continued to utilize the same techniques to prepare for class and study for exams. Ernie recognized that these techniques were probably inadequate and that he should be spending more time each day working on organic chemistry. By that point in the semester, however, he was firmly set in his ways and did not intend to change them – even if it would have resulted in higher test scores and increased understanding. Partially because of this inflexibility, Ernie earned a C in the second semester of organic chemistry – placing most of the blame for this on the results of a disastrous first exam.

George

George was a senior zoology major at the point when he agreed to participate in the study. When he had started at Miami several years previously, he had wanted to major in biology; however, since that option was not available at Miami, he ultimately selected zoology because it seemed closest to his interests in animals, wildlife, and the environment. Unlike most of his fellow zoology majors, George had no desire to attend medical school, and indeed, was seriously considering changing his major to engineering:

I didn’t really start zoology with an intention of going to medical school, and I think that’s what most people do here. I wanted maybe a degree that’s, you know, more solid. Just for having an
undergraduate degree in engineering, I feel like I have more of a paved pathway, whereas zoology, I’m not sure exactly what I’d do with that degree…and I was in zoology too because I’m interested in environmental science but environmental engineering also seemed interesting to me, you know, could maybe use more of a technical aspect to it.

This was the second time George enrolled in organic chemistry. He had taken organic chemistry during the summer the previous year and had not fared well. Despite the fact that he found the material to be interesting, he thought the summer course was too fast-paced and had difficulty with the testing:

Some of these tests, this is not to insult, like, Miami Plan courses or stuff but, you can get away with the last minute, you know, just looking at it like a high school test – a couple of hours the night before the test. With organic chemistry, unless you’re a wiz, you really can’t do that…I also feel that sometimes professors who are well trained in their field enjoy throwing in obscure problems to attempt to really “stretch” the students. In the end, all this does is frustrate and annoy. There needs to be a bit of that on tests but sometimes too much is just too much…Overall, organic chemistry is a neat subject, but sometimes the way students are assessed makes it hard to enjoy the class.

Despite the fact that George had taken organic chemistry previously, he was not certain why he and other zoology majors, be they pre-med or not, were required to take organic chemistry. On the one hand, he recognized that it was important for pre-medical students “to have some sort of knowledge about the nature of a particular [medically relevant] molecule, but overall, it seems to not be very pertinent to doctors, therapists, and dentists.” He based this latter conclusion on conversations over the years with his own doctors.

I have spoken with doctors and dentists and their knowledge of organic chemistry is limited. The material is interesting in organic chemistry, but it is soon forgotten by many professionals who
“had” to take it for their career. Many of my cohort are pre med, dent, physical therapy, etc… I imagine that the ladies and gentlemen that make up the acceptance committees to these professional schools would not be able to sleep at night if they knew their students had not taken organic chemistry and were unprepared. I jest, but in reality, I feel that organic chemistry is hyped up a bit more than it should be.

Based upon his previous experiences, George knew before beginning the course again that it was something that “you’d have to work at.” He was hoping to “pass the class with a B” and in the process “prove to myself that I can pass a difficult class such as this.” George had no illusions as to how important doing well in organic chemistry was for him at this point in his academic career: “This is kind of ‘Custer’s Last Stand’ for me – I’m a senior now and I already took it once and got out of it and, you know, I realize I need to do well.”

Although George needed to do well this second time, he admitted that he really didn’t do a great deal when it came time to prepare for class each day. In fact, he characterized himself as “a bit of a procrastinator,” which by his own admission, was not something that was going to help him achieve his goals for organic chemistry:

[Interviewer: So you said that organic chemistry’s not a good class for procrastinators. Why not?]...what they expect out of you is a lot and if you wait until the last minute, you’re going to be overwhelmed...you need to look at it progressively throughout, you know...intermediately between each exam or the last night, that’s difficult to do. I mean, I tried it once, I didn’t do so hot on the exam...

When it did come time to study for the exams, he usually started a few days before by looking over the online assignments and trying to do some of the practice problems. It wasn’t until the night before the exam when the professor would hold a review session for the students that George would “start looking at the stuff heavier.”
On one level, George recognized that this strategy was not effective, but because he had seen much of the material previously and because this course was not as fast-paced as the one he had taken during the summer semester, he felt that it was an appropriate way to proceed with his studying. Using this more relaxed approach, he was able to do quite well on the first exam – scoring above 90%. Unfortunately, as the material became more demanding, his scores on the exams quickly began to drop. In fact, he scored 40 points lower on the second exam, and almost 50 on the fourth. Although George had originally wanted to “pass the class with a B”, he was scarcely able to maintain a C during the fall semester.

In reflecting on the mistakes he felt he had made during the fall semester, George again referenced his motivational and time management problems:

Balancing the work load was a bit difficult. Also, though lectures were interesting, it was difficult to be motivated to go to class every class period. But in the end, time management was an issue. Studying a little bit every day makes the exam much easier to handle. Cramming and attempting to study the night before [the exam] was not a success.

He was insistent that he was going to correct these issues during the second semester; however, during the spring semester, George indicated that he had not made many changes in how he approached his study of organic chemistry. This certainly was reflected in his exam grades – he did not score above 61% the entire semester.

In comparing the two semesters, George believed that the “first semester for me was a bit easier than second semester.” Content-wise, he found many of the concepts in the second semester to be more theoretical in nature – for example, molecular orbitals and aromaticity second semester versus nomenclature first semester. Despite the fact that the professor posted the class notes online, missing a few classes could severely limit understanding due to the theoretical slant to the material. Furthermore, the second semester material necessitated a greater attention to detail:
It’s kind of easy to get your reagents mixed up a little bit because there are so many letters and different reagents... whereas in first semester... there’s a set way of doing that and this semester, it’s like, “oh, this reagent, does it put that on that carbon or that carbon?” It’s just a little bit harder to remember because they’re so closely related sometimes; it’s kind of hard to keep them straight.

George described the structure of the second semester course as one where the students were finally beginning to put all of the pieces together from the fall semester. Although he recognized that such a structure required students to remember everything from the previous semester, he thought this approach was good in providing a better understanding of the material:

[This approach is good] because you learn the basics and the method behind it. If you just charge right in, you can maybe make sense of it but, you know, maybe knowing where the electrons go, what’s a nucleophile and electrophile, or $\text{SN}_2$ – whatever type of reaction – might kind of help you put the puzzle together. I guess maybe it’s understanding the players a little bit better.

By the end of the second semester, George had revised his previous goals for the course and was just hoping to be able to pass with a C. Unfortunately, George’s allusion to General Custer was more prophetic than he probably would have liked – George ended up with the 2nd lowest grade in a class of well over 250 students – a victim ultimately of his unwillingness to modify study habits that by his own admission were not effective.

**Ginny**

Ginny was an exceptional student in every sense of the word. She had done well in general chemistry the previous year through a combination of not only natural talent but hard work and dedication. She was one of those rare students who approached learning not just as a requirement for an exam but for the true joy of simply learning for
learning’s sake: “not just to understand…each concept…but to actually learn for the process of learning not just for an exam.”

Ginny’s overarching career goal was to eventually attend medical or dental school; however, she was unsure what path to follow to reach that objective. She initially started her freshman year as a zoology major but came to realize as the year progressed that if she decided not to attend professional school that she really did not want to be a zoologist. As such, she decided to change her major to dietetics, as this seemed a more appealing backup option. Even then, however, she was not entirely sure about this route either and was subsequently considering another change of major as her involvement in the study began – this time to chemistry.

Although she thought organic chemistry may have some importance for her future, Ginny was unsure exactly how organic chemistry and dentistry related to each other:

...I’m not really sure [why organic chemistry is required for professional school]. I don’t know how much of the actual material shows up later or anything like that I guess…I think for dental you’ll need to know like reactions of things as far as like tooth decay or different kinds of medicines or different kinds of like products I guess that you would use for dental repairs, but as specifically like, you know, drawing benzene rings, I don’t know if that’ll come into play.

Despite her previous success in general chemistry, Ginny was quite apprehensive about organic chemistry:

Based on what I have heard, organic chemistry deals with complex, three-dimensional figures and involves a great deal of obscure thinking. I am a very math-oriented person which helped in my learning of general chemistry; however, I have been told that general chemistry and organic chemistry are very different and it does not matter if you did well in general chemistry, you may not do well in organic chemistry…I am more anxious this year because
this is all new material. On the contrary, general chemistry was partially a review from high school chemistry.

As the semester progressed, Ginny began to realize that although organic chemistry was a lot of work, it was not as difficult as people had made it out to be: “[Organic chemistry is] not as challenging…but, I felt even like last year some people just kind of know chemistry…I feel like I can understand chemistry. I just imagined it to be really, really hard and it’s nothing I can’t handle.” Ginny found the textbook to be well organized and a helpful tool to study for the course and prepare for the exams. The story could not have been more different, however, in her lab course, which she found to be quite difficult:

...lab is a little bit more shaky...just because...although I feel like in lab I understand like what’s happening when we mix this organic layer with the aqueous layer...[but] I just feel like there’s so much information to know or you might have to relate it to [a similar situation]...I’ve never had to do that kind of lab write-up where you have to do the procedure beforehand. In the regular [general] chemistry lab, I feel like everyone was doing the exact same thing maybe at the exact same time and it wasn’t as free to make mistakes whereas this year...I left my beaker on the hotplate too long and it crashed out of solution…”

Early in the semester, Ginny established a regular study schedule that served her well during the first few exams:

I would read the chapters before class and highlight the basic information – like key words kind of thing, not an all over highlighting...[A]nd then after class in the next day or two, read over it again and highlight it better. I usually don’t work the problems until I have like a few sections done rather than just work like two problems a night...I usually do [the online homework assignments] in two sittings. I do the first I know that I can do right off the bat and...I’ll sometimes make a guess and be like, “Oh, maybe I should go read that section over,” just so I can try for the second time.
To study for the exam, Ginny relied heavily on her lecture notes. When the professor worked example or homework problems in class, she followed along closely, taking note of any steps she did not understand. In her own study of the material, she made sure to review the parts of the lecture and homework problems that caused confusion. She made use of the professor’s office hours or supplemental instruction sessions when she could not figure things out on her own. Throughout this process, she kept a running tally of what she gauged to be “good questions,” i.e., questions she thought might appear on the exams.

As the semester progressed and the demands on Ginny’s time increased, her level of preparation for class began to decrease, and at points she would find herself as much as half a chapter behind in reading and doing the homework problems. Although this occurred occasionally in her other classes, being behind in organic chemistry was of more concern for her:

If I get behind in my other classes, it seems like you could still just review the notes before the test and collect your notes all at the end whereas the organic builds on itself. If you don’t know what an alkene is or how to name it, then you won’t know what happens when it, you know, reacts with this material or that material and then what kind of molecule will form. So, I guess it’s easiest to get behind [in organic chemistry].

In addition, Ginny found the course material much more difficult and in-depth than material in her other courses. She attributed most of this difficulty to the newness of the material. As she stated, “Organic’s all new material.” Despite the difficulty of the course and the time management problems she encountered, Ginny was able to maintain her high level of performance on the online homework and exams throughout the semester. In fact, she only missed five points in lecture that semester and went on to earn one of the highest grades in the class.
In reflecting upon her experiences during the fall semester, Ginny was emphatic about how necessary it was to “hit the ground running” at the beginning of the semester and to be proactive if you did not understand something. Because her efforts the previous semester had mostly been successful, Ginny decided to maintain the status quo when it came to her study/preparation routine – with one exception: she intended to print the lecture notes off beforehand and use them during class:

Last semester, I thought it would be better to write the notes out in class in order to learn them. I did not find this very useful because I was just copying off the PowerPoint and not really comprehending the material. If I have the notes printed off already, I think I will be able to learn better and be able to add to the notes from the lecture.

From the beginning of the spring semester, Ginny noticed a significant increase both in the difficulty of the course and the amount of time needed for studying and completing course activities:

I feel like the second semester is a lot harder. I guess like last semester I don’t feel like I did as much work as I’m doing this semester and I’m not doing as well. I feel like there are a lot more reactions so it’s a lot more to remember for one test versus first semester there was maybe like five reactions if there were reactions at all…like just basic hydrogenation and that kind of thing whereas now it’s like there’s five methods of hydrogenation alone…I feel like I’m putting in more time reviewing and studying and it’s, I mean paying off…I would obviously be doing worse if I wasn’t doing that but it’s not as easy as last semester.

Ginny also noticed a difference in the material itself. In particular, she found it much less intuitive than material from the first semester:

I felt like the first semester, a lot of things as he was saying them in lecture, they made sense – they were like commonsense…for example, that a more hindered carbon wouldn’t be as reactive because the nucleophile couldn’t get in.
Unlike the first semester which she described as “a lot of basics,” the second semester was concerned with putting “everything that you learned in the first semester…into practice.” She was expected to learn more reactions, more mechanisms, and perform more syntheses. Ginny found this latter activity to be especially difficult:

…it’s just you can remember…you can use H₂ and nickel to add hydrogen to a bond but then there’s like four other ways so if you’re just looking for like what you react with, you can remember just that one but if you need five options just in case it’s one of the other options that’s given on the test...So, you have to know like multiple ways…and some things are used to maybe reduce…for example, something is used to reduce like a carboxylic acid and something else, the same thing, is used to reduce an aldehyde but then something else is used to like oxidize.

Unlike most of the other students involved in the study, Ginny had few problems with the second semester textbook. Although it was “not as simple as the last textbook,” she thought that “it does focus on specific reactions, but it still relates them all to the basic idea.” She found it well organized, easy to follow, and felt that it tried to impress upon the reader why certain reactions, such as those that form carbon-carbon bonds, are so important. She found the errors in the answer key in the back of the book frustrating and wished someone could have provided her with an accurate key so she could have been certain that when she got a problem wrong it was because of a mistake she made and not an error in the book itself. Ginny believed that one of the reasons that students were having difficulty in the textbook was the fact that the professor had told them that it was written as a graduate level text:

I think if he hadn’t come out in the very beginning and said this is a graduate level text...as soon as he said that, I think everyone – including myself – got in their mind that this text is going to be so hard whereas I was like...so that means I’ve got to read it and understand it...whereas other people just were like, “we’re undergraduates! Why are we having a graduate text?”...[Ginny’s fellow students] were kind of turned off by that idea. If they
wouldn’t have even known that it was a graduate text, I don’t think people would hate it as much as they do.

In an effort to prevent her grades from slipping, Ginny found it necessary to begin studying for the exams sooner and added note cards to her study regimen:

This semester I make note cards because there are so many reactions...I feel like I’m more careful to stay on top of it like each week and I feel like I study more in advance. Last semester sometimes I wouldn’t study until like two days before the test whereas now it’s like...right now we have a test next Friday and I’m thinking I need to start making my note cards and start studying and...it’s still a week away...and maybe it’s because I’m not doing as well, too. I want...to try to do as best as I can whereas last semester I was kind of doing well which was affirming the fact that I really didn’t need to change my study habits and just kind of coasting along I guess. This semester I’m not getting as good of grades so then I’m just like “what am I doing wrong?” I study earlier, you know, just trying...to fix the problems.

As Ginny indicated, the increased pace and difficulty in course material were reflected in her grades that semester. Although her grades were still good, they did not equal those from the previous semester. Nonetheless, Ginny still acknowledged that the spiral approach was still “the best way it could be organized.” Ginny felt that it would have been too overwhelming at first to learn all the reactions at once and felt that the foundation that she had gained in the first semester was “key...in know[ing] what was going on.”

During her year studying organic chemistry, Ginny’s goals underwent an evolution. Initially, she had been focused on achieving a firm and solid foundation but as the year began to come to a close, she became much more interested in getting a good grade as well:

To be completely honest, it’s the grade because later I’m going to have to be applying to pre-professional school and I think grades
definitely do matter...and I think that also getting the basis for it so that later when I have to, for example, study for the DAT, organic chemistry seems to be like the hardest section – but hopefully I won’t have to relearn it all completely.

In the end, Ginny thought she had been successful during her year-long journey though organic chemistry, earning a B during the spring semester. Although this was lower than what she had been aiming for, Ginny left organic chemistry with what she felt was a good understanding of the subject and was hopeful she could use the concepts she had learned in future situations.

Hannah

Hannah was one of the few students involved in the study who had no intentions of attending medical school – she wanted to work with animals when she finished her degree in zoology: “I love animals. I would rather spend my time with animals and taking care of them...I have been taking care of abandoned and stray animals since I was little. They just hold a soft spot in my heart.” Hannah was also unique because she had been through the organic chemistry sequence at Miami the previous year but was back to try to improve because she had earned a D in CHM 241.

Beginning in high school, Hannah had heard horror stories from her friends about how difficult she could expect chemistry to be. In particular, she had been told that organic chemistry would be “ridiculous. It’s so hard, you’ll never understand it. The mechanisms are difficult; the memorization is impossible.” By and large, she felt that this was exactly what she had experienced in her first encounter with organic chemistry the previous year. Further complicating matters was the fact that she had no idea why she was being required to take organic chemistry:

...everyone I’ve talked to, you know, that works with animals or in the type of stuff I want to do – or even in research – they’re like, “yeah, we had to take [organic chemistry] but we never use it.” No
one has really explained why zoology majors need organic chemistry.

Her confusion at this point was all the more remarkable considering she had already studied a full year of organic chemistry. Hannah was also struck by the cumulative nature of organic chemistry – much more so than any other course she had taken:

    Well, I mean every course has that [building off previous material] somewhat. I mean, like in zoology, or microbiology, or basic biology courses you have like DNA replication where you have to learn how it replicates, how it recombines. You have to learn meiosis and you have to learn transcription and translation but then when you’re done with that, you move on to something entirely different. So, you have to learn it at chunks at a time but not like through a whole year like you have to do with chemistry…and even like in statistics and calc., I mean, it will focus like on probability for a month and then you’ll go to something else where you’ll focus on integrating for a month and then you’ll go on to something else. So, I think chem. is unique – and I know they all say that they all build and all this stuff – but I mean chemistry is the one that does it the most that I’ve seen in all the classes I’ve taken…I guess you could say history does but…not to the extent that o. chem. does because you just learn it, you’re not really applying it.

Although Hannah expected the worst from her repeat journey through organic chemistry, she came to realize that it was not going to be as bad as she had initially predicted. She attributed many of the improvements to the curriculum change that had been implemented:

    They’re not trying to cram like such specific mechanisms and reactions that you have to remember and then reproduce on the tests. It’s just like general and an overview…Dr. Hershberger tries to explain it as well as he can and I like the book. I think the book helps really well and it goes step-by-step and I do the problems in the book and then I like the homework – I like being forced to have to do it because that makes you understand it and apply and study.
So, I really like that. I think if they would have had stuff like that last year, I might have been more inclined to pay attention more and do better.

Beyond the perceived improvements due to the curriculum change, Hannah admitted that her study habits had changed as well:

...I go and attend the lectures everyday and I write down his notes and then after like class every Monday, Wednesday, and Friday I go home and read the sections that he talked about in class and do the problems in the chapter that cover those sections. Then I’ll go and get on the Wiley site and see if there are any problems that we covered like in class that would apply to the material we covered in class. Monday we talked about naming benzenes so I went through and saw if there were any homework problems naming benzene and then I do like those problems...I think that helps me retain it because I read it and then I do the problems and then I do the homework so that’s three different ways of knowing the material.

[When studying for an exam,] I go back and I read each of the chapters that the test will be over or every section that the test will be over. I look back through all the homework problems like within the chapter – I don’t really do the ones at the end of the chapter because I figure that if I understand the ones in the chapter, that’s good enough – and then I get on the Wiley website and I look at all of the homework questions again and then I try to answer them without looking at the answers that I’ve answered below...and I read his notes and practice drawing mechanisms and memorizing all of the reactions. I guess it’s a lot.

[Interviewer: So how is this different from last year? What would you typically do in 241 last year?] Just read the book – I never did problems. Well, I did at the beginning of the year but I just didn’t understand the material in lecture and I didn’t understand reading the book without any help from the teacher so doing problems for me was basically worthless because I would just look at the answers in the book. So, last year I would just read the book and hope to God things somehow magically clicked, which was really
bad, I know. So I really, really work at it a lot more this year because I don’t want to take it again – I just want it over with and done.

In reflecting on her improvements from the previous year, Hannah was adamant that they were a function of two factors: the improved course structure and her increased efforts, not the fact that it was her second time working with the material:

...yeah, I guess you could say, well, it’s your second time doing it but last year, I mean, you could have asked me how to add HBr to an alkene and I couldn’t have told you...like I couldn’t even understand the basic mechanism like a Markovnikov rule...it just didn’t click with me at all and now you can ask me any reaction that we’ve learned this semester and I can tell you how it works, how it adds. I can draw you the mechanism; I can do anything. So...I mean, yeah, I’m seeing it again but it’s just like, “Oh, I saw that last year but I didn’t understand it.”...[it’s not] like I’m just freshening up my memory, you know. For me, it’s actually relearning everything like from the beginning...

Hannah’s goals for the semester were simple: “I just want a C and [to] move on.” When we talked towards the end of October, however, Hannah was pleasantly surprised – shocked in fact – to report that she was doing significantly better than that and “much, much, much better” than she had ever expected. By maintaining her high level of preparation, Hannah was able to continue to excel the rest of the semester, earning an A for her efforts. Because Hannah had received a C in CHM 242 the previous year, she decided not to retake the second semester.

Katie

Katie was a freshman zoology major when she became involved with the study – something that made her unique, as all of the other students involved in the study were upperclassmen. She explained her choice of major:
...because I have always been interested in biology. I have recently considered applying to medical school when the time comes, but I am still unsure of what I would like to do. I chose zoology instead of the other life science options because I have always loved animals and I thought that I could learn more about animal physiology through the zoology program.

As the academic year progressed, Katie’s future plans began to solidify and eventually coalesced around the idea of her becoming a veterinarian.

Katie recognized that organic chemistry was one of the prerequisites for medical school, and by studying organic chemistry, she was hopeful that she could gain a better understanding of how life was created and sustained:

[Chemistry is] the basis of life. The most fundamental part of life is the molecules coming together to create life...and they have to all work together in order to create an organism...Once you have a solid foundation in inorganic and organic chemistry...you understand why things are alive or not alive.

During high school, Katie had been quite successful in her chemistry classes. By earning A’s in her AP chemistry course and achieving the requisite score on the AP test, she was able to earn credit for both semesters of general chemistry, and as such, immediately enrolled in organic chemistry during her freshman year at Miami. Katie was apprehensive about this since she was concerned that organic chemistry “[would] require remembering things from general chemistry here, which I did not take [at Miami]...” It also did not help that she had heard from a number of people – her high school chemistry teacher and members of the Miami University marching band among them – that organic would be difficult and require “a lot of memorization.”

As she progressed through the fall semester, Katie came to realize that her organic chemistry lecture course was not as difficult as she was initially expecting it to be. She thought “the professor’s a really good one. He explains everything well...and
he’s really open to helping you if you don’t understand.” She found the pacing of the course to be appropriate, and the difficulty only slightly higher than the other courses she was taking that semester. She attributed this increased difficulty mostly to the fact that organic chemistry was “an upper-level course, so they expect you to do more…[In addition,] less time is wasted. In some of my other classes, the professors like to go on tangents.”

Her experiences in lab were very different. She was anxious about the experiments and using equipment that the other students might have learned how to use in general chemistry. Although these fears turned out to be baseless, she encountered other difficulties:

I understand like the equipment and the lab procedures but…the lab lecture is difficult…There’s no real books or anything you can look at if you don’t understand…[there are] worksheets online but they don’t really explain anything and the lab manual is, it’s not bad, but it could be better. It’s just very…it’s not in-depth. It just tells you to do things but not really why it works or what’s going, what you’re doing. It just says follow these steps and hope it works.

When it came time to prepare for class each day, Katie did little in advance. She did, however, make it a point to “do the homework then…read over the book and my notes” afterwards. To prepare for tests, Katie typically started studying the weekend before the exam. She began by going back through the book and class notes, testing herself for understanding as she went. In those instances where she found she didn’t understand a concept, she worked problems from the book until she did. Initially, this system worked well for her – Katie scored 100 on her first exam; however, as the semester progressed, her exam scores began to decrease.

In reflecting upon the strengths and weaknesses of her study habits, she felt that she probably needed to start studying earlier since she usually had so many other
demands – both academic and extracurricular – upon her. Further, she felt that there was much material that she was required to remember for each exam: “Memorization – there was a lot to memorize and I didn’t take enough time to memorize everything well enough as we learned it. I tried to memorize it all too close to the exams…I was unsuccessful in trying to cram for exams.” Even with these problems, Katie performed better than she had initially expected. In early November, she was hopeful that she could still earn an A for the fall semester. She earned a B that semester.

Katie recognized that her biggest problem with organic chemistry during the fall semester was time management. She even knew what she needed to do to solve this problem: “spend a chunk of time each day studying it [organic chemistry] and not leave it all until the last minute.” Despite this knowledge, however, Katie made no initial changes to her study habits during the spring semester, and as such, the same time management problems began to appear. Indeed, she found that her involvement in extracurricular activities and other courses made it difficult to find time to study even when she absolutely needed to.

These time management problems were compounded by what Katie perceived to be an increase in the difficulty of the course. She attributed this increase in difficulty primarily to three factors: the sheer amount of material she was expected to remember, the cumulative nature of the course, and the increase in the number and complexity of synthesis problems students were assigned in the homework and asked to complete on exams:

I would say the main reason [for the increase in difficulty] is because it builds on things and it’s tough to remember back to all reactions and everything we’d already learned that I’d sort of forgotten….I think…the synthesis problems and trying to think of all of the reactions that we’ve ever learned and trying to put them together to make something…it becomes overwhelming.
Katie described the material in the second semester as “learning how to combine reactions that we learned last semester and building on them to actually do bigger things with them.” She did not like such an approach because she felt that... it makes it more confusing. I think I would rather learn it all at one time rather than trying to go back. I like doing things in order. It is easier for me to follow something all the way through instead of stopping half way through learning the entire sequence of reactions and then trying to go back and picking up where we left off so long ago.

The only advantage that she found to this spiral approach was that it would help her ultimately review for the comprehensive final she would take at the end of the semester.

As the spring semester progressed, Katie faced the prospect of earning a C in the course – something that caused her to seriously consider dropping organic chemistry. Late in the semester, Katie finally started following her own advice and began studying for her exams earlier. Although her grade on the last hour exam improved significantly over the previous three, it was not possible for her to make up the deficient from the earlier exams. Consequently, she earned the C that she had so desperately wanted to avoid. Katie’s recommendation to future organic chemistry students was simple: “Spend a lot of time...and you will go far.”

Lily

Lily had been quite successful in her studies of chemistry, earning A’s not only throughout high school, but also in both semesters of general chemistry during her freshman year. Despite her previous academic success, Lily remained undecided about her major throughout most of her freshman year, only declaring as a zoology major at the end of her freshman year “to ensure that I had a set structure/plan for the rest of my
college career.” In writing about her goals for organic chemistry, she hoped the subject would help her:

…gain a little more understanding of what I want to do with the rest of my life. Not that the information provided in organic will directly provide answers, but if the materials we learn this year are interesting enough, it might be what I need to push me in a particular direction in terms of career goals. Though I do not know [in] what specific area I wish to immerse myself, I know that working in a scientific field with animals or people is the general area I would like to continue exploring.

For Lily, taking organic chemistry was important because she hoped it would allow her to acquire a fuller understanding of the compounds that make up living organisms. Although she did not quite know what she wanted to do with her degree in zoology, she felt that “knowledge in this area would be essential when entering a field that deals with animals, humans, preparation for medicine, etc.”.

Initially, Lily admitted that she was apprehensive about taking organic chemistry because she had heard people around campus tell her how difficult it would be. Unlike many, however, Lily also had strong authority figures in her life who were well acquainted with organic chemistry and had presented her with a more positive view of the subject:

My mom’s a chemist...She loved organic chemistry – thought it was the greatest thing in the world...I don’t know...I didn’t really think of it as being, you know, a horrible thing that I was going to have to take organic chemistry. I also have other friends who do chemist-type work in their jobs, um...family, close friends of the family...and they all said they liked organic chemistry. So, it was really only at school where it was, “Oh my gosh,” you know, “you have to take o. chem.?! That’s awful and it was horrible when I took it.”
Lily indicated that she was more likely to believe the views of her family and friends than of students she had spoken with on campus. As she put it, “…I wouldn’t exactly take anything they [fellow students] said to heart because it would be different for different people.”

Overall, she found the reality of organic chemistry to more closely resemble what her family and friends had told her than the “horror stories” she had heard around campus. She found the difficulty and the pacing of the course to be equivalent to the other classes she was taking that semester. This was not to say, however, that she did not occasionally encounter problems with the course material. In particular, she found it difficult to predict whether a given reaction would proceed via an E1, E2, S_N1, or S_N2 pathway:

[Interviewer: So why do you think that they gave you the most problems?] Because you had so many things you had to look into… it was a lot easier to just be able to say, you know, with primary S_N1 and E1 never happen and that… those kind of things… um, but a lot of times solvents are not only solvents but they’re nucleophiles and that was a little difficult to be able to decide which one was acting as the nucleophile and what was acting as the solvent. Sometimes they would only give you one and I guess it was acting as both and then other times they would give you two different things and it’s, you know, both of them could act as nucleophiles and you knew that one was and one was solvent but considering they both could react as nucleophiles, it was difficult to decide which one would react and which one wouldn’t.

To help address these occasional problems, Lily developed a system for preparing for class and studying for exams that she felt worked well. Whenever possible, she would try to read the chapter before going to class. In this way, she could “get some kind of general idea of what we’re talking about.” In those instances when she did not have time to read the chapter before class, she would do so as soon as
possible afterwards. Midway through the semester, Lily decided to print the notes before lecture so she could focus more on “where he’s [Dr. Hershberger] pointing and where electrons are moving” instead of “furiously copy[ing] down what he has [written].”

To prepare for an exam, Lily started with the supplemental problems from the textbook, relying upon them when she was having particular trouble grasping a certain concept. Lily’s overall impression of the textbook was positive; she greatly appreciated the detailed explanations provided about why a certain answer was correct. Starting with the second exam, Lily began to make note cards since she was going to be required to remember reactions and reaction mechanisms:

...I had note cards of all the different reactions that had to do with alcohols – whether they react with metals or anything else – and I would go over them as far as memorizing them and then afterward when I felt that I had them, I would use the note cards and I would actually write it out before I looked on the other side to make sure I had it correct since we had to be writing out the mechanisms on the exam...Using them, I was able to ask myself questions, physically write down the answer – be it drawing a specific molecule, configuration, reaction, or trend – and then flip the card over to make sure my answers and thinking were correct.

Reflecting on her use of note cards, Lily felt that they were particularly useful for her when she needed to do targeted studying of course material or memorize large amounts of factual information – for example, lists of protic and aprotic solvents.

Overall, she believed her study habits to be effective and had no plans of changing them after the second exam. She anticipated doing “pretty well” in the course and this prediction came true – Lily earned a high A – and in the process, gained a better understanding of what she wanted to do with her life. She ultimately decided late in the fall semester to transfer to Ohio State where she planned to enter their dental hygiene program.
For as long as Luna could remember, she had wanted to become a doctor. This desire had started when Luna had accompanied her mother, who was also a doctor, to work and saw how much of a difference a doctor could make in the lives of her patients. As Luna got older, she found that she also really liked math and science – especially biology. Further, during the two previous summers, Luna had volunteered at the Cleveland Clinic. Throughout most of the first summer, she had worked mainly with patients in the office, but during the second summer, Luna worked in one of the research labs. All of these experiences reinforced Luna’s desire to become a doctor – as she put it, “things sort of all fell into place.”

From the time that Luna started taking chemistry in high school, she had been told how difficult she could expect organic chemistry to be. Her tenth grade chemistry teacher told her that organic chemistry was “a huge weed out class” and that she could expect only 30% of the class to still be there at the end of the year. Other friends told her that it was going to be tough and that it would be “this big hump you go through” where you prove to yourself and others that you have what it takes to be successful in medical school.

Luna’s zoology major did not require her to take organic chemistry; however, she did anyway because she knew it would be required for medical school. Although she didn’t know why it was important for her future career, she speculated that

Organic chemistry is the study of the chemistry of carbon, which is the basis of life. We will learn how organic reactions work, which is extremely important to medicine. Understanding the chemical reactions that occur in medicine, and their effects, and why it occurs is crucial.

Luna anticipated that organic chemistry was going to be a “real challenge.” The primary questions Luna had about organic chemistry before taking the course were
whether it was conceptually difficult or if it was difficult because there was a great deal of information to memorize. She was also concerned about how complete the textbook would be:

I was wondering, is the textbook complete by giving you lots of examples? Or, is it a lot you have to concentrate and figure it out on your own? So, I was hoping it wouldn’t, you know, you just have figure it out on your own. I was hoping there would be lots of examples and things that fully explain the concepts.

The reality that Luna encountered was very different from what others had told her. She found organic chemistry to be “a lot more manageable” than she had anticipated. She even admitted that she enjoyed the subject and actually looked forward to studying it because she liked it so much more than the other courses she was taking during the fall semester. Luna found organic chemistry to be “really straightforward,” and further, it reinforced her conception of the nature of scientific knowledge.

[Organic chemistry] is probably one of my easier classes just because it is straightforward...[In my] Spanish class, I feel like that is so subjective sometimes. My exams are like essays, you know, and it’s really difficult to get at exactly what the professor wants even though I may understand the material...So, I definitely think that because I am such a science person and I like to know that there is a right answer and I can get that right answer if I just know the processes, that organic is one of my easier classes.

Initially, Luna took a proactive stance when it came to preparing for class each day. She would look over her notes from the previous lecture and would read ahead in textbook. After class, she frequently re-read those sections they had covered and worked any relevant problems. When it came time to study for the exam, Luna reviewed her notes and went back and re-worked all of the problems that had been assigned. If she had questions about anything, she would ask her roommate for help or
take the question to one of the Supplemental Instruction sessions. Luna scored 100% on the first exam.

After such a strong start, Luna was confident that she could maintain the same level of performance throughout the semester and earn an A for the course. Unfortunately, Luna became a little too overconfident, and in conjunction with a time-consuming extracurricular activity, she did not spend nearly as much time studying and preparing for the second exam as she had the first. Subsequently, she did not do as well. While she recognized that her time management may have influenced her lower exam score, Luna also thought that some of the concepts tested on the second exam were harder to grasp:

...for example, S_N1, S_N2, E1, E2... is just sort of an odd concept to me versus exam one...I think it [the material on exam one] was a lot of, you know, \( a \rightarrow b \), \( b \rightarrow c \). For some reason, I just never got a strong handle on it, but I wonder if I had studied more, would I be able to or would I have just memorized things better?

Despite her lower performance on the second exam and a subsequent pledge to devote more time to for study organic chemistry, Luna found time management to be a constant problem during the fall semester. Even in those cases when she did devote more time to studying organic chemistry, she found the material increasingly difficult because she had to continuously play catch-up with the material she had been ignoring. Although her goal of getting an A for the semester seemed in jeopardy – her grades on the last three exams were all B’s – she was able to score one of the higher grades on the final exam and ended with the A she so desired.

Luna, like many of her fellow students, struggled with the first semester laboratory course. Beyond her initial unfamiliarity with many of the laboratory instruments and equipment, she believed that the laboratory procedures did not provide sufficient detail for her to successfully complete the labs. Furthermore, these
procedures were frequently modified at the beginning of class so she had to make adjustments quickly – something she was not good at. Because of these last-minute changes, Luna described the laboratory environment as “chaotic.”

Luna expected the spring semester to be even more difficult than the first and was determined not to let her time management problems resurface:

So, this semester, I knew I had to start off strong and not start off low because I would keep going down. So, this semester has been a lot harder...just the material and everything we’ve had to know for each exam. I have not been doing as well as I would like partially due to...not knowing the information as well as I should for the exams and because it is more cumulative. I tend to forget things from before.

Learning from the time management mistakes she made during the fall semester, Luna spent a great deal of time reviewing her notes: “We have exam four coming up and we’ve been going over material for the last two weeks...so, this afternoon, I looked over my notes for all of exam four. I’ve been doing that more frequently now...”

Beyond studying her notes more, she also modified what she did to prepare for exams. Because many of problems on the exams involved predicting the products of reactions and designing synthetic schemes, Luna worked to learn a few reactions everyday instead of all at once. She and her roommate made roadmap problems for each other to exchange for additional practice. The essence of most of Luna’s study methods distilled down to the act of writing; be it writing information on flashcards or writing reactions down repeatedly on a piece of paper. She found the act of writing to be a good way of testing herself:

...I think I would just sit there [if I didn’t write things down] and so by forcing myself to try to write it down from memory, it really tests whether I know it or not. By writing it down repeatedly, I can sort of visualize it that way. So, otherwise if I were just to quiz myself sitting there without writing it down...I can’t keep them straight and then, you know, it’s hard to see what I know.
Despite all of her preparation, Luna believed that organic chemistry was the most difficult course she took during the spring semester. In fact, because of all of the time she committed to study organic chemistry, she felt that it was the most difficult course she had taken all year. It wasn’t the content itself that Luna found most difficult, but the sheer amount of it and being expected to synthesize the concepts:

When we learn things like one reaction at a time or mechanism at a time, it’s not difficult. I think putting things together and having to do a synthesis problem is one of the more difficult things. Having to put everything together and sort of use your creativity, and knowing that you know everything solid to come up with a synthesis problem is difficult. That’s the most difficult thing of it other than just keeping everything straight...

Luna also had problems with using the second semester textbook. She found the problems annoying to work because she didn’t know if she was expected to be able to solve them because they didn’t cover all of the reactions highlighted in the book. In addition, because many of the answers in the back of the book were incorrect, she had difficulty deciding if she had done something incorrectly or if the answer was incorrect. Because of these problems, she rarely used the textbook to prepare.

Luna admitted that she was frustrated with her performance during the spring semester. Despite the fact that her exam scores were higher than those from the previous semester – and indeed, unlike many of the other students in the class, her grades increased during the semester – she was still not meeting the high standards she had set for herself. To her, nothing less than an A was acceptable:

At one level, there is success for myself knowing that I did the best I could and I prepared and I truly did the best I could – that’s being successful. And then there’s another level which everyone else sees which is your grade. If I got an A, I would say I’m successful, period. If I got a B, I’d be like, well, I’m semi-successful. [If I had to rate my success] like on a 0 to 10, I’d say 8.5.
[Interviewer: Ok, so 8.5 seems pretty good!] But 8.5 is a B!

Luna pushed herself even harder to succeed. She increased the amount of time each day she devoted to organic chemistry and started studying for the standardized final exam three weeks in advance. Luna did exceptionally well on the final, and given her consistently solid performance on the other exams, Luna earned an A for the spring semester.

Marietta

Marietta was a sophomore zoology major who dreamt of eventually becoming a veterinarian. Her goals for organic chemistry were “to gain an understanding of how this subject works and try to relate it to my future career.” In the process, she was hoping to earn “a B or higher;” however, she was worried about whether she would be able to earn such a grade given her test taking abilities and the free response tests she had heard organic chemistry utilized. Instead, she used her ability to verbally explain the topics to others as her measure of success.

If I can explain the topics to someone who doesn’t understand them without getting really confused myself, [I will consider myself successful.] That way if I’m not doing well on tests, I will know personally that it’s not my knowledge but my test taking abilities that have failed.

Before Marietta organic chemistry, she indicated that she had heard a number of “horror stories” about how difficult organic was going to be. She had been told by friends who had previously taken organic chemistry that the averages on exams were usually around 50% “so if you get a C, that’s technically an A.” Others had talked about how strict the grading was on these exams. For example, a friend had utilized a single reaction arrow instead of indicating that an equilibrium had existed and “apparently he got off like a ton of points.” Coupled with the large amount of
memorization rumored to be in the course, she expected organic chemistry to be “really, really brutal.”

Marietta believed that there were a couple of reasons why pre-professional students were required to take organic chemistry. She described organic chemistry as a “challenge course.” By excelling in such a course, Marietta felt that she, and other students like her with intentions of attending professional school, could prove that they could eventually be successful in such an endeavor. Secondly, she described organic chemistry as being at the base of all modern medicine:

...organic chemistry actually is the basis of a lot of medicine. So, I mean, if you’re going into that field then...you’re going to have to deal with it at some point or another...I know we’ve already talked about a few compounds that are regular, on-the-market medicines and then I saw in the book...the structure for serotonin...I mean, it may not be directly affecting, you know, what exactly you’re doing, but it’s going to be there anyway and you should know it.

When asked how she would respond to students who felt that the study of organic chemistry was not important because they had been told so by their own doctors, Marietta was still quite insistent that learning organic chemistry was a valuable activity to future doctors:

...it may not be apparent [why organic chemistry is important] but I’m sure it comes up at some point; in some indirect, maybe, even secondary source. There is organic chemistry because it makes up almost everything – any sort of compound practically...and I would tell them to focus on that. They have to take the class, so take the class...I mean, it’s a challenge and if you can do that, well, you’ll feel pretty sweet about yourself. Like, alright I did that! Two, I mean that’s more concepts you’ve got under your belt and helps you build on, you know, how you study and learn.

Given all the things Marietta had heard from others, she was anxious about how difficult organic chemistry was and how unhelpful the professors were. The reality she
encountered was very different from what she had initially expected. She thought the professor was “awesome” and always willing to help her and other students when they had questions. When she had questions, she would either visit the professor during his office hours or attend one of the weekly Supplemental Instruction sessions.

Regarding preparation for class each day, Marietta did not do much. This wasn’t because she didn’t want to; rather, she found it difficult to tell which sections in the textbook corresponded to the topics that were going to be covered in class that day. Because the textbook was used only as a “blueprint”, the professor frequently jumped around among the chapters. As such, most of the work Marietta did was done after class. Marietta studied in detail the textbook – reading the text and then carefully analyzing the reactions and the mechanisms for the sections covered that day in class. She then attempted to complete any relevant problems. If time allowed, she visited the website accompanying the textbook and explored any bonus material located there. This bonus material included interactive animations, end-of-the-chapter quizzes, and pre-made flashcards.

She prepared similarly in how she studied for an exam. Although she had done well on the first exam, her performance on the second exam was much lower. She attributed the lower performance in part to the increasingly difficult material. In particular, she had problems with substitution and elimination reactions and being able to tell which conditions and starting materials would lead to which product. Not content with decrease in her performance, Marietta began to search for what she hoped would be more effective ways of studying for exams. Her first change was to add flashcards to her routine.

When Marietta began her study of organic chemistry, she believed that it was not the sort of class that lent itself well to the use of flashcards; however, after seeing other students use them, she decided to try them out for herself. Initially, she used the flashcards only for pure memorization – for example, naming different benzene
derivatives – but quickly began to rely upon them to study reactions and mechanisms as well. She found the easy repetition that flashcards offered to be helpful in trying to learn all of the information and was further attracted to their visual nature. Marietta considered herself to be a visually-oriented person and viewed flashcards as a means of making a “visual connection” to the material.

Throughout much of the fall semester, Marietta found taking notes during class to be difficult:

So, every time I want to look back through my notes to maybe have some sort of resource in trying to figure out a problem, I look at them and go, “what does this mean?” Instead, I have to turn and go to the book and then read the book over…I don’t look at my notes a lot because I really don’t remember what they’re trying to tell me…I’m trying to work on taking notes but it’s kind of hard to be writing and paying attention to what he’s doing and listening at the same time.

To help with note taking, Marietta began printing the lecture notes before going to class each day. By not having to frantically write down all of the notes, she was instead able to better focus on what the professor was saying.

At the beginning of the semester, Marietta had indicated she would be happy with a C in the course; however, by mid-term, she was hoping to get a B+, a high B “would be pretty awesome.” By making modifications to her study and note taking skills, Marietta was able to reverse the downward trend in her exam scores and earned the high B she had been hoping for.

Despite her initial difficulties, Marietta felt that she had been generally successful during the fall semester. In reflecting upon her experiences, she thought that organic chemistry had been “a lot of work but it’s not impossible.” She indicated she would have started to use the flashcards from the very beginning and tried to find more free response-type problems to practice – including making her own up – when studying for
the exams instead of relying solely on the multiple choice questions included in the online assignments.

Having learned from her experiences during the fall semester, Marietta moved into the spring semester with enthusiasm. She had generally enjoyed the material taught during the fall semester and found the new material to be equally interesting. “I like what we’re learning,” she said. “I think all the different ways to create new carbons and put pieces together is really interesting.” Marietta described this new material as more “hands-on”:

...whereas last semester was here’s how to name a compound, here’s how to make this specific compound this specific way. This one’s more like “well, you could do this but other people have done experiments where you can do this instead” and so there’s about five different ways for doing one thing and the differences between them are like one tiny little reagent so it’s more based off of “do you know how you can put this together?” as opposed to “here’s what’s going on – just learn it.”

Marietta found this “hands-on” material to be more difficult than the previous semester. She felt that the material required you to “understand about what’s going on with the reactions as opposed to knowing just basic ways of naming or, you know, how to make small compounds. This is a lot more intense.” Despite the changes she had made to her note taking during the fall semester, Marietta once again found herself struggling with interpreting her notes after class:

...you have to pay attention to what he’s saying, look at the examples he’s giving, and try to write at the same time, and because I guess I can’t organize those three things together well, it ends up being a jumble of what I’m hearing, seeing, and trying to like watch at the same time...when I go back through them [notes], it’s like parts are missing and it’s not fully explained and I’m like, “Wait! How did we get this product? Where’s this extra little substituent coming from?” and just problems where I have to go and ask somebody...or go to SI and redo the entire example.
Marietta did not consider herself particularly adept at multitasking and was at a loss as to what she could possibly do to remedy the problems she was having with her note taking skills.

To fill in the gaps in her notes, Marietta frequently turned to the textbook for help; however, she found that resource difficult to use. In fact, using the textbook turned out to be the biggest challenge for Marietta during the spring semester:

The biggest challenge this semester is working with the book...when you’re trying to learn from the book, which is really the only other source we have besides lectures...and they’re expecting you to already know a lot of stuff about organic chemistry, which we do, but not enough to really go through the book and pick out the information we need...They have a lot of extra stuff that we don't need to worry about. [For example,] they have a lot of electronegativity that says, “well, this is this charge, and this is this charge” which ends up being inconsequential to the answer I’m looking for...the author of the book has his very specific way of writing stuff out – the way he writes out his equation formulas, the way he uses abbreviations – and they’re completely different from what Dr. Hershberger uses. So, bridging a gap between the two sources is kind of hard. So, I like the subject matter; I just don’t like the book. I think it’s not helpful at all.

Marietta indicated that she spent more time studying for organic chemistry than she did for any of her other classes. She did admit, however, that some of that time could have perhaps been better utilized in trying to really understand the concepts instead of just trying to memorize everything. Unfortunately, Marietta felt that because of the other time constraints in her life that memorization was the more efficient way to study:

[Interviewer: Is there anything that you feel is ineffective or needs improvement in what you do to study for organic chemistry?]...maybe too much memorization where in all of the stuff you’re memorizing, you forget, you know, the concept behind it. That’s probably something that I do because it’s a lot easier to
memorize and say, “Ok, I know what this is” but what does it do? “Oh shoot. I don’t know.” Honestly, though, sometimes it’s hard to maybe find the time I need to learn the concept and it’s just easier to memorize and worry about really learning the concept later.

At the beginning of the spring semester, Marietta reported that the professor had told the students that they would start putting together the pieces from the previous semester. Marietta was certainly able to see this process occurring and thought it was a good way of giving “a meaning to what you’ve learned,” provided you could remember the specific features of those pieces. Based upon her experiences during the fall semester, she felt that she could earn another B. However, this process was not as easy as she had initially anticipated and she earned a C. In describing her definitions of success in organic chemistry, Marietta felt that her grade was only one part of success – of equal importance was being able to “actually explain what you’re learning to someone else who may be familiar with chemistry but not exactly organic chemistry.” In this regard, Marietta considered herself successful.

Parvati

Ever since she had been a child, Parvati dreamt of becoming a doctor. She had grown up surrounded by immediate family members who were deeply involved in medicine and had been fascinated by the exciting stories they would share with her:

…my mom’s a nurse, a cardiac nurse, and she floats around wherever she needs to go. Right now she’s specializing in cardiology and she comes home with all of these wonderful stories – and some of them are not so wonderful – but it’s intriguing. It’s just sitting there and listening to her and I actually had the opportunity for the past three summers to work at the hospital, observe surgeries, and work with doctors and I think it’s the most wonderful thing ever. There’s nothing else I would rather do than become a doctor.
Parvati was particularly drawn to a doctor’s “ability to help someone on the spot and maybe you can even save a life by something simple that you do.” She also found the rush of energy and excitement associated with emergency medicine appealing.

Like many of her peers, Parvati had trouble understanding how organic chemistry was relevant to her future career as a doctor. In fact, many of the doctors she had worked with in the past had also perpetuated the belief that organic chemistry was not important for a future doctor like her: “…it discourages me when I talk to all of these doctors at the hospital – they’re like, ‘I don’t know why they still make you take organic chemistry’ and depending, I guess, on what field of medicine you go into, you really don’t need it…” Interestingly enough, Parvati reported that some of her friends were convinced that organic chemistry was an important subject for pre-medical students to learn, and in the past, she had had “arguments” with some of them with regards to its relevance:

[T]hey say that we need to take organic chemistry because it’s really important. You have to understand the basis of what’s going on – the reactions. I can see that. I know everything is organic and all of that, but the detail of reactions we do in class, starburst reaction, alcohols…I just can’t understand why I need to do that for med. school.

In the end, although she never quite understood why it was required of her, she eventually concluded “it’s a pre-req [for medical school]. I have to take it. I need it for my MCATs so I’m in there.”

Prior to eleventh grade, Parvati had been educated in the Middle East where the typical high school chemistry course incorporated some basic organic chemistry: “…we started like naming IUPAC compounds, basic reactions – [for example,] how carboxylic acids react – like general properties of all the different groups.” Because of this previous experience, she expected her more formal study of organic chemistry in
college to be difficult and time consuming. Parvati witnessed her roommate’s struggle with organic chemistry the previous year, leaving her anxious and worried:

...well, I lived in a triple last year and two of us were pre-med majors. So, my roommate was taking o. chem. – she’s a chemistry major – and she didn’t do so great in the class...So, we’d all be studying and she’d sit there and she’d study and she’d study and she’d study and she said the test went kind of well but when she came back, it didn’t go so well...I mean, I’d see her putting all of these efforts and these hours studying and not getting anywhere....and then second semester she took o. chem. 2 which she thought would go better because she studied all the time for that but apparently it didn’t go any better...

[Interviewer: So, she made it through eventually?] No. No, she didn’t make it through it and she’s a chemistry major. She’s actually taking the class second time around with Hershberger this semester. So, it’s worrisome.

As the semester progressed, she was pleasantly surprised to find that it was not as difficult as she had originally anticipated. Parvati happily reported that she was “doing better in this class than...in my general chemistry class. It’s interesting.” The pacing of the course was equivalent to the other courses she took that semester – about a chapter a week – and she admitted that she had “a better grasp on o. chem. than...some of my other science classes.” In other ways, though, her expectations did match the reality she encountered. She found the course was time consuming, and on occasion, difficult to understand; however, she believed that sufficient resources were available to assist students with their problems (e.g., the professor’s office hours and Supplemental Instruction). In addition, she strongly believed that she would eventually succeed in the course by investing the needed time and effort in preparing and studying. As she put it, “I expected it [organic chemistry] to be hard and intend on working hard in the class.”
Early in the fall semester, Parvati came to realize that if she was going to be successful in organic chemistry, it must become part of her daily routine. An integral component of this routine – during both the fall and spring semesters – was working with her roommate. Although her routine evolved over the course of the academic year, her reliance on a more collaborative learning strategy remained constant. Parvati printed out the lectures notes and used those as a guide during lecture. After lecture, she and her roommate sat down together and worked through the textbook problems, relying on their combined knowledge-base to answer any questions. In the event that both were confused about a particular topic, they took their questions to the professor’s office hours or the Supplemental Instruction sessions. Finally, they worked together to answer the online homework and quiz questions. Parvati found these problems particularly helpful because they forced her to remain up-to-date with the material.

Studying for exams was done collaboratively as well. She and her roommate started by re-reading all of the chapters, doing all of the example problems at the end of each section as they did so. Once finished with each chapter, they randomly selected a few problems from each section or concept from the end-of-chapter problems to ensure that they fully understood the material. When time allowed, Parvati worked through the online homework and quiz problems. Parvati reported that this formula worked well for her on the first exam – she earned a 92%. However, as demands for her time increased, she found it more and more difficult to maintain the stringent study schedule she and her roommate had developed earlier in the semester. Subsequently, her exam scores began to drop:

…”things got really busy because we had all of these exams, and I have all these other classes. So, I didn’t actually work on my textbook problems too much. I did a lot of the examples…after each section. I did my [online homework] and attended a couple of SI sessions and I did the extra problems there, but I know I definitely slacked off on my exam because I didn’t do as well.
Although she never reached the success that she had with her first exam, Parvati did maintain a solid B in the course – better than she had ever done before in a chemistry class.

In reflecting on the difficulties she encountered the first semester, Parvati was continually amazed by how much memorization there was in organic chemistry and how many possibilities you had to consider for each problem:

It’s a lot of information. It’s a lot of reactions and it’s hard to put everything together...it’s so many reactions. God! It’s like you have to sit down, like really think and pour everything from different places and make sure your answer is right because there’s so many possibilities that you could put down. The ones that come to your head immediately and you know they’re not right because the most obvious thing...and I don’t know whether to think this reaction, and oh wait, this is a strong base or no, it’s a weak base. So, it’s just like a lot of information to kind of put down on paper. It’s not so easy. It’s confusing...it’s all...if one is not this, it’s this, but if it’s this but it doesn’t have this, it’s this. So, it’s just...everything overlaps so there’s like a fine difference between everything and you really have to be on the dot to like know stuff...

She ultimately lamented that the root of some of the problems she encountered during the fall semester stemmed from her own lack of preparation. This, more than anything else, was the one thing she planned to change for the spring semester.

As the spring semester began, Parvati had high hopes that she would be able to spend the time that she needed to achieve the success she had witnessed on the first exam of the fall semester. Unfortunately, she began encountering the same problems from the previous semester almost immediately: “I didn’t do so well on my first exam just because I didn’t study as much as I should have.” After this lower-than-expected exam score, Parvati decided that it was time to take matters into her own hands:

Now after taking the first exam, I’m a lot smarter. So, I start studying a week in advance. There are three of us – we study
together. One girl makes the note cards like a week in advance and we copy down those note cards and we study them like it’s no one’s business. We study them and then we quiz each other back and forth, back and forth. We’ll be walking to class or eating and we’ll just turn around and like randomly quiz each other so you’re like put on the spot and you have to think about it. So, we do that and then...we go over [the professor’s] notes and we always study in that group – just the three of us. We go over his notes so if someone doesn’t understand something, usually the other person has the answer and then we do the [online homework]. We make sure we understand the [online homework] back and forth...we go over the practice exam separately and then we go over it together, the note cards, and his notes...and quizzing each other really helps. We’ve done that for every exam since the first and it’s worked really well.

[Interviewer: So how does that compare then to, to what you did last semester because didn’t you study in a group last semester as well?] Yeah, we did. We kind of studied on our own and just looked at each other. We never actually took the time to sit down for hours and quiz each other and go over things together to see whether we really understood or asked each other questions. We kind of just sat in the same room and studied together. We didn’t really interact that much as we did this semester.

Despite getting off to a rocky start, Parvati generally found the pacing of the second semester course to be slower and the material presented to be easier than what she had encountered in the first. In fact, there were times that she actually found herself enjoying organic chemistry. Parvati reported that her spring schedule was light, giving her some extra time to devote to studying for organic chemistry. She also felt that the spiral approach – with the exception of the textbook selected for the second semester – was more beneficial than the experiences she had heard her roommate talk about the previous year:

I like the way they have revamped the course...because when you come into the second semester you kind of have a general idea of
what’s going on like because of what you studied in the first semester. So, it’s not as much of like a head-on – all this stuff just being piled onto you. You kind of, you’re kind of slowing into everything which is nice. It’s more gradual.

For the rest of the semester, Parvati and her friends maintained their proactive study approach, enabling her to maintain “decent” exam grades. For the semester, Parvati earned a B, a grade higher than what she had originally expected. In talking about her definition of success, Parvati felt that successful students were those that had a firm “understanding of the material [and] being able to apply it in the future or something like the MCAT’s. If you can do that, then you’ve done well for yourself.” Using that as her definition of success, Parvati believed that she had been successful in her study of organic chemistry. Although she had been quite reluctant – and indeed, rather fearful – to tread into the territory that was organic chemistry, Parvati had come to appreciate the inherent beauty in the subject. In June, she took the MCAT and subsequently reported that she “aced” the organic portion of the exam.
Chapter 5

The Emergent Themes
Introduction

Preliminary data was analyzed for the emergence of themes, and future data collection was modified to explore them in greater detail. In this way, all emergent themes, and the conclusions generated from them, were grounded in the data. This chapter presents these emergent themes using the words and experiences of the students involved in the inquiry. Themes are divided into two broad categories: (1) the problems that students encountered while learning organic chemistry and (2) the strategies that students employed to address the problems they encountered while learning organic chemistry.

The Problems

1. A widespread undercurrent of fear and anxiety surrounding organic chemistry exists in much of the academic community.

When formulating their initial expectations about organic chemistry, students relied heavily on the words and experiences of others. Katie, Hannah, and Luna had been told by their high school chemistry teachers that organic chemistry was difficult and served as a weed-out course; Ginny, Lily, and Marietta heard similar things from family and friends. Unfortunately, all of what they heard – with the notable exception of the conversations Lily had with her mother – cast organic chemistry in a negative light. Others witnessed firsthand the struggle of friends with organic chemistry. Parvati’s observations of her roommate’s year-long struggle with organic chemistry served as a poignant reminder as to how hard she expected the course to be when she took it the following year. When visiting Vanderbilt during a recruiting trip, Susan had seen “frantic” students the night before an organic chemistry exam. Percy reported that women in his dorm would come back from taking their organic exams in tears, convinced that they had failed. Such displays powerfully shaped how future organic
students formed their initial perceptions of the subject.

Further, while many students did not recognize or could not articulate the importance of organic chemistry for their future careers, most did recognize that it was one of the courses professional schools used to judge their suitability for the demanding programs that would eventually train them to become doctors, dentists, and veterinarians. Others, like Charlie, Ernie, and Luna, were convinced that their level of success in organic chemistry served as a personal gauge regarding how well they could expect to do in professional school. Most students believed that their performance in organic chemistry was important, and as such, were quite apprehensive about how well they would do.

2. Organic chemistry starts off “straightforward” but quickly becomes less so during the spring semester.

At some point during the inquiry, at least seven of the 18 students used the word “straightforward” to describe the material presented in organic chemistry. Charlie defined this term best when he said

...In terms of the material, I think it’s pretty straightforward, like they’re just...I mean, you have these two things and this is how they interact and this is what you get... it’s all concrete things. There’s like right, there’s right and wrong answers. There’s not, like, “how do you feel about this?” you know. You know what I’m saying? There’s not a lot of opinion in organic chemistry.

Luna also picked up on this notion of “straightforward” and felt that the first semester of organic chemistry was one of her easier classes because of it:

[Organic chemistry] is probably one of my easier classes just because it is straightforward...[In my] Spanish class, I feel like that is so subjective sometimes. My exams are like essays, you know, and it’s really difficult to get at exactly what the professor wants
even though I may understand the material...So, I definitely think that because I am such a science person and I like to know that there is a right answer and I can get that right answer if I just know the processes...

Interestingly, both Charlie and Luna described organic chemistry – and indeed science in general – as being free of subjectivity. In many ways, the faith they placed in science being able to generate definitive right and wrong answers was well founded and certainly matched what they had encountered in their previous chemistry courses. Not surprisingly then, students brought this dualistic perspective\(^\text{11}\) to organic chemistry and expected it to be equally useful in characterizing the subject. During the fall semester, such a point-of-view proved helpful, with one notable exception: substitution and elimination reactions.

When asked to describe the problems they faced during the fall semester, three students – Lily, Luna, and Marietta – pointed to the difficulties they had with substitution and elimination reactions. In particular, they found it difficult to predict the product of the reaction since it frequently resulted in the generation of mixtures. The existence of multiple answers is decidedly less straightforward than the more simplistic “one problem, one answer” approach with which most students were familiar. Luna had expected organic chemistry to follow what she perceived to be the scientific way, i.e., “a→b, b→c;” for her, and others like her, the transition to “a→ b and c” was problematic.

As the year progressed, students were increasingly asked to evaluate and manipulate organic chemistry knowledge from a perspective other than the more simplistic, right-wrong dichotomy with which they were comfortable. During the spring semester, Charlie, Ginny, Luna, and Marietta referenced their struggles with designing viable syntheses as a major obstacle. Although at first glance a synthesis problem may seem to fit the more familiar “a→b” pattern with both a defined starting
and ending point, the number of pathways through which students could move from start to finish were numerous. Further, students frequently were required to choose among these pathways as some were more viable than others.

It is important at this point to also consider the difficulties students experienced with the second semester textbook. Most of the students involved in the study were quite pleased with the textbook used during the fall semester. The students appreciated its clearly written text and the plethora of sample problems that were broken apart step-by-step for them to study. In most cases, organic functional group transformations were accomplished in a single step and utilized a single set of reagents. By contrast, most of the students strongly disliked the second semester textbook. Susan said that she “absolutely hated” the textbook and Parvati called it “useless.” Neville admitted that he rarely even opened it. Indeed, 10 of the 12 students in the study who continued on to the second semester articulated their dislike of the textbook at some point.

The second semester textbook was intended to be used in an introductory graduate level organic chemistry course – a fact that the students knew. Gone were the glossy pages with their bright images of the first semester text; in their place was mostly text with a few black and white illustrations. The book contained no sample problems for the students to use as guides for students trying to solve the problems at the end of each chapter. Instead of presenting students with one way of accomplishing an organic functional group transformation, the book frequently highlighted several, some of which could be used only under certain conditions. Such a resource undoubtedly added to the students’ perceptions that the second semester course was less “straightforward,” because it also required students to move beyond the right-wrong dichotomy they were more comfortable with towards embracing multiple solutions to problems.
3. The search for relevance is a struggle for many students.

Some students were convinced that organic chemistry was important for their future careers as doctors, dentists, and veterinarians, indicating that it was vital because it would allow them to better understand the basic life processes they would encounter in the bodies of their future patients. However, eight of the students involved in the study – nearly half – were unsure why they were asked to take the course. While Ginny, Lily, and Marietta hoped that organic chemistry’s relevance would become apparent at some point in the future, the others indicated from the start that it was not important, or that its perceived importance was “hyped.” Indeed, George and Hannah described having conversations with a current doctor and a zoological researcher, respectively, who indicated that they did not use organic chemistry in their current positions.

George and Hannah were also unique in that they were repeating organic chemistry because they had not fared well the first time through. Despite studying organic chemistry for an additional year, neither understood why the subject was important. This search for relevance remained a struggle for many of the students throughout the year. Some, like Parvati, eventually came to justify their journey through organic chemistry simply as another requirement for professional school and something that would be tested on admittance exams like the MCAT.

4. Organic chemistry is very different from other courses students have taken in their college careers.

In many ways, the students who participated in the study felt that organic chemistry was unlike any other course they had taken during their college careers. Although many had been told by other professors that the structure of the material they
would be studying was cumulative and would build throughout the semester, organic chemistry took this idea to the extreme. In talking about this difference, Hannah felt that although other courses like biology and mathematics did build upon themselves, they did so only in short segments before moving on to new material that was completely unrelated to anything previously. Organic chemistry was unique in that these segments spanned the entire academic year. Additionally, unlike many other courses where students could wait until the last minute to study for tests and quizzes (and still do well in the process), organic chemistry was something that you had to study daily if you wanted to excel.

Finally, many of the students found the demands of the laboratory portion of the course to be exceptionally high and very different from previous chemistry experiences. Many indicated that the increased responsibilities they were asked to assume by preparing laboratory notebooks were significantly different from the simple summary reports they prepared in general chemistry. In short, students were asked to take increased responsibility for their learning, and unfortunately, many students were not prepared to do so. Although the main focus of this research was to document student experiences in organic chemistry lecture, the two courses were linked in the minds of many students. Indeed, while none of the students in the study indicated that they had considered dropping the lecture course during the fall semester, several had considered dropping the laboratory course. Many of the issues students cited as reasons for wanting to drop the course were issues that began to assert themselves during the second semester lecture course and eventually caused students difficulties.

5. Many students report experiencing time management problems.

When discussing why many students did poorly in organic chemistry, Ernie and Percy were adamant that the source of such difficulties stemmed from students not spending enough time studying organic chemistry. It was ironic, then, that at various
points during the course of the study, several students reported difficulties in managing their time. Such difficulties frequently resulted in students having less time to study and prepare for organic chemistry than they might have liked. Some students, like Ginny and Parvati, had a great deal of work in other classes to attend to, while others like Katie and Luna became overly involved in time-intensive, extracurricular activities. Whatever the source of such time-sinks, they could ultimately prove fatal to students’ performance in organic chemistry.

6. Despite knowing that their study habits are not conducive to academic success in organic chemistry, some students remain unwilling to change.

In examining the experiences of students like Ernie, George, and Katie, one of the more striking features of their accounts is the sheer inflexibility in modifying their study habits. Despite the fact that the material during the second semester became progressively more difficult for Ernie, he maintained the same routine he had established during the fall. For the first exam of the fall semester, George had relied on the information he had learned in his previous journey through organic chemistry to make up for the time he should have been spending on studying the material a second time. While this approach worked well for that first exam, his subsequent exam score was nearly 50 points lower and remained that way for the rest of the semester. He planned to correct these oversights for the second semester, but never did.

Katie acknowledged that she spent too much time on her extracurricular activities; however, it wasn’t until the end of the spring semester when she faced the prospect of earning a C that she seriously considered modifying her approach to organic chemistry. It was unfortunately too late by that point. Paradoxically, these students all were cognizant of the fact that their study habits were not working, and
further, knew what they needed to do to address the problems they were experiencing. Yet, they never did.

7. Some students focus so much on memorizing material that they lose sight of the underlying concepts.

Undoubtedly, the learning of organic chemistry requires students to organize and utilize vast amounts of information. The accounts of students like George, Ginny, Katie, Luna, Marietta, and Parvati bear witness to this fact. Feeling the pressure to perform well for the purpose of professional school, some students – most notably Katie and Marietta – made the conscious decision to simply memorize the material instead of trying to understand the concepts that underlie it. Such was the approach that Marietta described when she stated:

…maybe too much memorization where in all of the stuff you’re memorizing, you forget, you know, the concept behind it. That’s probably something that I do because it’s a lot easier to memorize and say, “Ok, I know what this is” but what does it do? “Oh shoot. I don’t know.” Honestly, though, sometimes it’s hard to maybe find the time I need to learn the concept and it’s just easier to memorize and worry about really learning the concept later.

While the utilization of such rote memorizational techniques may serve students well in the short-term, when asked to make use of this information later in the semester – or indeed the year because organic chemistry is cumulative – they frequently do not see the connections that naturally exist among many of the topics. Consider Marietta’s description of the second semester textbook:

The biggest challenge this semester is working with the book…when you’re trying to learn from the book, which is really the only other source we have besides lectures…and they’re expecting you to already know a lot of stuff about organic
chemistry, which we do, but not enough to really go through the book and pick out the information we need...They have a lot of extra stuff that we don’t need to worry about. [For example,] they have a lot of electronegativity that says, “well, this is this charge, and this is this charge” which ends up being inconsequential to the answer I’m looking for...

Marietta believed that when the textbook used electronegativities to explain an answer, it was “inconsequential;” however, the products of many reactions can be correctly predicted just by knowing the positions of the partial positive and partial negative charges in the molecules.

The Strategies

1. To be successful at organic chemistry, it must become a part of your daily lifestyle.

No matter what individualized strategies students utilized to prepare for organic chemistry, one commonality existed among those students who were academically successful: the belief that organic chemistry must become a part of the students’ everyday routine. Although some students would frequently spend a large amount of time studying a few days before the exam, others like Luna and Parvati found it much more productive to study a little bit every day. Some students like Ernie and Percy felt so strongly about this strategy that they believed all difficulties could ultimately be traced back to students not spending enough time working on organic chemistry. Perhaps Katie’s advice to future organic students summed it up best: “Spend a lot of time…and you will go far.”
2. For some students, cooperative learning is an invaluable tool.

Although cooperative learning is a technique that appeals only to a certain segment of the student population, those who utilized it to study organic chemistry found it an invaluable tool. Luna, Parvati, and Ron described using the collective knowledge of the group to work through homework problems and to study for exams. Frequently, the members of the group would randomly quiz each other and make up additional problems for the other members to work on.

It is important to note that groups appeared to be effective learning tools only when the members were actively working together to help each other. For example, although Parvati and her roommates studied together during both semesters of organic chemistry, what form those techniques took evolved greatly from fall to spring:

There are three of us – we study together. One girl makes the note cards like a week in advance and we copy down those note cards and we study them like it’s no one’s business. We study them and then we quiz each other back and forth, back and forth. We’ll be walking to class or eating and we’ll just turn around and like randomly quiz each other so you’re like put on the spot and you have to think about it. So, we do that and then...we go over his notes and we always study in that group – just the three of us. We go over his notes so if someone doesn’t understand something, usually the other person has the answer and then we do the [online homework]. We make sure we understand the [online homework] back and forth...we go over the practice exam separately and then we go over it together, the note cards, and his notes...and quizzing each other really helps. We’ve done that for every exam since the first and it’s worked really well.

[Interviewer: So how does that compare then to, to what you did last semester because didn’t you study in a group last semester as well?] Yeah, we did. We kind of studied on our own and just looked at each other. We never actually took the time to sit down for hours and quiz each other and go over things together to see whether we really understood or asked each other questions. We
kind of just sat in the same room and studied together. We didn’t really interact that much as we did this semester.

Parvati described a situation where she and her roommate were initially working together but were not working together collaboratively. In modifying her study habits to better reflect the reality that she encountered in the second semester course, the group members began to take an active role in the learning process. Such a transition undoubtedly contributed to her academic success during the spring semester.

3. Many students found it helpful to describe the material in their own words and created their own problems to work on.

For some students, the ultimate test of understanding was whether they were able to describe a concept in their own words. Marietta, who admitted that she wasn’t a terrific test taker, felt that this was a more authentic way of testing her knowledge. Others like Charlie took all of his notes and distilled them down to a shorter study guide that contained what he perceived to be the important concepts and reactions. Charlie felt that the creation of such a guide was particularly useful to him because by dictating it to himself it was “like having gone through [the material] twice right away.”

Luna, Marietta, Parvati, and Ron frequently created their own problems and exchanged them with the members of their cooperative learning groups. Ron felt that such exercises ultimately increased the number and types of problems that he worked. This was important to him because

...the greater the number of ways that you do certain things, um, then when you get to the test you don’t have to be like, “Oh, I’ve never seen this before.” You’ll be like “Oh, this is kind of like that problem I did yesterday” or something like that...where it kind of just cements the material in your head to the point where on a test you don’t blank and you can recall it.
Marietta agreed with Ron about how helpful it was to see and work many different problems in preparing for exams. The process of creating these problems, also allowed the students to test the boundaries of their own knowledge.

4. Flashcards are useful for some students.

At some point during the academic year, six of the students – Ginny, Lily, Luna, Marietta, Parvati, and Susan – described using flashcards study organic chemistry. Some students like Marietta started using the flashcards merely as a means of quickly memorizing factual information such as pKₐ values. Most came to realize, however, that flashcards could also be used to help study the myriad reactions and reagents they were learning in class.

Much like the use of cooperative learning, flashcards only reached their maximal effectiveness when they were used actively. Consider how Lily described her use of flashcards:

...I had note cards of all the different reactions that had to do with alcohols – whether they react with metals or anything else – and I would go over them as far as memorizing them and then afterward when I felt that I had them, I would use the note cards and I would actually write it out before I looked on the other side to make sure I had it correct since we had to be writing out the mechanisms on the exam...Using them, I was able to ask myself questions, physically write down the answer – be it drawing a specific molecule, configuration, reaction, or trend – and then flip the card over to make sure my answers and thinking were correct.

Lily described using her flashcards not only as a means of memorizing the information written on them, but further used them to ask herself questions and to begin making
active connections among the material. This latter piece was essential and made all the difference in whether the students’ use of flashcards was successful.

**Summary**

Although every student experience was unique, commonalities emerged among many of the students in the inquiry. This chapter presented the emergent themes using the words and experiences of the students involved in the inquiry. The implications of such themes for how students learn organic chemistry will be discussed in chapter 6 and will be analyzed in regards to the research questions which guided this research.
Introduction

This chapter explores the significance of the data presented in chapter 4 and the implications of the emergent themes discussed in chapter 5. Specifically, these themes are analyzed in regards to answering the research questions which shaped this inquiry. This chapter concludes with a discussion of the broader implications of the inquiry and offers suggestions for future research.

The Research Questions

The purpose of this study was to better understand the problems that students encountered as they progressed through a restructured CHM 241/242 course sequence and was guided by the following research questions:

1. What are the biggest problems students face in learning organic chemistry?
2. How do these perceptions change as students progress through the revised organic chemistry curriculum?
3. What strategies do students employ to address the problems that they face in learning organic chemistry?

 Meaningful Learning

Given the interconnected nature of the first two research questions, they are addressed in tandem. In describing their experiences during the yearlong, spiral organic chemistry sequence, seven important themes emerged in the data. These themes were discussed in chapter 5:

1. A widespread undercurrent of fear and anxiety surrounding organic chemistry exists in much of the academic community.
2. Organic chemistry starts off “straightforward” but quickly becomes less so during the spring semester.

3. Organic chemistry is very different from other courses students have taken in their college careers.

4. The search for relevance is a struggle for many students.

5. Many students report experiencing time management problems.

6. Despite knowing that their study habits are not conducive to academic success in organic chemistry, some students remain unwilling to change.

7. Some students focus so much on memorizing material that they lose sight of the underlying concepts.

While the issues regarding the fear and anxiety surrounding organic chemistry (emergent theme #1) and the focus on rote memorization versus conceptual understanding (emergent theme #7) are well documented, the remaining themes have not been described previously in the research literature.

In considering how these problems evolved over the course of the year, some like themes 1 and 3 eventually stabilized. Although students were initially apprehensive about organic chemistry, the unique nature of the first semester survey course insured that students did not become overwhelmed too quickly. This, in conjunction with a professor that the students described as supportive, allayed many students’ initial anxieties surrounding organic chemistry. Some students had heard from friends, family, and teachers that organic chemistry was different from other courses they had
taken. Indeed, this turned out to be true. While some students initially found the differences to be rather stark, most eventually adapted. Other themes – especially themes 2, 4, 5, and 7 – become even bigger challenges for students as the academic year progressed and they made the transition from the survey portion of the course to the spiral. The theoretical frameworks which shaped this inquiry offer insight regarding the significance of these themes.

Novak’s construct of meaningful learning states that the learner plays a central role in constructing knowledge. As outlined in chapter 2 (and shown in Figure 1), the construction of knowledge to be meaningful necessitates three key components: (1) new knowledge must be situated and anchored with sufficient prior knowledge; (2) the knowledge to be learned must be perceived to be relevant; and (3) the learner must consciously choose to utilize meaningful learning techniques and not rote memorization.

At the heart of the spiral curriculum is its cyclic nature. The first semester is designed to provide students with a broad, organic chemistry knowledge base with which to anchor the more advanced material taught during the second semester. This reliance on such prior knowledge was viewed by some students as an advantage; by others as a disadvantage. Some students like George and Parvati felt that by learning the basics during the first semester survey course, it served as a firm foundation to support subsequent learning during the second semester spiral. Others like Ernie witnessed firsthand what happened when cracks developed in that foundation. By forgetting much of the material from the first semester, he had to work even harder. Furthermore, many students failed to recognize the connections between the concepts they were learning in organic chemistry and the concepts they learned previously in general chemistry. Such a lack of recognition made learning organic chemistry even more difficult.
One of the more significant problems students encountered in learning organic chemistry was the constant search for relevance. Ginny, Lily, and Marietta were not quite sure why organic chemistry was relevant; however, they were convinced it would become apparent at some point in the future. Unfortunately, as time passed and the relevance of organic chemistry did not become apparent, their faith in organic chemistry’s importance began to diminish. Therefore, one of the three necessary reagents of meaningful learning disintegrated. Indeed, for some students like George and Hannah who had initially heard from doctors and researchers that organic chemistry was not useful, or that its importance was “hyped,” such a reagent may never have existed at all.

A belief in the lack of organic chemistry’s relevance also explains why some students remained so inflexible in modifying their failing study routines. How can students be expected to expend the considerable time and effort associated with designing and implementing new strategies for learning organic chemistry when there is little perceived importance in the material to be learned? Whether or not students viewed material as relevant was inconsequential if they ultimately decided to utilize rote memorization techniques as a proxy for learning. The factors that informed such decisions were complex; however, issues surrounding time management and motivation were of paramount consideration for many of the students involved in the inquiry. The evidence to support a functional presence of Novak’s third factor (meaningful learning set) is weak.

**Motivation Theory**

Although Marietta expressed a preference to learn organic chemistry meaningfully, she succumbed to the time pressures in her life and instead decided to memorize the material and worry about learning the concepts later. It is not unlikely that other students faced with a similar choice made a similar decision. As outlined
earlier in this work, the construct of motivation is a conglomeration of many interrelated factors, including self-efficacy beliefs, task value beliefs, goal orientation, and affect.20

Although self-efficacy initially increased during the fall semester, as the material became more complicated during the spring semester, self-efficacy began to decrease. While there was initially a great deal of confusion as to the task value of organic chemistry, many students felt that as the year progressed whatever task value might have been present (or the faith that such task value existed) slowly began to diminish. A shift in goal orientation also occurred for many students. Students like Ginny initially started organic chemistry with an interest in learning the subject and achieving a strong foundation for use in subsequent courses in both college and professional school. Ginny’s goal orientation shifted and it became more important that she earn a good grade in the course. Given the importance that students perceive professional schools place on organic chemistry, such transitions in goal orientation were not surprising.

With regards to the role of affect in motivation, students initially expected organic chemistry to be difficult, and therefore, were anxious and even fearful of it. The reality that they encountered was very different from the initial expectations and students began to relax. As the material increased in difficulty during the spring semester, the level of anxiety began to increase anew. In almost every instance, these changes translated into lower motivation for students – especially during the spring semester when they most needed to stay focused and motivated to succeed. In considering how these motivational factors changed during the course of the academic year, the general trend favored a decrease in overall motivation.
Cognitive Development

In addition to the power that meaningful learning and motivation hold for explaining the themes, the perceived change in the straightforwardness of organic chemistry connects to Perry’s theory of cognitive development. George and Lily were convinced that given enough time and effort, chemistry would yield the correct answer. Yet, organic chemistry frequently requires students to find several correct answers to the same problem or devise multiple pathways to get from start to finish. Such activities are decidedly less straightforward and caused difficulties for many students.

The students’ use of the word “straightforward” is consistent with analysis of the data using varying levels of intellectual development as described by William Perry. The analysis of how these levels relate to learning organic chemistry are summarized in Figure 5. George and Luna initially described science knowledge using the dichotomous “right and wrong” mindset; this point of view is consistent with students who are dualistic thinkers. This view had generally served students well in their previous chemistry courses, and as such, its use in organic chemistry seemed appropriate to students. Indeed, it was not until students encountered substitution and elimination reactions halfway through the fall semester – a topic requiring a multiplistic viewpoint – that students reported experiencing conceptual difficulties. Students found it difficult to accept that one starting compound treated with only one set of reagents could lead to more than one correct product. Yet, such is the reality.

As the year progressed, students like Charlie, Ginny, Luna, and Marietta found it increasingly difficult to design viable syntheses. Although such a design process seemed to fit the more familiar “a→b” pattern, the number of pathways connecting a to b were numerous. Furthermore, students frequently were required to judge which pathway was best. The Perry scheme would categorize such synthetic designs as relativistic in nature.
Prior research has shown that the average college freshman scores 2.4 on the Perry scheme and leaves four or more years later at 3.2. In other words, for most of their college careers, the average student is a dualistic thinker. Only as a student moves closer towards graduation does the transition begin to a more sophisticated cognitive lens. It would seem, however, that this transition does not occur soon enough for some students who take organic chemistry during their sophomore year.

**Learning Strategies**

Although commonalities existed among the difficulties that students in the study experienced in learning organic chemistry in the context of the spiral curriculum, every experience was unique. As such, it was not surprising that every student developed
personalized strategies to address these difficulties. Some students relied heavily upon the repeated solving of practice problems. Others used flashcards or cooperative learning groups. Still other students created study guides or crafted their own problems to work.

In looking at all of these strategies, two significant patterns emerged: (1) strategies are only successful if they become a part of the students’ everyday routine and (2) the most successful strategies are those that actively engage the students in their learning of organic chemistry. Successfully adapting to learning challenges required students to remain flexible and cognizant of the need to modify those strategies during the year. As such, it was important for students to self-monitor their learning and to actively and regularly reflect upon which strategies worked and which did not. Unfortunately, some of the students refused to modify their strategies despite knowing they were ineffective. Such decisions mirrored those made by some students who utilized rote memorization techniques instead of more meaningful methods despite knowing that the former were ineffective.

Implications of the Study

Thus far, this chapter has focused on answering the research questions that guided this inquiry. In doing so, implications for the teaching and learning of organic chemistry have emerged. This section will describe those implications.

1. Positive role models who believe in the importance of organic chemistry are vital for students.

Although Lily had heard from friends that she could expect organic chemistry to be difficult, her mother had told her that it would be the “greatest thing in the world.” Because of this positive influence, Lily was not as apprehensive as she might have been. Unfortunately, most students did not have authority figures in their lives who spoke
highly of organic chemistry. Quite to the contrary, several students related conversations they had with their doctors about how difficult organic chemistry was and how unimportant the material ultimately was for future professionals.

Though some may be quick to dismiss the importance of such conversations, the work of Belenky, Clinchy, Goldberger, and Tarule speaks otherwise. In the initial phases of cognitive development as described in *Women’s Ways of Knowing*, the viewpoints of those in positions of authority carry great weight. As such, it is not hard to imagine that when those in authority only say negative things about organic chemistry, negative attitudes among students may quickly follow. It is therefore imperative that professors, in their positions of authority, do everything possible to relate to students just how important the study organic chemistry is.

2. Teachers of organic chemistry must restructure the curriculum to better convince students of how important organic chemistry is to future professionals.

Many chemists have a difficult time understanding how chemistry, and in particular organic chemistry, is viewed by so students many as so irrelevant. Indeed, much of the world is organic chemistry, including all life. Unfortunately for many organic chemistry students, this relevance is not apparent. While many textbooks attempt to incorporate real world examples, they are typically relegated to a few paragraphs at the end of the chapter. Such insertions are not sufficient to convince most students that what they have to learn from organic chemistry is important and vital to their future careers. As students are rarely tested on such material, many do not even take the time to read it. Professors of organic chemistry, therefore, can no longer assume that their students see chemistry’s relevance and must make every effort to highlight it wherever and whenever appropriate.
3. It is vital that students recognize the time intensive nature of organic chemistry and that preparation for the subject must become integrated into their everyday routines.

While such an implication may seem obvious, it is important for professors of organic chemistry to be as explicit as possible regarding how time-intensive the subject is likely to be for most students. Further, advisors of pre-professional students must do a better job of keeping schedules at a minimum during the academic year in which students will be taking organic chemistry. It is unreasonable to expect students who are taking in excess of 20 credits a semester to have sufficient time to devote to organic chemistry, yet some students involved in the study were doing just that. It is also important that students are advised to limit their involvement in extracurricular activities as such time commitments can severely curtail their time available for studying.

4. Organic chemistry frequently requires students to develop and mature cognitively.

Prior to beginning their study of organic chemistry, the knowledge and problem solving most frequently associated by students with chemistry was dualistic in nature. At its core, however, much of organic chemistry is multiplistic and relativistic. Although the transition in thought required of students can only be brought about by personal choice and internal struggle, it is important that educators find ways of supporting students in their transition.

Further, it is imperative that educators also help students recognize that these transitions are required in the first place. This cognizance can only occur when students are given the opportunity to reflect upon their own learning and encouraged to assess their strengths and weaknesses in the process. Recognition, however, is not sufficient as evidenced by the sheer inflexibility on the part of several of the students in the study.
Students must be convinced that the knowledge and skills to be gained from organic chemistry are worth the considerable time and effort associated with such transitions in thought.

5. **Students focus so much on memorizing the little details that they fail to see the underlying patterns and concepts inherent in organic chemistry.**

Students cited memorization problems as one of the major difficulties they encountered in organic chemistry. What many students do not recognize is that memorization of all of the minute details is not necessary as long as they have a firm conceptual understanding of the material. Marietta believed that the second semester textbook description of electronegativities and dipoles of compounds in a reaction was “inconsequential.” Such details, however, are anything but inconsequential. For example, the products of a Grignard reaction can be easily predicted by knowing that a partially negatively charged carbon in the Grignard reagent is attracted to a partially positively charged carbon in the carbonyl-containing compound. Organic chemistry is replete with such examples and illustrates just how important it is that students have a solid conceptual foundation with which to construct new knowledge. Therefore, it is important for professors to continually emphasize the basic, fundamental concepts that underlie organic chemistry as they introduce students to new information.

6. **The choice to utilize meaningful learning techniques is a dynamic process that is influenced by a variety of factors.**

A student’s choice as to whether to learn a concept meaningfully is dynamic in nature and is influenced by a variety of factors as is thoroughly supported by the data
and subsequent analysis in this inquiry. Figure 6 illustrates a synthesis of the factors influencing the learning of organic chemistry.

![Figure 6. The equilibrium between meaningful learning and rote memorization.](image)

The depiction of these factors as a dynamic equilibrium is not accidental. Students are pushed and pulled from one end of the learning continuum to the other by factors such as time, relevance, and motivation. While many of the students involved in the study initially expressed a desire to learn organic chemistry meaningfully, many students shifted away from that desire as the academic year progressed and were instead pulled towards the use of rote memorization.

Future Research

Given the paramount importance that relevance plays in the process of meaningful learning, it is essential that professors make every effort to highlight the vital role organic chemistry plays in biological systems. Indeed, it is not unreasonable to believe that an entire curriculum could be crafted with such a goal in mind. Beyond merely emphasizing biologically relevant examples, however, it would be helpful for organic chemistry professors to better understand why pre-professional students are required to take organic chemistry in the first place. While many may hypothesize the
reasons that students are required to study the subject, only those who are actually involved in the training of future doctors, dentists, and veterinarians know for sure. Therefore, it is essential that a dialogue be initiated among those with a vested interest in the education of pre-professional students. The yearlong organic chemistry sequence must be brought into better alignment with what professional schools expect students to learn from the subject. Hopefully, such steps will help convince students that organic chemistry is worthy of their time and effort and has something important to teach them.

Although students generally responded well to the spiral curriculum, the most common complaint expressed during the spring semester was the lack of a supportive textbook. Given the greater cognitive demands the spring semester makes of students, such a resource becomes of even greater importance. If the organic faculty at Miami University ultimately decide to continue with the spiral approach, a more appropriate second semester textbook must be identified. If such a textbook is not commercially available, perhaps materials could be written internally for student use.

Given the problems that students encountered with organic chemistry activities requiring more mature cognitive lenses, it is important for researchers to devise and evaluate ways of helping students better make the transition in thought that organic chemistry requires of them. Specifically, students must come to recognize that these transitions are necessary in the first place. Therefore, it is important to explore ways of effectively incorporating metacognitive activities into the organic chemistry classroom and use such activities to promote the types of self-assessment that can lead students to recognize that a change is necessary.

One hypothesis emerging from this inquiry is that many pre-professional students take organic chemistry earlier than they perhaps should. Indeed, there may be distinct advantages in utilizing an “organic later” approach and advising students to delay organic chemistry until at least the junior year. By taking organic chemistry in the junior or senior year, students will have been exposed to a wider variety of classes, and
consequently, a wider variety of perspectives. Such experiences may help students make the transition to multiplistic and relativistic thought more smoothly and with fewer difficulties. In addition, students like Marietta will have had an additional year of coursework in which to work out the deficiencies in their study and note taking strategies. Furthermore, although juniors and seniors would probably not describe their schedules as easy, there is usually more flexibility in their schedules compared to the sophomores involved in the study. Given the time intensive nature of organic chemistry, such flexibility would be indispensible. Finally, many students believe organic chemistry is important only because it is required for medical school and tested on the MCAT. Most pre-medical students take the MCAT during the summer between their junior and senior years. By delaying organic chemistry, the concepts learned in the course will be fresh in their minds, theoretically requiring students to spend less time preparing for the organic portion of the exam.


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A Change in Structure: Understanding Student Attrition in Organic Chemistry
Student Questionnaire

We are conducting a research project that we hope will allow us to better understand the difficulties that students may face in learning organic chemistry. Throughout the fall and spring semesters, you will be asked to take part in two interviews (one per semester) and answer a series of online reflective essay questions (three sets between now and May 2007). These activities will take between 3 to 5 hours total. If you are willing to participate, and are selected to do so, you will receive a $25 gift card to the Miami University Bookstore for each semester that you participate in the study for a total of $50. Your participation in this research will in no way affect your grade in CHM 241/242.

If you are willing to participate in this research, please complete the information below. If not, please leave this form blank.

1. Name: _______________________________________________ email address: ____________

2. I would best describe myself as (check only one):
   ____ Freshman       ____ Senior
   ____ Sophomore      ____ Graduate Student
   ____ Junior

3. What is your gender?
   ____ Female        ____ Male

4. What is your ethnicity?
   ____ African American/Black
   ____ American Indian/Alaska Native
   ____ Asian/Pacific Islander
   ____ Hispanic
   ____ White/Caucasian
   ____ Other (please specify): ________________________________

5. What previous chemistry courses have you taken and what grade did you earn in each?
____________________________________________________________________________________________
____________________________________________________________________________________________
____________________________________________________________________________________________
____________________________________________________________________________________________

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A Change in Structure: Understanding Student Attrition in Organic Chemistry
Interview Consent Form

I understand that I am being asked to participate in an interview that will last approximately one hour. I understand that I will be asked questions about myself, my learning, and my organic chemistry class. If I wish, I may see a copy of the interview questions before I decide to participate. The information gathered from this interview will be used as part of a larger project that is attempting to understand student attrition in organic chemistry.

I understand that all personally identifiable information will be kept strictly confidential and will not appear in any reports generated using the information gathered from the interview. I understand that participation in this study is completely voluntary. I do not have to answer any questions I do not want to and can stop the interview at any time and withdraw from the study. Withdrawing from the study will in no way affect my grade in CHM 241/242.

I understand that participation in this study will require about 4 hours of my time over the course of the year. I also understand that I will receive a $25 gift certificate to the Miami University Bookstore for each semester I participate for a maximum of $50. I understand that I will be asked to complete two interviews and answer three sets of on-line essays to receive both gift cards. Finally, I give my permission for the interview to be recorded. I understand that the purpose of the recording is to assure that what I say is represented accurately in the research process.

I have had the opportunity to ask any questions I might have and they have been answered to my satisfaction. By signing below, I agree to participate in the interview.

If you have any further questions or concerns, please feel free to contact: Nathaniel Grove, Department of Chemistry and Biochemistry, 363 Hughes Hall, Miami University, Oxford, Ohio 45056 or email at grovenp@muohio.edu or my research advisor, Dr. Stacey Lowery Bretz, at bretzsl@muohio.edu. If you have questions about your rights as human subjects contact the Office for the Advancement of Research and Scholarship (513-529-3734) or humansubjects@muohio.edu

______________________________  __________________________
Research Participant               Date

______________________________  __________________________
Researcher                      Date

______________________________  __________________________
Researcher                      Date
A Change in Structure: Understanding Student Attrition in Organic Chemistry

Essay Consent Form

I understand that I am being asked to respond to a series of essay questions that will take approximately half an hour to answer. I understand that I will be asked questions about myself, my learning, and my organic chemistry class. If I wish, I may see a copy of the essay questions before I decide to participate. The information gathered from these essays will be used as part of a larger project that is attempting to understand student attrition in organic chemistry.

I understand that all personally identifiable information will be kept strictly confidential and will not appear in any reports generated using the information gathered from the essays. I understand that participation in this study is completely voluntary. I do not have to answer any questions I do not want to and can stop answering the essays at any time and withdraw from the study. Withdrawing from the study will in no way affect my grade in CHM 241/242.

I understand that participation in this study will require about 4 hours of my time over the course of the year. I also understand that I will receive a $25 gift certificate to the Miami University Bookstore for each semester I participate for a maximum of $50. I understand that I will be asked to complete two interviews and answer three sets of on-line essays to receive both gift cards.

I have had the opportunity to ask any questions I might have and they have been answered to my satisfaction. By signing below, I agree to participate in this study.

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_________________________  __________________
Research Participant        Date

_________________________  __________________
Researcher                  Date

_________________________  __________________
Researcher                  Date
Student Essay Prompts (Pre-Fall 2006)
A Change in Structure: Student and Faculty Perceptions of a Spiral Organic Chemistry Curriculum

- What is your major?
- Why did you choose your major?
- Why do you believe your major requires you to take organic chemistry?
- What are your goals for organic chemistry?
- In your own words, how will you determine if your learning in organic chemistry is successful?
- Many students believe that organic chemistry is difficult. Do you share this belief?
  - What do you expect will be difficult about organic chemistry?
  - What do you plan to do to address these difficulties?
- What part of organic chemistry are you most anxious about? Why?
- What part of organic chemistry are you most looking forward to? Why?
Student Essay Prompts (Post-Fall 2006)
A Change in Structure: Student and Faculty Perceptions of a Spiral Organic Chemistry Curriculum

- What is your major?
- Having completed CHM 241, why do you believe it was a required course for your major?
- Have you given any serious thought this fall to dropping CHM 241?
  - If yes, why?
- Have you given any serious thought this fall to changing your major?
  - If yes, why?
  - How have your experiences in organic chemistry affected your considerations to change your major?
- What do you believe are the biggest challenges you faced this semester in organic chemistry?
- What did you do to address the challenges you encountered in organic chemistry this semester?
  - Describe what was successful. Describe what was not successful.
- Knowing what you no know about organic chemistry, what (if anything) would you do differently if you had the opportunity to repeat CHM 241?
- What (if anything) do you plan on doing differently next semester in organic chemistry?
Student Essay Prompts (Post-Spring 2006)
A Change in Structure: Student and Faculty Perceptions of a Spiral Organic Chemistry Curriculum

❖ What is your major?
❖ Having completed both CHM 241 and CHM 242, why do you believe organic chemistry was required for your major?
❖ Have you given any serious thought this spring to dropping CHM 242?
   o If yes, why?
❖ Have you given any serious thought this spring to changing your major?
   o If yes, why?
   o How have your experiences in organic chemistry affected your considerations to change your major?
❖ What do you believe are the biggest challenges you faced this semester in CHM 242?
❖ How did these challenges compare to those you faced in CHM 241?
❖ What did you do to address the problems you encountered in organic chemistry this semester?
   o Describe what was successful. Describe what was not successful.
❖ Imagine you have a friend who will be taking organic chemistry next year, what advice would you offer based upon your own experiences this year?
Introduction
- Restate purpose, context, and intended use of interview
- Assure confidentiality
- Ask for permission to record conversation
  - Turn on recorder
- Ask for questions

Exploration of Reflective Essays
- Many students have mentioned hearing “horror stories” about organic chemistry. Have you heard any?
  - If so, could you give a specific example of one that you found particularly worrisome?
- Retention versus Understanding
  - Compare two student quotes

[Member Check]

Other Issues
- What is your major?
  - If pre-medicine of some sort: why do you want to become a doctor?
- Why do you think your major requires organic chemistry?
  - Relevant to life processes: can you give an example of where organic chemistry is important for life?
  - Requirement for med-school or MCAT: why do you think it is a requirement?
- What did you expect organic chemistry to be like?
  - How do these expectations compare to reality?
  - Ask for specific examples
- Describe what, if anything, you do to prepare for class each day.
- Describe how you study for exams in this course.
  - What about your study habits are effective? How do you know?
  - What about your study habits are ineffective or need improvement?
    - How do you know this?
- What are the biggest challenges you have faced in organic chemistry so far?
  - How does the pacing of this course compare to other courses you are taking this semester?
How does the difficulty of the course compare to other courses you are taking this semester?
   ▪ If indicate the course is difficult, ask specifically what they find difficult about it.
   ▪ If indicate the course is less difficult, explore what is more difficult in other courses.

❖ How well do you expect to do this semester?
❖ Are you doing as well as you expected to so far?
   o How do you know?
   o Do you plan to make any changes for the rest of the course?
      ▪ Give specific examples.

[Member Check]

Drop Issues
❖ Has the thought of dropping CHM 241 crossed your mind?
   o If yes, why?
      ▪ What factors are you weighing in this decision?
   o If no, can you imagine any circumstances under which you would drop? Please describe.
❖ If you could tell Dr. Hershberger about one thing that is being done particularly well in CHM 241, what would it be?
❖ If you could tell Dr. Hershberger about one thing about CHM 241 that needs improvement, what would it be?
   o If not for yourself, how about for other students?

[Member Check]

❖ Thank you
❖ Recontact with further questions?
Student Interview Guide: Spring Semester
A Change in Structure: Understanding Student Attrition in Organic Chemistry

Introduction
- Restate purpose, context, and intended use of interview
- Assure confidentiality
- Ask for permission to record conversation
  - Turn on recorder
- Ask for questions

CHM 241 Recap
- Looking back, how would you describe CHM 241 to someone about to take it?
  - Strategies for success?
  - Mistakes made/anything do differently?

CHM 241/242 Comparisons
- How have your experiences so far in CHM 242 compared to those in CHM 241?
  - How would you describe the relationship between CHM 242 and CHM 241
    - How does the content compare?
    - How does the teaching style compare?
    - How do the exams compare?
    - How does the pacing compare?
    - How does the difficulty compare?
  - Give me an example of something learned last semester that is connected to this semester.
  - What do you think about revisiting topics you learned last semester in more detail?
    - What advantages/disadvantages do you see with this approach?

[Member Check]
- Describe what you do to prepare for class each day.
- Describe how you study for exams in this course.
  - What about your study habits are effective?
  - What about your study habits are ineffective or need improvement?
    - How do you know this?
- What changes (if any) have you made in your study habits since last semester?
  - Why did you make these changes?
What are the biggest challenges you have faced in organic chemistry so far?
   o How does the pacing of this course compare to other courses you are taking this semester?
   o How does the difficulty of the course compare to other courses you are taking this semester?
     ▪ If indicate the course is difficult, ask specifically what they find difficult about it.
     ▪ If indicate the course is less difficult, explore what is more difficult in other courses.
   o How well do you expect to do this semester?
   o Are you doing as well as you expected to so far?
     ▪ How do you know?
     ▪ If no, what do you plan to do to change this?

[Member Check]

Drop Issues
   ❖ Has the thought of dropping CHM 242 crossed your mind?
     o If yes, why?
       ▪ What factors are you weighing in this decision?
     o If no, can you imagine any circumstances under which you would drop? Please describe.

Success in Organic Chemistry

   ❖ For you, what defines success in organic chemistry?
     o If you were not allowed to define success in terms of grades, what qualities or characteristics describe successful organic chemistry students?
     o Based upon the qualities/characteristics defined above, do you believe you have been successful so far in organic chemistry?
       ▪ Why or why not?
       ▪ How do you know this?

[Member Check]

❖ Thank you
❖ Recontact with further questions?