Factors that Contribute to

Organic Chemistry Performance

by

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ABSTRACT

Guided by cognitive, socio-cognitive, and socio-cultural learning theories, large-scale studies over multiple semesters, multiple instructors and at two different institutions have been performed in order to understand the factors that contribute to student performance in general organic chemistry. Students' cognitive abilities were assessed in a new way based on a categorization of problem types in a standard organic chemistry curriculum. Problem types that required higher cognitive load were found to be more predictive of overall course performance. However, student performance on high cognitive load problems was different when compared in terms of non-cognitive factors, e.g. whether they were pre-health students or not. These results suggested that organic chemistry performance may be significantly influenced by non-cognitive factors. Students' motivation and related self-regulation factors were then studied using an instrument specifically designed for general organic chemistry, the Organic Chemistry Motivation Survey. Of all the factors examined, self-efficacy was found to be the most significant predictor of performance. Socio-cultural factors were also studied using a newly developed instrument for measuring college students' cultural and social capital, the Science Capital Questionnaire (SCQ). Of the different socio-cultural variables measured by the SCQ, students' social connections in college were found to be most predictive of organic chemistry performance. Finally, cognitive and socio-cognitive variables were studied together in the context of gender differences in organic chemistry. Females were found to underperform in comparison to the males. This gap was found to be alarmingly large on the basis of final letter grade, in some semesters the percentage of males earning an A grade was twice as large as that for females. Spatial ability was not a factor that contributed to this difference, nor was the gender of the instructor. Instead, self-efficacy was found to be both significantly different between males and females, and also the factor that connected most strongly to course performance. It is suggested that sociocultural factors be the subject of further study in college science courses.

DEDICATION

To my husband Patrick, who has truly been my strength throughout my Ph.D. journey. To my parents for supporting me through all of my endeavors. Finally, to my students, who will always be my guiding light.

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Chapter 1: Introduction

The two-semester organic chemistry course sequence is an important required course for many undergraduate students pursuing degrees in science, technology, engineering, and mathematics (STEM), and those students who are on the pre-health track in the United States. Organic chemistry has a reputation for being a “roadblock” or “gatekeeper” course for students in the STEM pipeline and on health career tracks, especially for women and underrepresented minorities (Barr, Gonzales, & Wanat, 2008; Lovecchio & Dundes, 2002). Even high-performing students find the course challenging, and Seymour and Hewitt (1997) reported that a significant number of high-performing students identified organic chemistry as the reason for switching from a STEM major to a non-STEM major. It is not surprising that attrition rates for the course can be quite high, almost 50% in some cases (Grove, Hershberger, & Bretz, 2008; Rowe, 1983). To address these negative perceptions and improve student performance, it is important to understand the factors that contribute to student success in these courses.

Despite organic chemistry being a high stakes course for many students, the number of papers in the literature that address the issue of enabling success in these courses is small, which leaves considerable room for new contributions in this area. Learning theories can be used as a guide to select the factors to be studied, and how to study them. Connections to learning theory also help to ensure that new instructional strategies are supported by evidence. Of the many learning theories, cognitive, socio-cognitive, and socio-cultural theories have been most frequently used and discussed in the context of college-level science. The majority of the literature on organic chemistry learning has focused on purely cognitive issues. The overall goal of this thesis is to focus on the less-studied socio-cognitive and socio-cultural factors, since these are believed to have a bigger potential for impact on the field (Fortus, 2014; Villafañe, Garcia, & Lewis, 2014).

In this introduction, I give an overview of previous work on understanding student performance in organic chemistry, followed by an overview of learning theories, and how these relate to the specific issues in organic chemistry learning that are addressed in this thesis. Detailed literature reviews are reserved for the individual chapters.

Factors that Predict Organic Chemistry Performance

Several studies have attempted to identify factors that are predictive of performance in organic chemistry performance. Usually, these studies are not from the basis of fundamental learning theory, but instead they try to develop predictive models based on empirical, or demographic factors and prior achievement (Garcia, Yu, & Coppola, 1993; Lopez, Shavelson, Nandagopal, Szu, & Penn, 2014; Steiner & Sullivan, 1984; Szu et al., 2011; Turner & Lindsay, 2003). For example, Szu et al. (2011) found that prior GPA significantly correlated to organic chemistry performance, and other authors found similar behavior using variables such as general chemistry grade and standardized test scores (Garcia et al., 1993; Lopez et al., 2014; Sevenair, Carmichael, O'Connor, & Hunter, 1987; Turner & Lindsay, 2003). Some studies also examined possible gender effects, and in some cases, performance differences were identified (Sevenair et al., 1987; Turner & Lindsay, 2003), although gender was found not to be predictive of problem solving performance in another study (Lopez et al., 2014), and was found to be less important than other factors such as motivation and learning strategies in a third study (Garcia et al., 1993). Although studies of predictive factors related to demographical characteristics and prior grades is interesting, these variables do not necessarily connect to existing learning theories, which limit the ability to make predictions beyond the specific subjects under study. More useful are models of learning that have a sound theoretical basis in learning theory.

Learning Theories

Learning theories develop hypotheses about how learning takes place, i.e. the process of acquiring or adding to one's knowledge, skills, values and behaviors in useful ways. Learning theories take into account cognitive processes that handle information processes and how these develop, social factors that motivate and control learning at the individual level, and larger scale social and cultural factors that also influence the way that individuals learn. As mentioned above, the theories that have mainly been applied in the included chemistry education research are cognitive, socio-cognitive and socio-cultural.

Cognitive Learning Theory

Cognitive learning theories focus on the study and analysis of mental processes and cognitive skills to explain how students learn. Many notable education researchers have contributed to the development of cognitive learning theories, including Jean Piaget (Piaget, 1964), Jerome Bruner (Bruner, 1966), and David Ausubel (Ausubel, 1963). Each of these can be further categorized as contributing to constructivist approaches toward learning, i.e. that each learner's understanding must be constructed individually because each has their own unique prior experiences. Piaget, Bruner and Ausubel provided different perspectives on how learners acquire knowledge and understanding (Lawton, Saunders, & Muhs, 1980). Piaget (1964) emphasized how an individual's biological development is associated with a gradual increase in cognitive skills, while Bruner and Ausubel were more interested in explaining what a learner does with newly acquired information. Bruner (1966) theorized that learning occurs when individuals discover and construct their own knowledge. Ausubel (1963) believed that learning occurs when an individual is directly exposed to relevant, meaningful information that can be linked to their existing knowledge structure. Cognitive approaches have influenced curriculum design in chemistry education, for example, in inquiry-based discovery learning (Bruck & Towns, 2009; Cheung, 2008; Cummins, Green, & Elliott, 2004), in proposals for spiral curricula (Bulte, Westbroek, de Jong, & Pilot, 2007; Grove et al., 2008), and for concept mapping (Francisco, Nakhleh, Nurrenbern, & Miller, 2002; Markow & Lonning, 1998).

In the context of organic chemistry learning research, more attention has been placed on specific cognitive skills rather than curriculum design. Several kinds of cognitive skill have been studied in the context of organic chemistry learning, including problem solving ability (Bhattacharyya & Bodner, 2005; Cartrette & Bodner, 2009; Grove, Cooper, & Cox, 2012), spatial ability (Pribyl & Bodner, 1987; Stieff, 2011; Stieff, Ryu, Dixon, & Hegarty, 2012), understanding visual representations (Bodner & Domin, 2000; Strickland, Kraft, & Bhattacharyya, 2010), and individual concepts (Cooper, Grove, Underwood, & Klymkowsky, 2010; McClary & Talanquer, 2011). Students' concept mapping skills were found to have moderate positive correlation with organic chemistry performance (Lopez et al., 2014; Szu et al., 2011). Studies of student's spatial ability and gender, however, have produced some conflicting results. For example, Turner and Lindsay (2003) found a moderate correlation between males' spatial ability to their organic chemistry performance while the same relationship was not found for females. In contrast, Stieff et al. (2012) concluded that student's spatial ability was not an important factor determining performance, instead, both male and female students used heuristics and algorithms that avoided the need for spatial ability skills in solving organic chemistry problems.

Most of the studies on cognitive ability have investigated students' performance on specific organic chemistry problem types rather than across the cognitive load of the entire course. For example, Bhattacharyya and Bodner (2005) studied how students used electron pushing to discuss S_N1 and S_N2 reaction mechanisms, and Stieff (2011) reported on students' strategies in converting chair-boat conformations to Fischer-Newman projections. These task-specific approaches are reasonable since the standard organic chemistry curriculum is often divided into topics of different type and cognitive load. However, many kinds of organic chemistry problem comprise only a small percentage of the entire course content, and it is difficult to generalize students' overall course performance by their cognitive skill on one particular problem type. There is a need for a holistic analysis of all problem types in organic chemistry, and one of the goals of this thesis is to provide such an analysis.

Socio-Cognitive Learning Theory

Based largely on the work of Albert Bandura, socio-cognitive learning theory describes learning as being modulated by an individual's social observations, interactions, and experiences (Bandura, 1989, 2001). Socio-cognitive factors often associated with learning include affect, specifically, motivation, self-efficacy and self-determination, which in turn control self-regulation (Bandura, 1982; Deci & Ryan, 2010;

Pintrich, 2004; Pintrich & De Groot, 1990; Ryan & Deci, 2000; Zimmerman, 1989, 2000). In the literature, motivation is often categorized into two types: intrinsic and extrinsic (Ryan & Deci, 2000). Intrinsic motivation drives learning when students find the subject matter itself inherently interesting, while extrinsic motivation stems from students' beliefs that the learning task is related to external rewards such as a good grade or a better career. These motivation factors are associated with, and can influence, self-regulatory beliefs and behaviors. Self-determination is described as the amount of control students they have over their learning (Black & Deci, 2010; Deci & Ryan, 2010), and self-efficacy is students' own beliefs about their ability on a given learning task (Bandura, 1982; Zimmerman, 2000).

The role of motivation and self-regulation factors on STEM education have been examined previously and have been found to be important for learning (for example: Cavallo, Rozman, Blickenstaff, & Walker, 2003; Glynn, Brickman, Armstrong, & Taasoobshirazi, 2011; Taasoobshirazi & Glynn, 2009). However, despite recognition in the education literature of the importance of these affective factors, only a small number of reports in the chemistry education literature relate to these issues (Ferrell, Phillips, & Barbera, 2016; Liu, Ferrell, Barbera, & Lewis, 2017; Villafañe et al., 2014), especially for organic chemistry (Black & Deci, 2000; Garcia et al., 1993; Lynch & Trujillo, 2011; Turner & Lindsay, 2003; Villafañe, Xu, & Raker, 2016).

Self-efficacy has received more attention than the other socio-cognitive factors because it has been most consistently seen to be positively correlated with organic chemistry performance. Lynch and Trujillo (2010) examined motivations and self-efficacy factors in the same study, and although all of the factors studied showed a positive relationship to performance, self-efficacy had the largest correlation coefficient compared to those of intrinsic and extrinsic motivation. Villafañe et al. (2016) also found a positive relationship between self-efficacy and organic chemistry performance, and reported that students' self-efficacy increased if they had a positive experience on exams. Despite these positive results, Villafañe et al. (2016) noted that their study was limited by the sample size, and the fact that it only included participants from a single institution for a single semester.

Small sample sizes and student populations are a common issue in studies of organic chemistry learning, which makes generalizations difficult. Considering that organic chemistry courses are often taught in large lecture format classes, there is an opportunity to study affective factors and the way that they connect to student learning with large sample sizes and populations. A second overall goal of this thesis was to perform such a large-scale study that should be more readily generalizable. The motivation studies described in this thesis represent the largest studies reported to date on college-level chemistry student populations.

Socio-Cultural Learning Theory

Socio-cultural learning theory is based on the idea that the learner's social and cultural environment plays a pivotal role in his/her learning (Lemke, 2001; Vygotsky, 1963, 1978). Of the many socio-cultural variables that can influence student learning, cultural and social capital are factors that are frequently discussed in the sociology and education literature (for example: Collier & Morgan, 2007; Dumais & Ward, 2009; Tramonte & Willms, 2010; Wells, 2008a, 2008b). Based on Bourdieu's ideas about social reproduction (Bourdieu, 1973, 1997), capital is understood as the resources an individual acquires that enables an advantage in a specific context. Cultural capital is gained by high-status cultural experiences while social capital is gained from students' interactions with other members within a particular social group.

Both social and cultural capital have been linked to student retention and persistence in college, especially for underrepresented minorities (Adamuti-Trache & Andres, 2008; Collier & Morgan, 2008; Dumais & Ward, 2010; Ovink & Veazey, 2010, Torres, 2009; Zweigenhaft, 1993). Previously, proxies have been used to measure students' level of cultural and social capital, such as parents' education level (Adamuti-Trache & Andres, 2008; Archer, Dawson, DeWitt, Seakins, & Wong, 2015; Lee & Bowen, 2006), family resources (Wells, 2008a, 2008b), and cultural activities (Aschaffenburg & Maas, 1997; Katsillis & Rubinson, 1990; Dumais & Ward, 2010). In the context of STEM education, the concept of capital was expanded to include "science capital" in studies of pre-college schoolchildren in the U.K. (Archer et al., 2012, 2015). No attempts have been made to develop ways of measuring the important forms of capital for students in college-level science courses, or even defining what these forms of capital are. Addressing this gap in the literature is another overall goal of this thesis.

Goals of Thesis

Although organic chemistry course is known to have significant impact on undergraduate students in STEM disciplines and on pre-health tracks, there are numerous gaps in education research relevant to this course. Filling all possible gaps in literature in any type of research is obviously impossible. However, I have identified some key factors that contribute to the student success in organic chemistry that deserve either further study or are areas where there is essentially no existing literature. The overall goal of this thesis is to address these specific areas, which are detailed below.

In addition, much of the previously published research on organic chemistry learning was limited by sampling, for example with small populations, included only one instructor, or only one semester of data, etc. Therefore, an additional major goal of this thesis was to perform large scale studies that included more than one instructor and institution, in order to obtain results that will be more widely applicable. This goal was achieved by recruiting participants from a large public research institution in the southwestern U.S. and also from a medium sized private research institution in the northeastern U.S. Each institution is has large numbers of students enrolled in their organic chemistry, but they are quite different geographically and institutionally. In each of the studies described here, data was collected from both institutions over multiple semesters and from courses taught by different instructors.

In the subsequent chapters, detailed studies on specific aspects of the cognitive, socio-cognitive, and socio-cultural factors related to organic chemistry performance are described. Students' cognitive ability is first addressed in Chapter 2. Unlike previous works on cognitive factors in organic chemistry that focus on specific problem-solving ability or a particular organic chemistry topic, a holistic study of all types of standard organic chemistry problems was performed, and their contributions to organic chemistry performance were analyzed.

Socio-cognitive factors, motivation and self-regulation, are examined in Chapter 3. An existing survey instrument, the Science Motivation Questionnaire-II developed by Glynn et al. (2011), was adapted and modified to be specifically suited to organic chemistry student populations. Students' motivation and self-regulation factors were measured were compared to course performance in order to understand the socio-cognitive factors that are best correlated to organic chemistry learning.

Compared to socio-cognitive factors, there were essentially no previous studies of the possible role of socio-cultural factors on organic chemistry performance in the literature. I approached this problem from the perspective of students' social and cultural capital. Standardized instruments to measure cultural and social capital of college-level science students do not exist, and reliable instrument had to be developed first. This instrument development is explained in detail in Chapter 4. In the process, a new capital factor relevant to college science learning was uncovered, which was termed "College Connections". The capital factors from the new instrument were compared to organic chemistry performance to determine the important forms of capital that are related to performance.

In Chapter 5, cognitive, socio-cognitive, and socio-cultural factors were examined in the context of differences in performance in organic chemistry by gender. The results obtained from the work described in Chapters 2 and 3 related to students' cognitive ability on organic chemistry problem types and their motivations and self-regulation respectively were used as guides to explain the previously unrecognized gender differences found in organic chemistry course performance.

The thesis concludes with a summary of the major findings and suggestions for future work in Chapter 6.

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Chapter 2: Measuring Student Performance in General Organic Chemistry

Abstract

Student performance in general organic chemistry courses is determined by a wide range of factors including cognitive ability, motivation to cultural capital. Previous work on cognitive factors has tended to focus on specific areas rather than exploring performance across all problem types and cognitive skills. In this study, the different kinds of problems encountered in general organic chemistry have been categorized, and correlated performance in each problem type with overall class performance. Fairly reproducible results are found for ten consecutive semesters over five academic years. Problem types that require higher-level cognitive skills tend to correlate better with overall class performance than those that rely more heavily on memorization. Performance on some problem types was found to predict up to ~90% of the variances of overall class performance. Correlations across problem types with external student characteristics, such as general chemistry grade, are interpreted as highlighting the important contributions of other factors, in addition to cognitive ability, to success in organic chemistry.

Chapter 2: Measuring Student Performance in General Organic Chemistry

The two-semester general organic chemistry course in the U.S. is required for many college students who are not chemistry or biochemistry majors, and is often considered to be one of the more challenging in their undergraduate careers (Grove & Bretz, 2010; Zoller, 2011). Organic chemistry is also described as a roadblock course for pre-health students who wish to enter medical, dental, and other professional schools (Barr, Matsui, Wanat, & Gonzalez, 2010; Lovecchio & Dundes, 2002; Rowe, 1983), particularly in underrepresented student populations (Barr, Gonzales, & Wanat, 2008; Carmichael, Burke, Hunter, Labat, & Sevenair, 1986). Many approaches to improve student success in organic chemistry have been described in the literature. Examples include curriculum and course content development (Flynn & Biggs, 2012; Grove, Hershberger, & Bretz, 2008; Lopez et al., 2011; Raker & Towns, 2012; Reingold, 2004), incorporation of active learning strategies (Muthyala & Wei, 2013; Paulson, 1999), implementation of peer-led team learning (Gosser & Roth, 1998; Tien, Roth, & Kampmeier, 2002), the use of in-class technology (Dertin, 2008; Flynn, 2011; Ryan, 2013), and electronic and online homework systems (Chamala et al., 2006; Chen & Baldi, 2008; Chen, Kayala, & Baldi, 2010; Dori, 1995; Parker & Loudon, 2013; Penn, Nedeff, & Gozdzik, 2000).

Predictors of student performance in organic chemistry have been the subject of several recent studies (see, for example, Lopez, Shavelson, Nandagopal, Szu, & Penn, 2014; Szu et al., 2011). To completely understand student performance it would be necessary to characterize the relative contributions of three fundamental contributing factors, i.e., cognitive ability (Ausubel, Novak, & Hanesian, 1978), motivation (Deci, Vallerand, Pelletier, & Ryan, 1991; Zimmerman, Bandura, & Martinez-Pons, 1992) and cultural capital (Bourdieu, Harker, Mahar, & Wilkes, 1990). A quantitative description of performance in terms of these three factors would represent a challenging long-term research project. Part of the problem is simply quantifying performance since the information content in a final grade or single point total at the end of the semester is rather low. The purpose of this study was to provide a more informative way of describing student performance using simple standard assessments.

Cognitive ability is perhaps the most frequently studied contributing factor in organic chemistry. Previous work has focused on specific cognitive skills such as the ability to visualize 3-dimensional structures (Ferk, Vrtacnik, Blejec, & Gril, 2003; Oke & Alam, 2010; Stieff, 2011), specific types of problem solving ability (Bhattacharyya & Bodner, 2005; Cartrett & Bodner, 2010; Ferguson & Bodner, 2008; Kraft, Strickland, & Bhattacharyya, 2010), representational models (Bodner & Domin, 2000), thinking patterns (Taagepera & Noori, 2000), and concept development (Grove, Cooper, & Cox, 2012; Nash, Liotta, & Bravaco, 2000). Rather than concentrating on a specific cognitive area, a more holistic approach toward understanding student performance might be useful. For example, nomenclature problems involve mainly the application of memorized rules, and are more relevant to the "Remember" and "Understand" categories of the cognitive domain of the revised Bloom taxonomy (Anderson et al., 2001). Solving complex multi-step synthesis problems, or deriving the mechanism of a reaction that has not previously been seen, however, are more relevant to the "Apply", "Evaluate", and "Create" categories. These latter types of organic chemistry problems test the ability of students to apply existing knowledge in new contexts, consistent with conventional understandings of true problem solving and learning (Bruner, 1960). Students might be expected to perform differently on organic chemistry problems that call on different categories of the cognitive domain, due to divergent cognitive skill sets.

A simultaneous analysis of student performance over the entire range of organic chemistry problem types, and presumably cognitive skills, is described in this chapter to obtain a more detailed insight into student performance. The study takes advantage of a large dataset that includes almost 4000 individual student performances collected over five academic years. Problems used in the course examinations were categorized into different types based on conventional organic chemistry topics, and student performance was analyzed by problem type. Reproducible patterns of student performance over the different problem types were observed. Some problem types were found to be highly predictive of overall performance.

Method

Student performance data were collected for the general organic chemistry courses offered at a large public institution in the Southwestern United States. The study was assigned exempt status by the institution's IRB. At this institution, general organic chemistry is taught as two separate courses in different, usually consecutive, semesters; the first semester course is taught in fall and the second in spring. Data were collected from the first semester course of fall 2009 through the second semester course of spring 2014, i.e., ten consecutive semesters over five complete academic years, to generate a student performance dataset of 3925 (the number of individual students who participated is lower since some students took both the fall and the spring semester classes). The number of students studied in each semester and their overall mean scores are summarized in Table 2.1. The mean scores for the various semesters were similar (Table 2.1), however, an analysis of variance indicated a statistically significant difference across the fall semesters, $F(4, 2047)=5.36$, $p<.01$, and also across the spring semesters, $F(4, 1868)=24.7$, $p<.01$. Thus, the overall class performances were similar but not identical over the time period of the study. It is not surprising that small differences were found since although all classes had the same instructor and similar materials, there were inevitable small changes in teaching style, content coverage and diversity in class populations over 5 years.

The first semester course covers basic organic chemistry principles such as bonding and mechanistic concepts, alkane conformations, nomenclature, chirality, spectroscopy, substitution and elimination reactions of alkyl halides, and reactions of alkenes. The second semester course covers the remainder of the standard functional group chemistry, retrosynthetic analysis, and simple pericyclic reactions, but excludes the chemistry of biomolecules or polymers. Students were assessed each semester using three midterm exams and one comprehensive final exam. All examination questions were short answer type, multiple choice was not used. Different graders were used each semester, but all graders generated their grading rubrics in consultation with the class instructor.

Each exam question was categorized according to one of ten major problem types as summarized in Table 2.2. No attempt was made to also categorize the questions in terms of cognitive category for several reasons. First, the main focus of this investigation is to learn how to quantify student performance in a more informative way rather than directly study their cognitive ability. Second, categorization of problems and student

Table 2.1

Numbers of Students, Demographic Data, Their Average Final Course Scores and Corresponding Standard Deviations for all Semesters of Organic Chemistry Included in this Study[a]

	First Semester (Fall)					Second Semester (Spring)				
	2009	2010	2011	2012	2013	2010	2011	2012	2013	2014
No. of Students	351	408	402	432	459	344	373	373	367	416
Female (%)	57.0	48.3	46.5	49.3	58.2	56.4	48.0	44.0	43.1	53.1
Male (%)	42.7	51.5	53.5	50.7	41.4	42.7	51.7	56.0	56.7	46.9
White (%)	61.8	60.0	64.2	56.7	54.7	59.9	57.9	63.5	60.5	57.2
Hispanic (%)	17.4	14.0	11.9	16.4	14.4	16.9	15.0	14.2	15.5	12.5
Asian (%)	15.7	17.6	16.4	18.5	22.0	17.2	18.2	15.3	16.1	22.8
Black/African American (%)	0.9	3.4	2.0	2.8	1.1	0.9	2.9	3.2	1.9	1.9
Native American (%)	0.6	1.0	0.5	0.7	0.4	0.3	1.1	0.3	0.8	0.5
Two or More Races (%)	1.1	0.3	3.3	3.7	5.9	1.2	0.5	2.4	4.1	4.3
Avg. Score (%)	67.3	73.9	71.7	69.5	72.4	68.8	74.2	65.6	75.6	73.9
Std. Dev (%)	18.2	15.9	16.9	17.4	16.6	18.3	17.2	17.8	16.1	15.9

[a] In cases where gender and demographic data do not sum to 100%, the remainder is not reported.

Table 2.2

Question Categorization into Problem Types, and the Number of Discriminating Questions per Category by Semester

	First Semester (Fall)					Second Semester (Spring)					
Problem Type	2009	2010	2011	2012	2013	2010	2011	2012	2013	2014	Total
Nomenclature (1)	4	2	1	3	2	3	1	4	2	3	25
Bonding/Concepts (2)	8	8	8	10	10	1	1	0	2	1	49
Acidity/Basicity (3)	3	3	2	5	3	4	4	2	3	3	32
Spectroscopy (4)	4	2	6	5	5	2	2	1	0	0	27
Chirality (5)	1	1	1	0	0	--	--	--	--	--	3
Mechanism (6)	18	8	5	5	6	10	11	16	7	9	95
Reagents/Products (7)	14	10	5	3	3	24	20	15	6	14	114
Synthesis (8)	--	--	--	--	--	11	12	9	6	9	47
Pericyclic Reactions (9)	--	--	--	--	--	3	7	3	4	5	22
Conformations (10)	5	4	4	5	5	--	--	--	--	--	23
Total Questions	57 (64)	38 (49)	32 (38)	36 (39)	34 (36)	58 (67)	58 (70)	50 (54)	30 (38)	44 (49)	437 (504)

Note. The numbers in parentheses are the total number of questions per semester, including non-discriminating ones.

performance in terms of familiar course themes can more directly inform improvements in instruction. Third, most of the questions have overlap among the standard cognitive categories (see further below).

The definitions of most of the problem types are straightforward. An exception is the broad Bonding/Concepts (2) problem type, which includes atomic and molecular wavefunctions, hybridization, Lewis structures, isomers, resonance, and polar bonds as topics for the first semester course, and conjugated π-molecular wavefunctions, resonance, aromaticity, and retrosynthetic analysis in terms of the synthon concept in the second semester course. The Nomenclature (1) problem type involves mainly IUPAC nomenclature. The Acidity/Basicity (3) problem type refers to both Brønsted and Lewis acid/base concepts. The Spectroscopy (4) problem type includes problems that ask about fundamental spectroscopic principles (e.g. factors that determine NMR chemical shifts and IR absorption frequencies), but most of these problems involve determination of an unknown structure from provided spectra. The Chirality (5) problem type refers to problems that require identification and characterization of enantiomers and their properties and reactions. The Mechanism (6) problem type includes simple multi-step curved arrow pushing mechanism problems for both reactions the students have seen previously and reactions they have never seen before. The Reagents/Products (7) problem type refers to problems in which students are asked to supply missing reagents/conditions or major organic product, and the Multi-Step Synthesis (8) problem type refers to problems in which students are asked to provide a synthesis a target structure from a provided starting structure. The Pericyclic Reactions (9) problems include both F.M.O. and aromatic transition state theory, and the Conformations (10) problem type refers to conformational analysis of both cyclic and acyclic alkanes. Example questions are provided in Appendix A.

To be included in the analysis, each question had to pass a standard item discrimination test (Nunnally & Ator, 1964). Questions with a discrimination index of 0.2 or greater were included in the analysis. Upon completion of the discrimination item analysis, the Chirality (5) problem type, which included identification of isomers and assignment of absolute configurations, was found to have so few problems that it could not be considered further in the analysis, Table 2.2.

Individual student scores for each discriminated question in a problem type were summed, averaged by the available points for that particular problem type, and converted into a percentage. Each student's overall score for all of the discriminated questions in each semester was converted into a percentage of the total available points. Several scatter plots showing the correlations between the students' average score for several problem types versus overall course score are shown in Figure 2.1, for the fall 2013 semester, as an illustrative example. Qualitatively, it is evident that the scatter is not the same for each problem type. For this particular semester, the Mechanism (6) problem type had a lower scatter, and the Nomenclature (1) problem type, a significantly higher scatter.

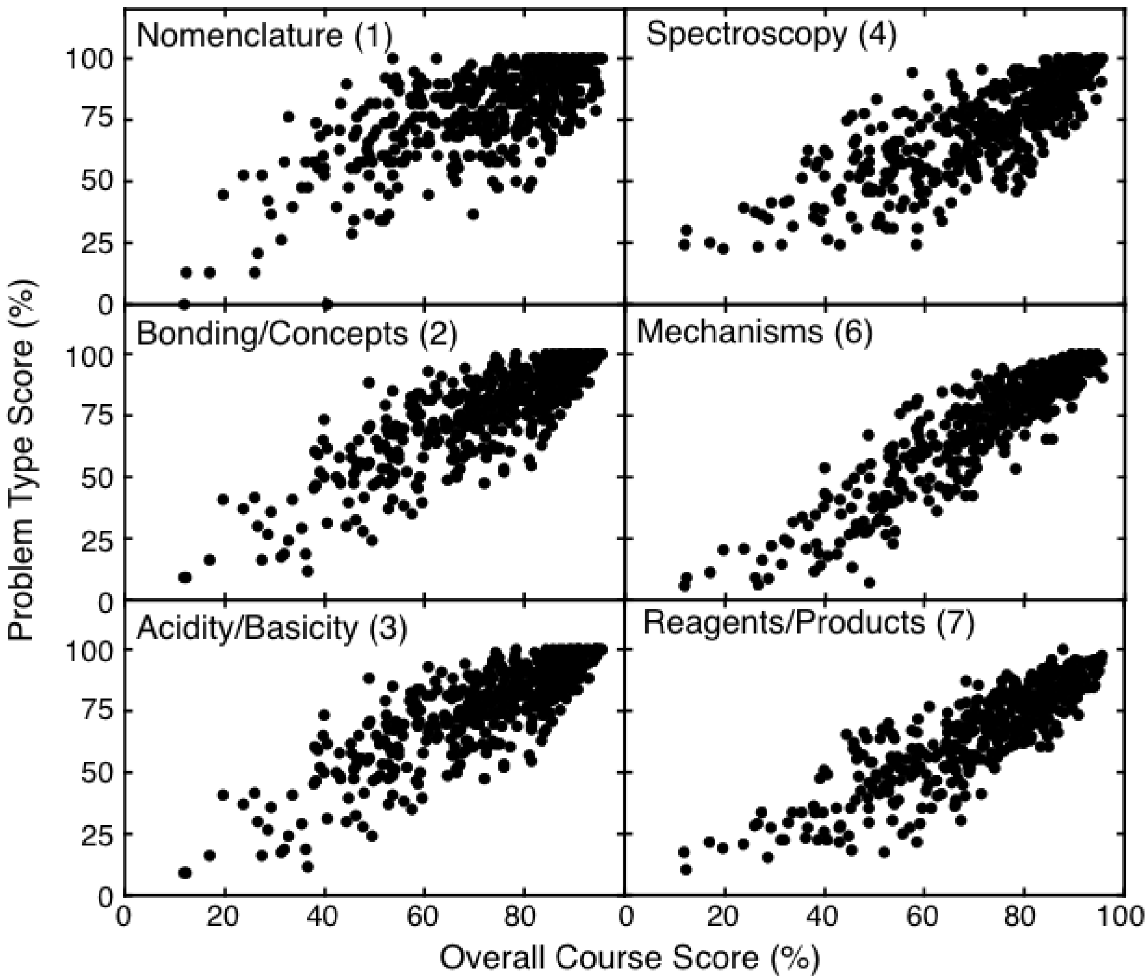

Figure 2.1. Scatter plots of percentage scores for various types of organic chemistry problem versus overall course percentage score, for the fall 2013 first semester organic chemistry class as an example, showing different correlations for different problem types.

Results

Linear correlation analysis of performance per problem type versus overall performance was performed for each semester; the relevant correlation coefficients (*r*) are summarized in Table 2.3. All problem types were positively correlated to the overall performance, and the correlation coefficients (*r*) varied over a very wide range, from 0.44 to 0.93. The Mechanism (6) problem type consistently exhibited the highest correlations for both semesters, whereas the Nomenclature (1) problem type was always among the least correlating problem types.

Stepwise multiple linear regression was also performed as a way of simultaneously analyzing all of the data. The different problem types were treated as the predictor variables to account for the variance in the overall class performance. As an example, the results of the stepwise multiple linear regression analysis for the fall 2013 semester of Figure 2.1, are summarized in Table 2.4. For this particular semester, data were available for seven problem types, Table 2.2, which were used as the predictor variables in the analysis. The final model, $F(5, 453)= 20306.1$, $p<.001$, $R^2=.996$, did not include two of the problem type predictor variables, Nomenclature (1) and Acidity/Basicity (3), since these did not increase the predictive value of the final scores. As expected from Figure 2.1 and Table 2.3, the Mechanism (6) problem type was the most predictive of overall class performance, $\beta=.915$, $F(1, 453)=2343.2$, $p<.001$, adj. $R^2=.836$, followed by the Bonding/Concepts (2) problem type, which accounted for an additional 12% of the variance of the overall class performance. The other problem types, Conformations (10), Spectroscopy (4), and Reagents/Products (7), accounted for only an additional 2.8%, 1.1%, and 0.9% of the variance respectively.

Table 2.3

Correlation Coefficients for Linear Regression Analysis of Student Performance by Problem Type for All Semesters

	First Semester (Fall)					Second Semester (Spring)				
Problem Type	2009	2010	2011	2012	2013	2010	2011	2012	2013	2014
Nomenclature (1)	.75	.59	.65	.76	.70	.68	.44	.74	.72	.74
Bonding/Concepts (2)	.86	.83	.88	.88	.88	.39	.47	--	.54	.54
Acidity/Basicity (3)	.70	.74	.61	.85	.83	.69	.71	.55	.71	.73
Spectroscopy (4)	.75	.71	.83	.84	.79	.68	.62	.58	--	--
Mechanism (6)	.94	.94	.92	.92	.92	.89	.88	.95	.89	.91
Reagents/Products (7)	.90	.90	.91	.91	.87	.94	.94	.96	.96	.95
Synthesis (8)	--	--	--	--	--	.96	.95	.95	.95	.93
Pericyclic Reactions (9)	--	--	--	--	--	.70	.68	.76	.76	.78
Conformations (10)	.75	.79	.88	.89	.87	--	--	--	--	--

Table 2.4

Stepwise Multiple Linear Regression Analysis of Student Performance by Problem Type for the Fall 2013 First Semester Organic Chemistry Class

	Model 1			Model 2			Model 3			Model 4			Model 5		
Variable	B1	SE_B	β	B2	SE_B	β	B3	SE_B	β	B4	SE_B	β	B5	SE_B	B
Constant	24.0	1.05		8.23	.775		4.91	.551		2.14	.442		1.51	.251	
Mechanism (6)	.670	.014	.915	.424	.011	.579	.328	.009	.447	.282	.007	.385	.226	.004	.309
Bonding/Concepts (2)				.445	.014	.474	.350	.011	.373	.331	.008	.352	.319	.005	.340
Conformations (10)							.223	.010	.271	.189	.007	.230	.145	.005	.177
Spectroscopy (4)										.140	.007	.156	.127	.004	.141
Reagents/Products (7)													.146	.005	.169
r	.915			.974			.988			.994			.998		
R^2	.837			.948			.976			.987			.996		
Adj. R^2	.836			.948			.976			.987			.996		

The problem types that were the highest predictors of variance in the overall class performance for each semester are summarized in Tables 2.5 and 2.6. As mentioned above, the class performances were not identical in terms of mean student scores from semester to semester, nevertheless, the same problem types were found to be the highest predictor variables each semester. For the first semester course, the Mechanism (6) problem type was always the highest predictor variable; the second highest predictor was always the Bonding/Concepts (2) problem type, Table 2.5. The third highest predictor variables varied among Reagents/Products (7), Conformations (10), and Acidity/Basicity (3) problem types. For the second semester course, the highest predictors were always Mechanism (6), Multi-Step Synthesis (8), and Reagents/Products (7) problem types. The problem type Nomenclature (1) was almost always the least predictive problem type for both semesters.

The most predictive problem types were those that were more likely to be characterized by higher categories of cognitive domain. In the first semester course, the Bonding/Concepts (2) problem type includes the majority of the new concepts that students are exposed to in first semester organic chemistry. Only a limited number of chemical reactions are covered in the first semester course, and the conceptual basis for these reactions are mostly covered by Bonding/Concepts (2) problems, which means that Bonding/Concepts (2) carries a much higher cognitive load than Reactions/Products (7) in the first semester course. The second semester course focuses much more on chemical reactions, and new concepts are introduced more within the context of new reactions, which places a much higher cognitive load on Reagents/Products (7) in the second semester course. Multi-step synthesis (Synthesis (8)) is taught in the second semester

Table 2.5

The Most Predictive Problem Types from Stepwise Multiple Linear Regression for the First Semester Organic Chemistry Course.[a]

	Fall 2009		Fall 2010		Fall 2011		Fall 2012		Fall 2013	
	Model 1	Model 3	Model 1	Model 3	Model 1	Model 3	Model 1	Model 3	Model 1	Model 3
Prob. Types	(6)	(6),(2),(7)	(6)	(6),(2),(10)	(6)	(6),(2),(7)	(6)	(6),(2),(3)	(6)	(6),(2),(10)
r	.937	.987	.935	.985	.924	.986	.920	.984	.915	.988
R^2	.879	.974	.875	.969	.854	.971	.847	.967	.837	.976
Adj. R^2	.878	.974	.875	.969	.854	.971	.847	.967	.836	.976

[a] Model 1 describes the single most predictive problem type, Model 3 describes the three most predictive problem types in decreasing order of predictive value. The problem types are summarized in Table 2.2.

Table 2.6

The Most Predictive Problem Types from Stepwise Multiple Linear Regression for the Second Semester Organic Chemistry Course.[a]

	Spring 2010		Spring 2011		Spring 2012		Spring 2013		Spring 2014	
	Model 1	Model 3	Model 1	Model 3	Model 1	Model 3	Model 1	Model 3	Model 1	Model 3
Prob. Types	(8)	(8),(6)(7)	(8)	(8),(6),(7)	(7)	(7),(6),(8)	(7)	(7),(6),(8)	(7)	(7),(8),(6)
r	.955	.991	.954	.992	.956	.998	.957	.993	.946	.992
R^2	.912	.983	.910	.984	.913	.995	.916	.985	.895	.984
Adj. R^2	.912	.983	.910	.984	.913	.995	.916	.985	.894	.984

[a] Model 1 describes the single most predictive problem type, Model 3 describes the three most predictive problem types in decreasing order of predictive value. The problem types are summarized in Table 2.2.

course and requires a deep understanding of concepts and reactions by the students, which is highly cognitively demanding. Multi-step synthesis is also challenging for students because they are required to solve problems they have never seen before and that by definition are impossible to memorize. Mechanism problems (6) are also cognitively demanding for students in both the first and second semester classes since they are again required to solve problems they have never seen before and obviously cannot memorize.

One potential problem with the simple linear regression analyses is that the scores for each student were averaged over different numbers of problems for each type. Types for which there were a larger number of problems might be expected to correlate better with overall performance on that basis alone. However, the types with the larger numbers of problems did not always exhibit the best correlations and/or were the best predictors. For the fall 2013 semester, for example (Figure 2.1 and Table 2.3), the Mechanism (6) problem type, which had 6 problems, was a better predictor of the overall performance than the Bonding/Concepts (2) problem type, which had 10 problems. The Reagents/Products (7) problem type, which had 3 problems, was a better predictor variable than the Conformations (10) problem type for which there were 5 problems. In addition, the standardized coefficients from the stepwise linear regression (Tables 2.4 – 2.6) are intrinsically corrected for different numbers of problem types, and the observed trends in terms of which problem types are most predictive of performance are the same for both analyses. Thus, the observed behavior are not determined by the number of discriminated problems.

Two other statistical problems potentially influence the results of both the linear and the stepwise regressions, however. The scatter plots of Figure 2.1 show clear ceiling effects, particularly for Nomenclature (1), Bonding/Concepts (2), and Acidity/Basicity (3) problem types. The scatter plots also show somewhat different extents of deviation from normal distribution for the different problem types. To ameliorate these effects, a simple non-parametric data analysis method was also used. Students were ranked in terms of percentage scores from lowest to highest both in terms of the overall class performance and for each problem type. For each problem type, the percentage of students who were in both the lower half in that problem type and in also in overall class performance was then obtained. The larger this percentage, the more that particular problem type was representative of overall performance. The percentages ranged from a low of 67% to a high of 93%, depending upon the problem type and the semester, Table 2.7. The averages of these percentages over the five semesters for each course, Table 2.6, showed that the Mechanism (6), Bonding/Concepts (2), and Reagents/Products (7) problem types were those that best correlated with the overall performance in the first semester course, and that the Mechanisms (6), Reagents/Products (7), and Synthesis (8) problem types were the most correlating in the second semester class. The problem types that were best correlated with overall performance were thus found to be essentially the same from all of the different methods of analysis.

Another possible issue is that the instructor was the same for all classes, and the observations may be a consequence of instructor bias. Specifically, certain problem types may be more predictive of overall performance simply because they were emphasized to a greater or lesser extent by the instructor. However, emphasis or de-emphasis of a specific topic might be expected to lead to universally high (emphasis) or low (de-emphasis) performance for all students in that topic, and this is clearly not the

Table 2.7

Percentage of Students by Problem Type Who Were in Both the Lower Half of the Class Overall and the Lower Half in That Problem Type

	First Semester (Fall)						Second Semester (Spring)					
Problem Type	2009	2010	2011	2012	2013	Avg.[a]	2010	2011	2012	2013	2014	Avg.[a]
Nomenclature (1)	77	69	74	79	72	74(4.0)	74	76	75	79	77	76(1.9)
Bonding/Concepts (2)	85	84	84	84	87	***85(1.3)***	68	67	--	76	79	73(5.9)
Acidity/Basicity (3)	76	73	68	83	81	76(6.1)	76	76	69	80	76	75(4.0)
Spectroscopy (4)	73	77	85	81	80	79(4.5)	74	67	73	--	--	71(3.8)
Mechanism (6)	89	87	85	86	87	***87(1.5)***	84	87	91	91	90	***89(3.0)***
Reagents/Products (7)	85	86	86	86	84	***85(0.9)***	88	87	91	91	90	***89(1.8)***
Synthesis (8)	--	--	--	--	--	--	90	89	93	90	91	***91(1.5)***
Pericyclic Reactions (9)	--	--	--	--	--	--	73	70	83	76	78	76(5.0)
Conformations (10)	77	82	84	87	82	82(3.6)	--	--	--	--	--	--

[a] The numbers in parentheses are the standard deviations.

case for the problem types are are highly predicting. For a problem type to be highly predicting the students scores need to span the entire range of the overall scores. Thus, although there are limitations associated with only using data from a single instructor, instructor bias is unlikely to be responsible for the trends across problem type observed here. It is possible that different instructors could write problems that distribute the cognitive load differently, but the conclusion that students are more differentiated by problems with a higher cognitive load seems reasonable, even if the types of problems with the higher cognitive load might be different from those in this study.

Discussion

Even though the overall class performance was not identical for the classes included in this study, the data show quite reproducibly that student performance is not the same across all problem types. The problem types that are more cognitively demanding tend to be better predictors of overall performance, sometimes with remarkably high predictive value. The differences in performance between problem types were still fairly small, however, which may be due to the inherent difficulty of cleanly categorizing some of the questions into a single problem type, and also because many questions draw from different cognitive categories. For example, in addition to applying memorized rules, the nomenclature questions in these courses also require students to be able to recognize and assign the stereochemistry of geometrical isomers and also at asymmetric centers. Inevitable mixing of concepts within questions will tend to reduce the differences between the problem types.

Nevertheless, it was of interest to try to relate performance by problem type to influences on student performance discussed in the literature.

Table 2.8

Comparison of Student Mean Percent Scores by Pre-Health, First Generation College Goers and General Chemistry Grade for the First Semester Fall 2013 Class

		Category						
Student [a]	Overall	(1)	(2)	(3)	(4)	(6)	(7)	(10)
Not Pre-Health (116)	73.0	78.6	76.5	76.9	73.9	73.3	67.0	78.3
Pre-Health (254)	72.2	78.9	74.8	76.4	73.0	72.3	68.2	77.4
Not First-Generation (99)	73.7	79.4	76.9	77.3	75.0	73.9	68.8	78.8
First-Generation (271)	68.9	77.2	71.1	74.4	68.7	68.9	65.1	74.6
Gen. Chem Grade A (216)	78.0	83.5	81.7	81.0	77.7	79.3	72.9	83.1
Gen. Chem Grade B (108)	65.0	72.5	67.3	70.4	67.1	63.6	61.1	69.4
Gen. Chem Grade C (32)	58.5	67.1	59.1	64.7	61.3	56.7	54.9	65.1
B + C Grades (140) [b]	63.5	71.2	65.4	69.1	65.8	62.0	59.7	68.4

[a] The number of students in each category is given in parenthesis. [b] Combined mean scores for 'B' and 'C' general chemistry students. Student who earned a lower grade than C are not allowed to register for the organic chemistry course at the subject institution.

Three of these student characteristics possibly related to performance were analyzed: 1) first semester general chemistry grade, 2) whether the student is a first generation college goer, 3) whether the student self-reports as a pre-health student. Data for this part of the study was collected by survey of first semester fall 2013 class. Survey participation was voluntary, but 81% of the class participated and so the results should be quite representative. The relevant data are summarized in Table 2.8.

Prior achievement in science courses has previously been found to be a good predictor of organic chemistry performance (see, for example, Lopez et al., 2014; Turner & Lindsay, 2003). Table 2.8 shows a clear trend between general chemistry grade and overall class performance. The results from the analysis of variance for overall class performance shows a statistically significant difference in overall scores by general chemistry grade, $F(2,353)=39.6$, $p<.001$. The Tukey-Kramer post-hoc test shows that both the 'A' and 'B' students ($p<.001$) and the 'A' and 'C' students ($p<.001$) are statistically different, but the 'B' and 'C' students are not ($p=.097$), presumably because the population of 'C' students is so small, Table 2.8. Therefore, to determine whether performance difference varied with problem type, the 'B' and 'C' student mean scores were combined and compared to those of the 'A' students. The largest difference between these scores was found for the Bonding/Concepts (2) and Mechanisms (6) problem types, and the smallest difference was found for the Nomenclature (1) problem type. These results exactly match the overall trends discussed above, i.e., that lower performing general chemistry students are differentiated from higher performing general chemistry students to a greater extent by problem types that have higher cognitive demand. General chemistry grade is, however, a predictor of organic chemistry performance, and does not describe a fundamental student characteristic.

A more fundamental characteristic that may contribute to success is whether students are first-generation college goers (Horn & Nunez, 2000; Pascarella, Pierson, Wolniak, & Terenzini, 2004; Richardson & Skinner, 1992). The overall mean scores and the mean scores across problem type were found to be numerically lower for first-generation college goers in the fall 2013 class, Table 2.8. The differences in this case, however, were considerably smaller than observed with general chemistry grade. The overall mean scores were found to be statistically different, $t(368)=2.42$, $p=.016$, but only the Bonding/Concepts (2) and Spectroscopy (4) problem types' mean scores were also found to be statistically different. Although this characteristic was found to influence student performance, the effect is too small to be analyzed by problem type.

As mentioned above, organic chemistry is often seen as a roadblock for the students on pre-health tracks in the United States (Barr et al., 2010; Lovecchio & Dundes, 2002). The performances of pre-health and non-pre-health students in terms of both overall score and across the problem types were compared, Table 2.8. For the fall 2013 class, there was no significant difference in overall mean scores, $t(368)=.406$, $p=.685$. There was also no statistical difference in the mean scores between these two groups for any of the problem types. The characteristic that differentiated strongly between students in terms of overall performance (general chemistry grade) also differentiated by the cognitive demand of the problem type. The characteristic that barely differentiated students by overall performance (first generation college goer) also barely differentiated by problem type. The characteristic that did not differentiate students (pre-health versus not pre-health) also did not differentiate by problem type. If this connection between student characteristic and performance is general, then it is quite revealing. It implies that characteristics that contribute to higher overall performance, also contribute to higher performance on problems with higher cognitive load, even if they have no direct connection to cognitive ability. It also implies that characteristics that do not substantially contribute overall performance do not influence performance on problems with differing cognitive loads, even if a connection to cognitive ability might be expected. Although this cannot be said with certainty since different kinds of student characteristics have not been studied enough, but it is important enough to explore further implications anyway.

If general chemistry grade is predictive of overall performance in organic chemistry, and higher performing general chemistry students perform better on the more cognitively demanding problems in organic chemistry, then this would suggests that the cognitive skills required to perform well in organic chemistry are similar to those required to do well in general chemistry. However, it is often discussed in the literature that the quantitative emphasis in general chemistry is quite different from the qualitative emphasis of organic chemistry (Ferguson & Bodner, 2008; Lopez et al., 2014). Thus, it is unlikely that the relationship between general chemistry and organic chemistry performance is purely a consequence of similar student cognitive abilities. Of course, student performance is also strongly influenced by other fundamental factors, specifically motivation (Black & Deci, 2000; Koballa & Glynn, 2007; Jurisevic, Vrtacnik, Kwiatowski, & Gros, 2012; Richardson, Abraham, & Bond, 2012; Turner and Lindsay, 2003; Zusho, Pintrich, & Coppola, 2003) and cultural capital (Hailikari & Nevgi, 2010; Szu et al., 2012; Tai, Sadler, & Loehr, 2005). The larger the influence of, for example, motivation on student performance, the more likely it will be that students who are high performing in general chemistry will also be high performing in organic chemistry, since the cognitive influence is diminished. The results described here point to the important contribution of factors in addition to cognitive skills to student success in organic chemistry as shown in other studies concerning non-cognitive factors (Black & Deci, 2000; Lynch & Trujillo, 2011).

Conclusions

Quantitative analysis of performance across problem types is a readily accessible tool that provides insight into influences on student performance for factors that have a substantial influence on performance. Whether students were first generation college goers only weakly influenced performance, and analysis by problem type was not possible. General chemistry grade, however, is a strong predictor of organic chemistry performance, and problem-type analysis clearly points to the important role of non-cognitive factors such as student motivation. This work clearly needs to be expanded to include quantitative studies of other kinds of student characteristics and also qualitative analysis of student approaches to the general organic chemistry course, which are discussed later in this thesis.

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Chapter 3: Relating Motivation and Student Outcomes in General Organic Chemistry

Abstract

A central tenet of self-regulated learning theories is that students are motivated towards learning in order to self-regulate. It is thus important to identify student motivations in order to inform efforts to improve instructional strategies that encourage self-regulation. Here is a study aimed at characterizing the important motivation factors for students taking general organic chemistry, and how they connect to, and correlate with student performance. A cross-sectional study was conducted involving 2648 undergraduate student participants at two institutions over five semesters and four instructors. Motivation was measured using the Organic Chemistry Motivation Survey (OCMS), a modified form of Glynn et al., (2011)'s Science Motivation Questionnaire II (SMQ-II). The results suggest that the students were highly motivated towards earning a high grade, but that this grade motivation correlated only weakly with performance. Other intrinsic and extrinsic motivation factors were found to be low, suggesting that the students perceived organic chemistry to have little relevance to their interests and careers. However, student performance was strongly correlated with self-efficacy, and, to a lesser extent, self-determination. This finding implies that high-performing students tended to be self-regulated learners who are not motivated primarily by the relevance of the course content. Alternate sources of motivation that can drive self-regulation are discussed.

Chapter 3: Relating Motivation and Student Outcomes in General Organic Chemistry

In the United States, over 70,000 college students enroll in organic chemistry courses each year, but the majority of these students are not chemistry or biochemistry majors (Merritt, 2005). Although the role of organic chemistry in pre-professional preparation may be under review (Halford, 2016), many professional programs in the United States (e.g. medicine, dentistry, pharmacy) require a two-semester sequence in general organic chemistry as an admission prerequisite. Students often fear organic chemistry and attrition rates can be high, approaching 50% in some cases (Grove, Hershberger, & Bretz, 2008; Rowe, 1983). Together with physics and calculus, organic chemistry is often described as a roadblock to success for many pre-professional students (Barr, Matsui, Wanat, & Gonzalez, 2010; Lovecchio & Dundes, 2002), particularly in underrepresented populations (Barr, Gonzalez, & Wanat, 2008; Carmichael, Bauer, Hunter, Labat, & Sevenair, 1988; Carmichael, Burke, Hunter, Labat, & Sevenair, 1986). Understanding the student-centric factors that connect to learning in organic chemistry is essential to the design of instructional strategies to improve students' perceptions of, and performance in, organic chemistry courses.

Several studies on student factors that are predictive of performance have been described in the literature. A range of different variables have been investigated, including student demographics (Lopez, Shavelson, Nandagopal, Szu, & Penn, 2014; Steiner & Sullivan, 1984), prior academic performance (Steiner & Sullivan, 1984; Szu et al., 2011; Turner & Lindsay, 2003), study habits (Szu et al., 2011), and attitude, anxiety and confidence (Steiner & Sullivan, 1984; Turner & Lindsay, 2003). However, understanding general predictive factors is not as useful as understanding those that directly connect to learning theories, since these can be used to better inform the development of new instructional strategies.

Several investigations of student performance in organic chemistry courses have been performed from the perspective of different learning theories. These studies have tended to emphasize cognitive aspects of learning over affective ones. Cognitive traits that have been investigated include working memory (Tsarparlis & Angelopoulos, 2000), spatial ability (Pribyl & Bodner, 1987), three-dimensional visualization (Ferk, Vrtacnik, Blejec, & Gril, 2003; Lopez et al., 2014; Oke & Alam, 2010; Stieff, 2011), problem-solving strategies (Bhattacharyya & Bodner, 2005; Cartrette & Bodner, 2010; Kraft, Strickland, & Bhattacharyya, 2010), and conceptual understanding (Grove, Cooper, & Cox, 2012; Nash, Liotta, & Bravaco, 2000). In turn, suggestions for strategies to improve student learning and outcomes in organic chemistry are most often based on building student cognitive abilities and problem-solving strategies (see, for example: Flynn & Biggs, 2012; Grove & Bretz, 2010; Grove et al., 2012; Raker & Towns, 2012).

Although affective factors, such as motivation, are often considered important in science education in general (see, for example: Glynn, Brickman, Armstrong, & Taasoobshirazi, 2011; Glynn & Koballa, 2006;; Lynch, 2006; Schunk, 1995; Schunk & Parajes, 2001; Schunk & Usher, 2012; Simpson, Koballa, Oliver, & Crawley, 1994; Taasoobshirazi & Glynn, 2009; Usher & Pajares, 2008), only a few investigations of affective factors have been reported for general organic chemistry courses. Garcia, Yu, and Coppola (1993) reported that in addition to prior achievement, students' intrinsic and extrinsic motivation also correlated with performance in an organic chemistry course with small to moderate effect. A detailed study based on self-determination theory (Black

& Deci, 2000) showed that student performance in a general organic chemistry course correlated both with the extent of self-regulation, and also the extent to which the course instructor encouraged self-regulation. Specifically, students' perceived competence and interest/enjoyment of chemistry as variables were found to correlate with course grade with moderate effect size. Similar effect sizes were found for correlation of student grade with course instructor support in terms of perceived competence and interest/enjoyment of chemistry. Lynch and Trujillo (2011) reported that self-efficacy had a moderate to large effect on performance in organic chemistry and that intrinsic and extrinsic motivation factors were gender dependent, with males reporting higher levels of control and task value with moderate effect sizes. A recent study of a first semester general organic chemistry course showed that student performance correlated with self-efficacy, and also that performance was reciprocally connected to student self-efficacy. Self-efficacy as a variable was significantly correlated with exam score with small to moderate effect size (Villafañe, Xu, & Raker, 2016). These studies are important not only because they highlight the role of affective factors in organic chemistry learning, but also because they can also be used to guide strategies to improve student success that reach beyond the traditional approaches that focus mainly on cognition (see, for example: Villafañe et al., 2016). In particular, student motivation is a critical factor in social-cognitive theories of learning.

Motivation and Social-Cognitive Learning Theory

The fundamental principle underlying social-cognitive learning theory is that student performance can be understood in terms of self-regulating beliefs that are influenced by and also influence motivation. In turn, these beliefs control cognitive and affective learning behavior (Bandura, 2001; Schunk & Pajares, 2001). From this perspective, students learn when they have a source of motivation to self-regulate their cognitive development. A number of different motivation factors have been identified that can influence self-regulated learning (Glynn & Koballa, 2006; Pintrich, 2004). These include *intrinsic motivation*, which describes student learning for its own sake, or because they find the subject interesting or internally rewarding; *self-determination*, which describes the amount of control students believe they have over their learning; *self-efficacy*, which describes students' beliefs that they can succeed in the subject; and *extrinsic motivation*, which accounts for the students' external influences on motivation, such as earning a high grade or advancing towards a career. Although these factors are somewhat interrelated, it is common to characterize them individually in order to build tractable models of student learning.

Social-cognitive theory suggests that understanding motivation (and other social factors) is as important as understanding cognitive factors (Black & Deci, 2000). Measuring motivation factors, however, is difficult since they are not directly observable. For instance, it might be possible to quantify a specific cognitive skill such as spatial ability by directly measuring student response to a specific task. But quantifying motivation can only be made indirectly, by measuring an empirical response that must then be related back to the specific motivation factor. Motivation instruments must, therefore, be carefully validated and checked for reliability.

In order to help students develop self-regulation skills in general organic chemistry, it is clearly important to understand their motivations for learning in the course since this can help to guide improvements in strategies for learning. For example, if they are motivated to learn due to extrinsic factors, such as a belief that the subject material might be relevant to their future careers, then a reasonable strategy might be to contextualize the course material, as has been attempted in general chemistry (see, for example, Middlecamp et al., 2014; Sjostrom & Talanquer, 2014). On the other hand, if students are more motivated by intrinsic factors, such as the desire to develop deeper understanding, then more discovery or problem-based based learning approaches might be explored.

Research Goals

The overall goal of the present study is to contribute to an understanding of student motivation to learn in large organic chemistry college courses, in order to inform social-cognitive approaches to teaching and learning. A more specific goal is to develop a survey instrument to measure motivation factors in general organic chemistry in order to characterize the student populations in these courses. A further goal is to determine which of these motivation factors connect most with overall course performance.

Method

Participants

The participants in the study were students taking general organic chemistry at two institutions. One is a large research university in the Southwestern United States (SWU), the other is a medium sized research university in the Northeastern United States (NEU). The two institutions were selected because they differ geographically, because they differ in type, since SWU is a public institution whereas NEU is private, and because both have large general organic chemistry classes. At both institutions, general organic chemistry is offered as a two-semester course sequence. The first course is taught in the fall semester and the second in the spring semester; in other words, each semester constitutes a separate course. Enrollments in the general organic chemistry courses was typically around 500 at SWU and around 300 at NEU. The course at SWU is taught primarily in traditional lecture style, while at NEU, peer-led team learning sessions are offered in addition to the traditional lecture. The same instructor taught all of the courses included in this study at SWU. At NEU, one instructor taught all of the first semester (fall) courses and two different instructors taught the second semester (spring) courses. Data at SWU were collected starting in the spring semester of 2014 through the spring semester of 2016, i.e. for five consecutive semesters. Data at NEU were collected over four consecutive semesters, from fall 2014 to spring 2016. The study was granted exempt status from the IRBs at both institutions. Although the two institutions differed both geographically and in type (public versus private), the demographics of the participating students were similar, Fig. 3.1 (see also Appendix B), the major differences being a somewhat larger Hispanic/Latino population at SWU, and a larger percentage of students not identifying race at NEU.

To be included as a participant in this study, students provided written consent, completed all course assessments, and completed the survey. Students who took the course but did not provide written consent, did not complete all course assessments, or did not complete the survey were not included in the study. The total number of individual participant responses from both institutions obtained over the course of the entire study was 2648. Many students took both the first and second semester courses and are therefore counted twice as participants in the study. On average, 85% of the general organic students who completed the courses at SWU during the time of the study were participants in the study, and 81% of the students who completed the courses at NEU during the time of the study were participants in the study.

Measuring Motivation: Instrument Development

Student motivation factors in this study were assessed using the Organic Chemistry Motivation Survey (OCMS). The OCMS is based on the more general Science Motivation Questionnaire - II (SMQ-II), a validated and reliable instrument for measuring student motivation towards learning science described by Glynn et al. (2011). SMQ-II is a 25-item instrument designed to measure student motivation in five areas (Table 3.1). The SMQ-II authors have also generated discipline-specific versions of the instrument for biology, chemistry, and physics by substituting the discipline for the word “science” in each question (see: https://coe.uga.edu/outreach/programs/science-motivation). For a recent example where the chemistry version of SMQ-II was used in a study of general chemistry students, see Hibbard, Sung, and Wells (2016). Similarly, a survey instrument was created by replacing the word "science" in each question with "organic chemistry.” As the SMQ-II was validated with general science and non-science majors, and the survey in this study was for a specific group of students, exploratory and confirmatory factor analyses were used to determine if the OCMS behaved similarly to the SMQ-II, or if further refinement was necessary.

Exploratory factor analysis was performed on the complete dataset by combining the student responses for all 25 questions from both SWU and NEU over all semesters studied. As indicated above, the total number of student participants was 2648. The principal axis factoring method with promax rotation was used because it accounts for the

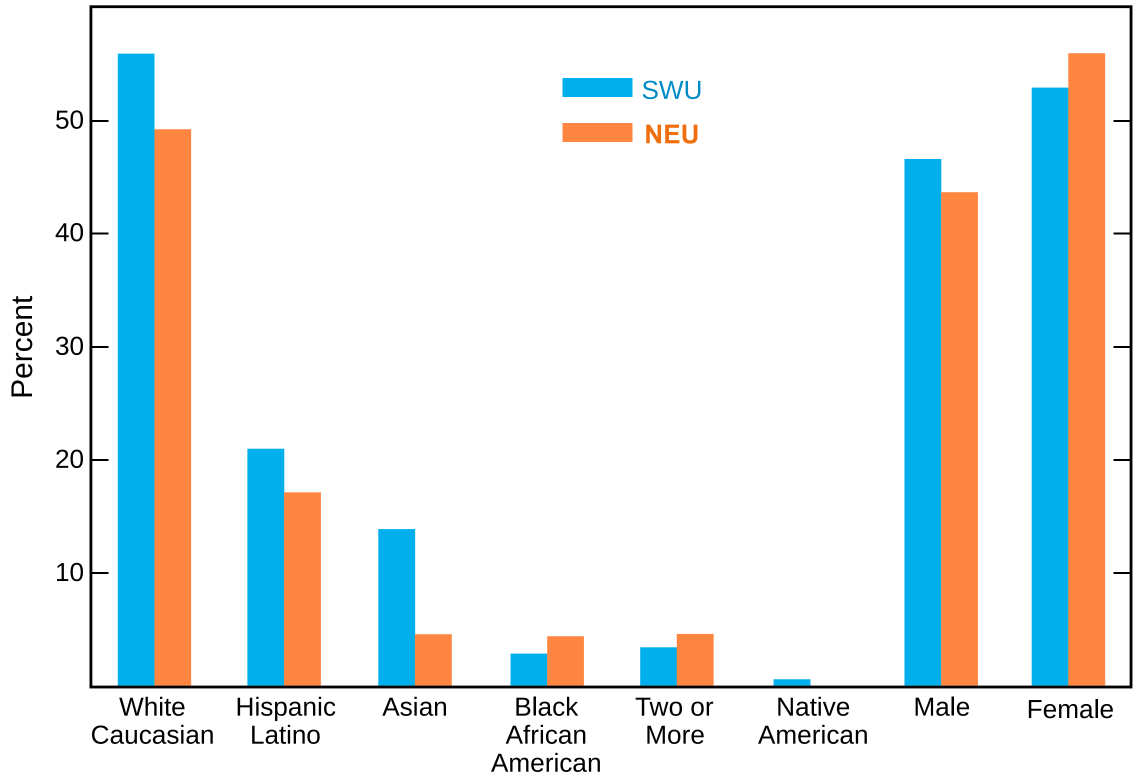

Figure 3.1. Bar graph representation of demographic and gender data for the study participants. A larger percentage of the students reported "Race not identified" at NEU (19.7%), compared to SWU (1.8%). Detailed demographic information is provided in Appendix B.

possibility of covariation among the variables and to accommodate the large nature of the dataset (Leech, Barrett, & Morgan, 2011). Four motivation factors emerged in the initial solution from this analysis rather than five factors as described in the original SMQ-II. The self-efficacy question “I am confident that I will do well in organic chemistry labs and projects” was not included in the initial solution because it did not meet the minimum factor loading criterion of 0.3. At both institutions, the organic chemistry lecture and laboratory courses are separate. Because the survey was administered to students enrolled in, and in the context of, the lecture course, it is understandable that students could respond differently to questions that are laboratory course specific. For the same reason, the self-determination question “I prepare well for organic chemistry tests and labs” and the grade motivation question “Scoring high on organic chemistry tests and labs matters to me” were removed from further analysis. In addition, the intrinsic motivation question “I am curious about discoveries in organic chemistry,” was removed due to low initial and extracted communalities values, 0.273 and 0.246 respectively.

In the second solution, the intrinsic motivation questions “Learning organic chemistry is interesting” and “I enjoy learning organic chemistry” cross-loaded under two factors with similar loading values and were thus also eliminated.

The final factor analysis solution contained 19 of the 25 original SMQ-II questions that loaded onto four factors, with none of the items loading below a value of 0.3 as show in Table 3.2. The remaining questions derived from the original career motivation and intrinsic motivation factors of SMQ-II were now combined under a single factor with a total of 7 questions.

Table 3.1

Questions Included in the Science Motivation Questionnaire (SMQ-II), and the Modification for Use in an Organic Chemistry Context, from Glynn et al., 2011[a]

Intrinsic Motivation
1. The science (*organic chemistry*) I learn is relevant to my life.
2. Learning science (*organic chemistry*) is interesting.
3. Learning science (*organic chemistry*) makes my life more meaningful.
4. I enjoy learning science (*organic chemistry*).
5. I am curious about discoveries in science (*organic chemistry*).
Career Motivation
6. Learning science (*organic chemistry*) will help me to get a good job.
7. Understanding science (*organic chemistry*) will benefit me in my career.
8. Knowing science (*organic chemistry*) will give me a career advantage.
9. My career will involve science (*organic chemistry*).
10. I will use science (*organic chemistry*) problem-solving skills in my career.
Self-Determination
11. I put enough effort into learning science (*organic chemistry*).
12. I use strategies to learn science (*organic chemistry*) well.
13. I spend a lot of time learning science (*organic chemistry*).
14. I prepare well for science (*organic chemistry*) tests and labs.
15. I study hard to learn science (*organic chemistry*).
Self-Efficacy
16. I am confident that I will do well on science (*organic chemistry*) tests.
17. I am confident that I will do well in science (*organic chemistry*) labs and projects.
18. I believe that I can master science (*organic chemistry*) knowledge and skills.
19. I believe I can earn an A grade in science (*organic chemistry*).
20. I'm sure I can understand science (*organic chemistry*).
Grade Motivation
21. I like to do better than other students on science (*organic chemistry*) tests.
22. Getting a good science (*organic chemistry*) grade is important to me.
23. It is important that I get an A grade in science (*organic chemistry*).
24. I think about the grade I will get in science (*organic chemistry*).
25. Scoring high on science (*organic chemistry*) tests and labs matters to me.

Note. The questions were randomly ordered in the surveys.
[a] The questions in the original SMQ-II ask about and include the word "science". For the present study, the word "science" was replaced by "organic chemistry", as indicated by the italic text in parentheses.

Attempts to force a five-factor solution at this point as in the original SMQ-II, resulted in an eigenvalue for the fifth factor of 0.706, *i.e.*, lower than the minimum criterion value of 1. The Kaiser-Meyer-Olkin measure of sampling adequacy for the four-factor solution was .914, *i.e.*, higher than the standard recommended value of .7 (Kaiser, 1974). Additionally, Bartlett's test of sphericity was found to be significant, χ^2 (171) = 27057.16, $p<.001$. This analysis shows that the intrinsic motivation questions from SMQ-II cannot be meaningfully separated from the extrinsic career motivation questions for this population of students. Together these represent a new factor called "relevance", see Table 3.2. The term relevance has several specific meanings in the education research literature (see, for example; Stuckey, Hofstein, Mamlock-Naaman, & Eilks, 2013). In the present context, relevance was defined as the extent to which the students perceive the course content to be interesting and useful to them at the time they are taking their course and also to their future careers. The original self-efficacy, self- determination, and grade motivation factors remained, and each contained four items after dropping the questions that related to the laboratory course, Table 3.2. The Cronbach's alpha values for each of the four factors were all above the acceptable value of 0.7 (Tavakol & Dennick, 2011). The high Cronbach's alpha values indicate that the questions within each factor measure a similar construct, indicating acceptable internal reliability of the instrument. The questions and their factors as summarized in Table 3.2 together represent the new OCMS.

To test the external reliability of OCMS, confirmatory factor analysis was performed on the data from SWU and NEU populations separately. The confirmatory factor analysis results for NEU population, KMO=.891; $\chi^2(171)=8737.16$, $p<.001$, and for the SWU population, KMO=.917; $\chi^2(171)=17967.55$, $p<.001$, were similar.

Table 3.2

Exploratory and Confirmatory Factor Analysis Results of the Modified SMQ-II Questions. The Four Derived Factors Represent the Organic Chemistry Motivation Survey (OCMS)

	F1	F2	F3	F4
Cronbach's alpha (α): Exploratory [a]	.891	.868	.864	.742
Cronbach's alpha (α): SWU population [b]	.883	.851	.867	.750
Cronbach's alpha (α): NEU population [b]	.894	.886	.856	.750
Factor 1: Relevance				
Understanding organic chemistry will benefit me in my career.	.899			
Knowing organic chemistry will give me a career advantage.	.836			
My career will involve organic chemistry	.792			
Learning organic chemistry will help me to get a good job.	.714			
The organic chemistry I learn is relevant to my life.	.620			
Learning organic chemistry makes my life more meaningful.	.593			
I will use organic chemistry problem-solving skills in my career.	.574			
Factor 2: Self-Efficacy				
I believe I can earn an A grade in organic chemistry.		.855		
I am confident that I will do well on organic chemistry tests.		.823		
I believe that I can master organic chemistry knowledge and skills.		.720		
I'm sure I can understand organic chemistry.		.680		
Factor 3: Self-Determination				
I study hard to learn organic chemistry.			.827	
I spend a lot of time learning organic chemistry.			.811	
I put enough effort into learning organic chemistry.			.783	
I use strategies to learn organic chemistry well.			.595	
Factor 4: Grade Motivation				
Getting a good organic chemistry grade is important to me.				.790
It is important that I get an A grade in organic chemistry.				.684
I think about the grade that I will get in organic chemistry.				.565
I like to do better than other students on organic chemistry tests.				.487

Note. In the surveys the questions were randomly ordered

[a] For exploratory analysis of the full dataset. [b] For confirmatory analysis of the split datasets, see text.

The similarity of these results for the two populations and also the similarity of the Cronbach's alpha values for the different factors (Table 3.2) provide strong support for external reliability. It was concluded that OCMS provides a consistent and reliable measurement of the four motivation factors of Table 3.2 for the populations and experimental conditions included in the present study.

Measuring Student Performance and Motivation Factors

Student course performance was determined in the same way at both institutions, *i.e.*, by summing the points on three midterm exams and one final exam. The total points for the four exams were then converted into a percent score.

Students' self-reported levels of motivation were assessed using the OCMS. Student responses to the questions were scored using a five point Likert scale (0=Never; 1=Rarely; 2=Sometimes; 3=Often; 4=Always). While the original SMQ-II had the same number of questions for each motivation factor, OCMS has different numbers of questions per factor. In order to compare the different factors on the same numerical scale, the raw point total was converted into a percent score based on the maximum possible point score for each factor (relevance = 28; self-determination=16; self-efficacy=16; grade motivation=16).

OCMS was administered to the students one week prior to the final exam in each of the semesters included in the study. Students who completed the questionnaire received points that were equivalent to 0.5% of the total available points for the course as extra credit. Students could choose not to participate and still receive these incentive points by completing 4 short essay questions. The questionnaire was administered at the end of the semester based on prior work suggesting that the correlation between student motivation and performance increases as the semester progresses (Bong, 2001; Turner & Lindsay, 2003; Villafañe et al., 2016).

Results & Discussion

OCMS Motivation Factors

The student motivation factor scores and the overall mean exam scores are summarized by semester and institution together with their standard deviations in Table 3.3. It is important to consider the context within which the OCMS data were collected. The surveys were distributed at the same time each semester at both institutions, which was one week before the end of the courses. Therefore, the data reflect student motivations after the students had been exposed to most of the course material. At this point the students had at least some idea of their ability to perform in the class, of their position in class relative to their peers, and how likely they were to attain the grade they felt they needed in the class.

Although not directly comparable due to differences in the questions, it is still interesting to compare the results from OCMS with those reported by Glynn et al. (2011) for SMQ-II. In SMQ-II, the extrinsic grade motivation was the highest scoring factor for both science majors (n=367) and the non-science majors (n=313). The same was true for organic chemistry students studied here, Table 3.3. This is readily understandable since the majority of the students in these courses are on pre-health tracks as discussed in Chapter 2, and earning a good grade in organic chemistry is often considered important for entry into health-professional schools (Lovecchio & Dundes, 2002).

In SMQ-II the extrinsic career motivation factor was the second highest scoring factor for science majors, but was the second lowest scoring factor for non-science majors. In OCMS, the relevance factor combines elements from the SMQ-II intrinsic and extrinsic career motivation factors, and was the lowest scoring factor, Table 3.3. The relevance factor average score ranged from ca. 50 - ca. 60%, depending upon semester and institution. The average scores for relevance for the organic chemistry students were thus similar to the scores for career and intrinsic motivation *for the non-science majors in SMQ-II*, which, when converted to percent scores, are 56% and 57%, respectively. For comparison, the percent career and intrinsic motivation scores for science majors in SMQ-II were much higher, at 80% and 71%, respectively. The OCMS survey questions are specifically focused on the organic chemistry course, whereas the SMQ-II questions in the Glynn et al. (2011) study refer to science in general. It is perhaps understandable that students would be more positive about science in general than a specific and critical course they are currently immersed in. It was concluded that although the organic chemistry students were motivated towards earning a high grade, at the time in the course when OCMS is administered, they appeared to find the content not very relevant to their interests or careers.

The self-determination and self-efficacy mean scores for the organic chemistry students across semesters and institutions, ranged between ca. 60 - 70%. These scores were within the range of the corresponding scores for the science and non-science majors in SMQ-II, which, when converted to a percentage scale, range from 56% - 75%. Self-determination was generally higher than self-efficacy at both institutions, with self-efficacy being somewhat lower at NEU compared to SWU.

Table 3.3

Mean Scores and Standard Deviations of the Various Motivation Factors,[a] and the Mean Overall Percent Performance Scores and Standard Deviations by Semester for Both Institutions[b]

	SWU					NEU			
Motivation Factor	Spring 2014	Fall 2014	Spring 2015	Fall 2015	Spring 2016	Fall 2014	Spring 2015	Fall 2015	Spring 2016
Relevance	59.3 (20.4)	65.9 (18.4)	62.4 (18.9)	62.5 (19.4)	58.0 (20.8)	52.5 (20.5)	49.9 (19.5)	53.6 (21.1)	52.8 (20.7)
Self-Determination	67.4 (21.2)	70.1 (20.1)	70.7 (19.7)	74.0 (17.7)	71.1 (19.4)	69.6 (18.7)	67.1 (18.6)	69.3 (17.0)	67.3 (19.0)
Self-Efficacy	66.7 (23.7)	71.6 (22.1)	68.7 (23.2)	72.1 (19.9)	63.1 (24.9)	57.1 (23.2)	54.5 (23.5)	60.7 (21.1)	57.9 (25.2)
Grade Motivation	80.8 (19.0)	86.9 (14.3)	84.5 (15.9)	86.3 (13.7)	82.7 (17.7)	83.9 (14.4)	81.2 (14.7)	84.3 (15.6)	81.6 (18.1)
n [c]	370	398	309	366	339	298	195	178	171
Exam Performance	74.8 (14.7)	73.3 (15.7)	71.9 (16.9)	78.4 (11.2)	72.4 (16.0)	62.1 (15.8)	62.0 (15.5)	59.4 (13.7)	61.6 (15.4)

[a] The motivation score is determined as a percentage of the total points available per motivation factor. The standard deviation for each mean score is given in the parentheses. [b] The performance score for each student is determined as a percentage of the points available for the 3 midterm exams and one final exam each semester. The standard deviation for each mean score for the participating students in each course is given in the parentheses. [c] The sum of the *n* values over all of the semesters in this table is 2624, compared to the total number of study participants, 2648, since this data excludes students who were eliminated as outliers in the multiple linear regression analysis, see text.

Correlation of Motivation Factors with Overall Course Performance

Although student motivation data is of interest on its own, it was of larger interest to determine which of the various motivation factors were connected to student performance. Student performance was measured as a percentage of the total available exam points. Average performance scores from Spring 2014 to Spring 2016 at both institutions are shown in Table 3.3. Multiple linear regression analysis was performed for the students' percent scores in the four different motivations factors of OCMS with their overall course percentage score. An analysis of standard residuals was first performed to remove any outliers above or below the standard residual range of ±3.0. On this basis, a total of 18 students were removed from the SWU dataset across the five semesters, and total of six students were removed from the NEU dataset across the four semesters. The assumptions for the normality of residuals were met based on the histogram and normality plot of residuals (Field, 2009). To test for collinearity in the factors, tolerance and variance inflation factor (VIF), values were examined for each semester at both institutions, as shown in Table 3.4. Acceptable values for each of these were obtained, and all tolerance values were greater than 0.25 and all VIF values were less than 2.0 (Keith, 2006).

The results of the multiple linear regression analysis are summarized in Table 3.5. All four motivation factors correlate positively with student performance for each semester at both institutions, $p<.001$. Self-efficacy was consistently found to be the factor with the strongest correlation with performance. Specifically, the effect sizes were all large for this factor ($f^2 \geq 0.35$, see Cohen (1988)), in several cases were greater than 0.7, Table 3.5. The factor with the second largest effect size tended to be self-determination, with moderate values at SWU, f^2 = .11 - .30, and small to moderate values at NEU, f^2 = .05 - .16, followed by grade motivation, which had small to moderate effect sizes at both institutions, f^2 = .05 - .16. The relevance factor almost always had the smallest effect size, Table 3.5, especially at SWU.

R^2 values for the overall model, which included all of the factors, are compared to the R^2 for self-efficacy alone in Table 3.6. It is clear that self-efficacy was the largest contributing factor to the multiple linear regression predictive model, and in some instances, it was the only significant variable in the overall model. For example, self-efficacy accounted for 52% of the overall variance in course performance for the fall semester of 2014 at SWU, $F(4, 393)=113.78$, $p<.001$, $R^2=.54$. Including the self-determination and relevance factors each increased the predicted variance by only 0.7% compared to self-efficacy alone. For the same semester at NEU, self-efficacy explained 41% of the overall variance in course performance, $F(4, 293)=52.23$, $p<.001$, $R^2=.416$, and inclusion of the other factors did not increase the predicted variance at all. This result on its own is not particularly surprising, since strong correlations between student self-efficacy and performance have been observed many times previously, especially when measured towards the end of the semester when students are more aware of their confidence and capabilities (see, for example: Ferrell, Phillips, & Barbera, 2016; Zusho, Pintrich, & Coppola, 2003).

Nevertheless, it is still quite remarkable that the four self-efficacy questions alone accounted for such a large percentage of the variance in the total exam scores at both institutions, while the other factors only contributed on average an additional 1.6% at SWU and 2.8% at NEU to the overall model, Table 3.6.

Table 3.4

Tolerance (Tol) and Variance Inflation Factor (VIF) Values to Test the Assumption of Collinearity for the Prediction Model including All Motivation Factors

	SWU										NEU							
	Spring 2014		Fall 2014		Spring 2015		Fall 2015		Spring 2016		Fall 2014		Spring 2015		Fall 2015		Spring 2016	
Motivation Factor	Tol	VIF	Tol	VIF	Tol	VIF	Tol	VIF	Tol	VIF	Tol	VIF	Tol	VIF	Tol	VIF	Tol	VIF
Relevance	.68	1.47	.79	1.26	.80	1.25	.86	1.17	.74	1.36	.80	1.25	.71	1.40	.80	1.24	.68	1.46
Self-Determination	.57	1.69	.60	1.66	.67	1.49	.66	1.51	.70	1.44	.89	1.12	.86	1.16	.84	1.20	.71	1.42
Self-Efficacy	.59	1.80	.58	1.73	.64	1.56	.62	1.63	.60	1.68	.86	1.17	.65	1.55	.80	1.26	.66	1.52
Grade Motivation	.56	1.76	.67	1.49	.65	1.53	.77	1.30	.70	1.43	.73	1.38	.83	1.21	.76	1.31	.71	1.42

Table 3.5

Correlation Coefficients, r, the Corresponding R^2 and Effect Size, defined as Cohen's f^2, for Multiple Linear Regression Analysis of Student Performance by OCMS Motivation Factors[a]

		SWU					NEU			
Motivation		Spring 2014	Fall 2014	Spring 2015	Fall 2015	Spring 2016	Fall 2014	Spring 2015	Fall 2015	Spring 2016
Relevance	r	.25	.25	.27	.27	.27	.24	.24	.20	.39
	R^2	.06	.06	.07	.07	.07	.06	.06	.04	.15
	f^2	.06	.06	.08	.08	.08	.06	.06	.04	.18
Self-Determination	r	.43	.48	.37	.32	.43	.23	.29	.37	.26
	R^2	.18	.23	.14	.10	.18	.05	.08	.14	.07
	f^2	.22	.30	.16	.11	.22	.05	.09	.16	.08
Self-Efficacy	r	.59	.72	.66	.65	.65	.64	.66	.52	.64
	R^2	.35	.52	.44	.43	.42	.41	.43	.27	.41
	f^2	.54	1.08	.79	.75	.72	.69	.75	.37	.69
Grade Motivation	r	.37	.38	.34	.30	.34	.22	.27	.29	.35
	R^2	.14	.14	.12	.09	.12	.05	.07	.08	.12
	f^2	.16	.16	.14	.10	.14	.05	.08	.09	.14

[a] All coefficients were found to be significant (p<.001). [b] See Cohen (1988).

Table 3.6

R^2 Values from Multiple Regression Models Containing only Self-Efficacy Compared to Models with All Motivation Factors[a]

	SWU			NEU		
Semester	Self-Efficacy	All Factors	$\Delta R^{2\,b}$	Self-Efficacy	All Factors	$\Delta R^{2\,b}$
Spring 2014	.35	.37	.02	--	--	--
Fall 2014	.52	.54	.02	.41	.42	.01
Spring 2015	.44	.45	.01	.43	.46	.03
Fall 2015	.43	.43	.00	.27	.32	.05
Spring 2016	.42	.45	.03	.41	.43	.02

[a] All models were significant ($p<.001$). [b] The improvement in R^2 for the overall model that includes all factors over self-efficacy alone.

Although including self-determination does not improve the predictive model substantially, in general it has the second-highest correlation with performance. This is also not particularly surprising, since self-efficacy and self-determination are both closely connected to self-regulated learning, see further below.

The general trends in the motivation and performance data can be illustrated graphically, as shown in Fig. 3.2. Here, the mean scores for each of the motivation factors averaged over all of the semesters studied are summarized in the form of bar graphs. Also shown are the averages of the corresponding coefficients for correlation of each of the motivation factors with class performance over all semesters, in the form of line graphs (the data is given in Appendix C). The trends in student motivation in the bar graphs compared to the trends in correlation with performance in the line graphs clearly show that there is no connection between the absolute values for the various motivation factors and whether they correlate with performance. At both institutions, the grade motivation scores were consistently the highest of the factors, Fig. 3.2 and Table 3.3, but grade motivation exhibited the second weakest correlation with performance, Fig.3.2 and Table 3.5. A plausible explanation is that essentially all students were motivated towards earning a high grade, particularly those on pre-medical tracks, and indeed, the standard deviations for the grade motivation factor tended to be smaller than for the other factors, Table 3.3. Grade motivation is not as broadly distributed for these students, and is therefore not quite as discriminating as the other factors. In contrast to grade motivation, the relevance factor scores were almost always the lowest of the factors, Fig. 3.2 and Table 3.3, and the relevance factor also exhibited the weakest correlation with performance, Fig. 3.2 and Table 3.5.

Implications for Learning

For the students in this study, self-efficacy correlates most strongly with course performance, followed by self-determination at SWU. Grade motivation is the highest scoring factor, but has a significantly weaker correlation with performance. The relevance factor is the lowest scoring factor, and also has the weakest correlation with performance, Fig. 3.2.

The finding that self-efficacy correlates strongly with course performance is perhaps not surprising, since it is frequently observed to be significant predictor of performance in college-level science courses (Ferrell et al., 2016; Schunk, 1995; Schunk & Pajares, 2001; Usher & Pajares, 2008). This result is also consistent with several previous studies of organic chemistry courses in particular (Lynch & Trujillo, 2011; Villafañe et al., 2016; Zusho et al., 2003). At both institutions, self-efficacy was the factor that most closely related to performance, and at SWU, self-determination was clearly the second most important closely related factor. This result suggests that students who performed well were also those who were more effective at self-regulation (see, for example: Black & Deci, 2000; Zimmerman, 1989; 2000; 2001). This in turn suggests that implementation of self-regulating learning approaches in general organic chemistry courses could be beneficial for all students (Black & Deci, 2000; Lynch & Trujillo, 2011). Methods for encouraging self-regulated learning in college-level classes have been extensively discussed in the literature (see, for example: Nilson, 2013; Pintrich & Zusho, 2007) and include:

1. Helping students to become goal-oriented and modelling systematic study behavior.

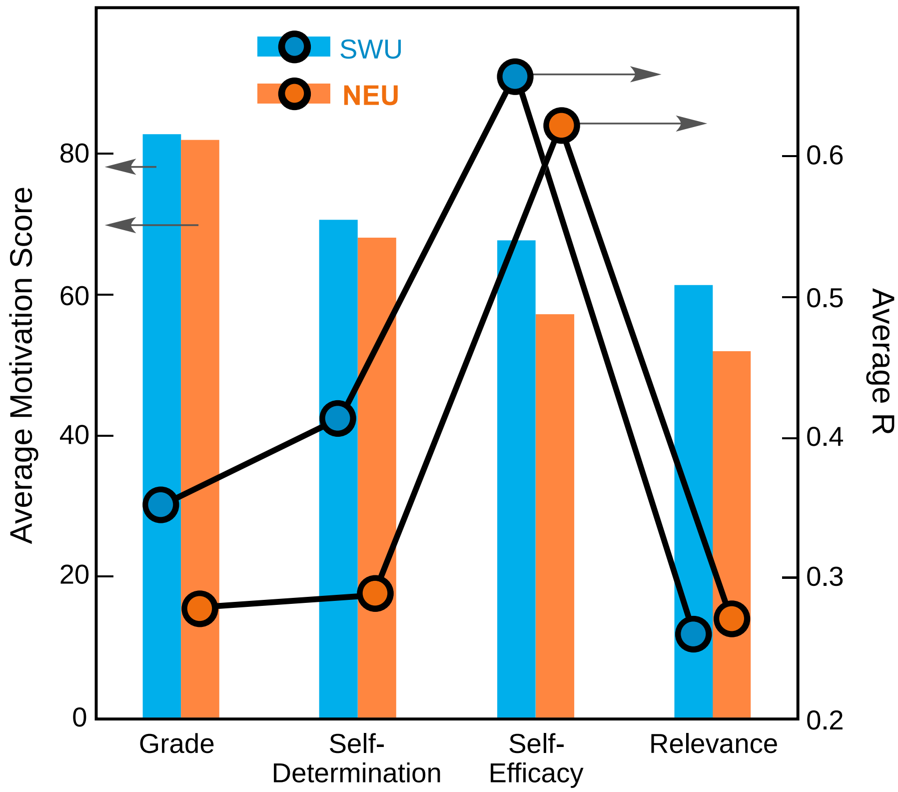

Figure 3.2. Graphical representations (bar graphs) of the scores for the different motivation factors averaged over all students and all semesters at the two institutions, and (line graphs), the all students and all semesters at the two institutions. Detailed numerical data for these graphs are provided in Appendix C.

2. Helping students to understand effective strategies for mastering the knowledge and skills related to problem solving in the course, and providing multiple opportunities to practice new concepts in multiple contexts.

3. Helping students' metacognition (their self-awareness and control of their own thought processes) via timely and informative feedback.

4. Helping students to improve their confidence (self-efficacy) in their ability to learn, explaining that making mistakes is an important part of the overall learning process.

5. Aligning the course with the students' personal goals or career plans, so that they can be self-motivated to participate in the course rather than seeing it as something that happens to them.

Although most of these seem common sense, there are challenges to implementing such strategies in a large lecture course, where providing individual student feedback is difficult. Importantly, point 5 highlights a central tenet of self-regulated learning theory, i.e. that students should be intrinsically or extrinsically motivated to learn in order to self-regulate (see, for example: Zimmerman, 2000; 2001). An extrinsic factor that might be expected to motivate students is the course grade. Grade motivation was found to be a high scoring factor, however, it was also found to correlate only weakly with performance. The relevance factor contains questions that were part of the original "career" and "intrinsic" motivations of SMQ-II, i.e. it combines questions normally associated with conventional extrinsic and intrinsic motivation factors. However, the relevance factor also exhibited a weak correlation with performance and was also one of the lowest scoring factors. It is a significant finding that neither the course grade nor the relevance of the course seemed to be sufficient to drive student self-regulation. The obvious question, therefore, is what *were* the motivating factors that drove successful self-regulation?

The students may have found motivation in the learning process itself, although the present study cannot not provide direct evidence in support of this hypothesis. In a study on the factors that contributed to achievement across different college science subjects, Cavallo, Rozman, Blickenstaff, and Walker (2003) reported that for biology majors, "motivation to learn for the sake of learning was most important for course achievement.” Achievement motivation can be defined as the need for accomplishment (McClelland, Atkinson, Clark, & Lowell, 1953), and the motivation towards attaining performance goals or learning goals (Ames & Archer, 1988). An important component of achievement motivation is intrinsic motivation. According to Rabideau (2005), "individuals perceive the achievement setting as a challenge, and this likely will create excitement, encourage cognitive functioning, increase concentration and task absorption, and direct the person toward success and mastery of information which facilitates intrinsic motivation". This suggests that if self-regulation in organic chemistry students is not driven by the extrinsic and intrinsic factors measured in OCMS (grade and relevance), it may instead be driven by the intrinsic motivation connected to the learning process itself. If this is the case, then instructional strategies that enable students to attain learning and performance goals could be useful. Achievement motivation would therefore be an interesting subject for further research in general organic chemistry courses, similar to recently published research in general chemistry (Ferrell et al., 2016; Liu, Ferrell, Barbera, & Lewis, 2017; Villafañe, Garcia, & Lewis, 2014).

Conclusions

An instrument for measuring student motivation in general organic chemistry courses, OCMS, has been adapted from the previously described SMQ-II. Its use in a multi-semester, multi-instructor, and two-institution study of motivation factors is described. Different motivation factors correlated quite differently with student course performance. Performance was found to be strongly correlated with student self-efficacy, and also with self-determination at SWU. This finding is in agreement with several previous studies that have demonstrated correlations of self-efficacy on performance in organic chemistry (Lynch & Trujillo, 2011; Villafañe et al., 2016; Zusho et al., 2003). This suggests that the successful students were self-regulating their learning. Although the students were highly motivated by grade, grade motivation did not correlate strongly with performance, and was unlikely to be the motivational factor that drove self-regulation. The relevance motivation factor was the lowest scoring factor and also exhibited the weakest correlation with performance. This suggests that the students found general organic chemistry to be only weakly relevant to their interests and careers, and that subject relevance was also unlikely to be the factor that drove self-regulation. Because the successful students had higher self-efficacy and self-determination, implementation of instructional strategies that promote self-regulation could be effective in improving student performance, especially for those with low self-efficacy. Although the students appear to have low intrinsic subject motivation, if they are motivated by the learning process itself then helping students to achieve performance and learning goals could be useful, although further research in this area is required.

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Chapter 4: Cultural and Social Capital in a College-Level Science Course

The need to increase the number of skilled workers in science, technology, engineering and mathematics (STEM) fields has been widely discussed in the literature (see, for example: Hill, Corbett, & St. Rose, 2010; Palmer, Maramba, & Dancy, 2011). Although there have been suggestions that projected shortages of STEM workers may have been exaggerated (Anft, 2013), it seems clear that such shortages may be real, at least in some STEM fields (Yi & Larson, 2015). In addition, although the size of the STEM workforce in the United States has been steadily increasing, this growth has been unequal across different social groups (Hurtado et al., 2007; National Science Foundation, 2017; US Department of Commerce, 2011; US Department of Labor, 2010). The metaphor of a “leaky pipeline” has frequently been used in discussions of unequal representation in STEM by different social groups (Alper & Gibbons, 1993). Although the pipeline metaphor has been criticized (Miller & Wai, 2015), underrepresentation in STEM careers is still often connected to corresponding underrepresentations and performance gaps in college-level science courses by social group (Hurtado et al., 2007; National Research Council, 2011).

College science courses such as basic physics, calculus and organic chemistry have been described as roadblocks to success for many students in STEM fields, particularly for underrepresented populations (Barr, Gonzalez, & Wanat, 2008, Barr, Matsui, Wanat, & Gonzalez, 2010; Lovecchio & Dundes, 2002). A range of factors have been discussed that could contribute to differences in persistence of different social groups in science college science tracks. These include different levels of preparation in high school (Chang, Sharkness, Hurtado, & Newman, 2014), social challenges in the transition from high school to college (Cooper, Chavira, & Mena, 2005), and stigmatization and stereotype threat experienced by specific groups (Beasely & Fischer, 2012). Understanding these factors is important to guide strategies to decrease attrition rates and improve student success in such courses, particularly among underrepresented groups. The primary goal of this study is to contribute to the understanding of the factors that contribute to success in a traditional college roadblock course, specifically, general organic chemistry. General organic chemistry is a required course for many students in the U.S. on pre-professional health tracks. It has been reported that for undergraduate students who left pre-medical tracks due to concerns about grades, 88% of women named organic chemistry as the single course that contributed to their decision, compared to 69% for men (Lovecchio & Dundes, 2002).

The factors that contribute to student performance in college-level science classes have been widely discussed in terms of social-cognitive learning theories (Bandura, 1986). Specifically, student motivations (Deci & Ryan, 2000; Schunk & Usher, 2012), and the ways that motivation connect to the concept of self-regulation have been extensively studied (Lynch, 2006; Pintrich, 2004; Schunk, 1995; Schunk & Usher, 2012). A common finding is that self-efficacy (Bandura, 1995) is a major predictor of success in college science courses (Black & Deci, 2000; Lynch, 2006; Lynch & Trujillo, 2011; Zajacova, Lynch, & Espenshade, 2005; Zimmerman, Bandura, & Martinez-Pons 1992). Social-cognitive studies on general organic chemistry have shown that student motivation can be correlated with achievement (Black & Deci, 2000; Garcia, Yu, & Coppola, 1993), and in particular, that self-efficacy is a primary predictor of performance (Lynch & Trujillo, 2011; Villafañe, Xu, & Raker, 2016).

Sociocultural theories switch the focus of cognition and motivation from the individual student to the social environment, i.e., how social and cultural factors mediate and influence student performance and achievement (John-Steiner & Mahn, 1996; Nolen & Ward, 2008). Sociocultural theories encompass a wide range of concepts, from zone of proximal development that focuses on the individual student (Dixon-Krauss, 1996; Vygotsky, 1978), to more modern ideas that learning is situated in the context, culture, and the community in which it occurs (Lave & Wenger, 1990; Wenger, 1998). A concept that explicitly describes student's social and cultural experiences that has been extensively discussed in the education literature is cultural and social capital (Bourdieu, 1997). Bourdieu has argued that cultural capital can be directly related to academic achievement (Bourdieu, 1973), and the extent to which cultural other forms of capital (see further below) may influence student performance has been discussed by several authors (see, for example: Collier & Morgan, 2007; Dumais & Ward, 2010; Jez, 2008; Tramonte & Willms, 2010; Wells, 2008a, 2008b). Cultural and social capital have also been directly linked to student retention and performance (Hansen & Mastekaasa, 2006; Longdon, 2004; Wells, 2008a; Wildhagen, 2009). The conventional cultural capital concept has been expanded to various other forms of capital, and of particular interest in the present context is the introduction of the concept of science capital by Archer, Dawson, DeWitt, Seakins, and Wong (2015). Archer et al. (2015) developed a science capital survey tool that was used study the social origins of differences in science capital. However, this science capital tool was developed for studies of pre-college students. Only a few studies have been reported that attempt to relate cultural and social capital to achievement at the college-level (see, for example: Wells, 2008a, 2008b), and there is no college-level science specific instrument. The lack of guidance on the possible influences of cultural and other capitals in college level science courses represents a significant gap in the science education literature. The main focus of the present work is to start to fill this gap.

Theoretical Background

Sociocultural learning theories derive from the work of Vygotsky, who proposed that cognitive development is shaped by the ways in which students interact with their social and cultural environment (Vygotsky, 1963, 1978). Within this context, Bourdieu's ideas about social reproduction and cultural capital (Bourdieu, 1973) bring focus on a social and cultural concept that can be well-defined and acted upon (Panofsky, 2003). Importantly, Bourdieu suggested that an individual's capital is not static, and can be acquired and developed, and that capital can be directly related to academic achievement (Bourdieu, 1973). Capital is understood as the resources an individual acquires that enable an advantage in a specific context. Bourdieu describes many forms of capital, including cultural, economic and social (Bourdieu, 1997). Cultural capital is acquired by qualifications, experiences, and objects connected to higher status cultures. Economic capital is measured in terms of assets such as money or ownership of property. Social capital is gained from interactions with other members of a particular group, and the advantages that arise from the activities of the group to do things for its members. Capital is more important if it is directly relevant to the field in question. In the context of science education, an obvious example would be an individual acquiring capital by private tuition in science. However, forms of capital that are less obviously connected to the field can still be important. For example, the development of higher status language and vocabulary can be advantageous in many diverse fields, since this helps to legitimize all forms of capital. Several additional forms of capital have been introduced into the literature (see, for example, Robbins, 2000), although traditional cultural and social capitals are the focus of most of the research in science education

Several attempts have been made to measure students' cultural capital in pre-college educational settings, in terms of high culture factors such as appreciation for the arts, interest in music or attending museums (Aschaffenberg & Maas, 1997; De Graaf, N., De Graaf, P., & Kraaykamp, 2000; Dumais, 2002; Dumais & Ward, 2010; Kalmijn & Kraaykamp, 1996; Katsillis & Rubinson, 1990; Lareau & Weininger, 2003). Some researchers have used parental education level as an indicator of cultural capital since it is argued that higher educated parents are more likely to increase a child's cultural capital *via* extracurricular activities (Adamuti-Trache & Andres, 2008; Lee & Bowen, 2006). Many of these previous studies have observed positive correlations between students cultural capital and educational achievement (see for example: Dumais, 2002; Dumais & Ward, 2010; Hansen & Mastekaasa, 2006; Kalmijn & Kraaykamp, 1996; Lyons, 2006; Torres, 2009; Wells, 2008a, 2008b).

Much of the published work on the role of cultural capital in college-level settings has focused on understanding the origins of underrepresentation of specific social groups (Adamuti-Trache & Andres, 2008; Collier & Morgan, 2008; Dumais & Ward, 2010; Ovink & Veazey, 2010; Torres, 2009; Wells, 2008a, 2008b). Wells (2008a) found that cultural capital, defined mainly in terms of family resources, is significantly correlated with persistence for college students from first to second-year across different racial/ethnic groups. Similar findings have been made for African-American students from lower socio-economic backgrounds enrolled in elite universities (Torres, 2009). For first-generation college students, it was found that cultural capital was not a strong predictor of academic success in this case, but the extent of cultural capital and parental influence was directly connected to the likelihood that a student would even enroll in college (Dumais & Ward, 2010). In a related study on first-generation college students by Collier and Morgan (2008), students with higher cultural capital were found to be able to better respond to the expectations of faculty members.

Compared to cultural capital, social capital has been less extensively investigated in education contexts (Bourdieu & Passeron, trans, 1977; Wells, 2008a, 2008b). A study of Harvard graduates showed that those with higher cultural and social capital were more likely to enter specific professions, such as law, and hold memberships in elite institutions (Zweigenhaft, 1993). Students with higher social and cultural capital were found to be more likely to persist in higher education (Wells, 2008a, 2008b), particularly in 4-year university compared to community college populations (Wells, 2008b). With the obvious exception of the science capital work of Archer et al. (2015) mentioned above, there have been very few studies on the influence of cultural or social capital in science education settings (Aikenhead & Jegede, 1999; Claussen & Osborne, 2012). For chemistry in particular, only one study was found. Tobin and McRobbie (1996) reported that high school Chinese-Australian students with limited English could use their cultural capital associated with commitment to succeed in chemistry.

Although most of the reports in the literature suggest a positive correlation between cultural and other capitals with academic success, other studies have found smaller (Aschaffenberg & Maas, 1997; De Graaf et al., 2000) or even negligible effects

(Katsillis & Rubinson, 1990; Zweigenhaft, 1993). These results warn that all forms of capital are not equally important, and that the most important forms need to be identified in specific educational settings.

Research Goals

Cultural and social capital are well-defined concepts in socio-cultural learning theory that have been shown, with reasonable caveats, to connect to student academic achievement. Little work has been done, however, to show how to correlate these concepts with performance in college-level courses, and no work has been done to show how to measure the important forms of capital for the specific case of college-level science courses, such as general organic chemistry. In addition, many of the literature studies have relied on data obtained from national databases (e.g. Adamuti-Trache & Andres, 2008; Aschaffenburg & Maas, 1997; Dumais & Ward, 2010; Wells, 2008a, 2008b; Wildhagen, 2009) rather than specifically developed instruments. The exception is the science capital measurement tool that was developed Archer et al. (2015), however, this was for pre-college schoolchildren in the United Kingdom. Although the importance of cultural capital is expected to decrease as students proceed up the education ladder (Gripsrud, Hovden, & Moe, 2011; Zweigenhaft, 1993), Wells (2008a, 2008b) has obtained evidence that cultural capital can still influence student achievement at the college level. However, the importance and specific forms of capital that are most relevant to college science students have been unexplored.

This paper represents the initial exploration into this topic. It has two specific research goals. The first was to explore and then develop an instrument to measure the kinds of capital that are relevant to college-level science courses in the U.S. The second was to determine the extent to which these different forms of capital correlate with student performance in a specific college-level science course, general organic chemistry. The overall goal of this work is to contribute to an understanding of the factors that determine student performance in roadblock college science courses such as general organic chemistry, especially the social and cultural factors that might encumber the success of students in underrepresented populations.

Method

Participants in Instrument Development

The students included in this part of the study were enrolled in general organic chemistry courses at two institutions that were diverse both geographically and in terms of their populations. One is a large public research university located in the Southwestern United States (SWU). The other is a mid-sized private research university located in the Northeastern United States (NEU). Both institutions have large organic chemistry course enrollments, ca. 500 students per semester at SWU and ca. 300 students per semester. General organic chemistry is offered as a two-course sequence, with students taking the first course in the fall semester, and the second course in the spring semester.

Semi-structured interview and survey data were collected at SWU, beginning with the 2013 fall semester and ending with the 2015 fall semester. The same interview and survey data were collected over 4 consecutive semesters at NEU, beginning with the 2013 spring semester and ended with the 2015 fall semester. Demographic data for the students included in the study are summarized in Table 4.1.

Table 4.1

Demographical Data of Study Participants at SWU and NEU

	SWU	NEU
White/Caucasian	54.6%	48.9%
Asian	20.3%	16.6%
Hispanic/Latino	15.7%	4.9%
Black/African American	3.2%	4.2%
Two or More Races	3.8%	4.6%
Native American/American Indian	0.5%	0%
Race Not Identified	1.9%	20.8%
Male	44.9%	41.1%
Female	55.1%	58.9%

To be participants in the study, students had to provide written consent to use their interview or survey data, and where relevant, to complete a survey during the first week of the course. Those students invited to complete surveys were provided with extra credit equivalent to 0.5% of their total course points. Students who chose not to participate could earn the same credit by completing 4 short essay questions. The participation rates for survey completion was 75.1% at SWU and 86.5% at NEU. The study was approved by the IRB at both institutions for the duration of the study.

Because the two courses were offered in sequence, many students took both the first and second semester courses each academic year. For these students, only the survey data from the first semester course were included in the instrument development to eliminate any influence from the participants seeing the survey twice. With these constraints, 1230 students from SWU and 667 from NEU were participants in the instrument development.

Identifying Possible Social and Cultural Capital Variables

The study started with semi-structured interviews with purposefully sampled students at both SWU and NEU in the 2013 fall semester. The students who were invited to participate in the interviews were selected to represent as accurately as possible the demographic distribution of the students in the classes as a whole, Table 4.1. 24 SWU and 13 NEU students volunteered to be part of the survey building interview process, and the author conducted all 37 interviews. Of the 24 students from SWU, 12 were male and 12 were female, and participants' self-reported their race/ethnicity as follows: 12 White/Caucasian, 5 Asian, 5 Hispanic/Latino(a), 1 Black/African-American, and 1 Native American/American-Indian. The 13 NEU students consisted of 10 females and 3 males, and of these 9 self-reported as White/Caucasian, 2 as Hispanic/Latino(a), 1 as Asian, and 1 as Black/African-American. To allow an emic component to the definition of the constructs, the questions were general and open-ended. Each student was asked to describe their background prior to attending college related to how learning and academic success were viewed by their families and on the availability of family resources related to school. Then the students were asked questions in related to their current lifestyle in college and about their career aspirations. These general areas chosen because they were most frequently discussed in the literature on cultural and social capital in education settings (Claussen & Osborne, 2012; Lareau & Weininger, 2003; Nora, 2004; Ovink & Veazy, 2011; Tramonte & Willms, 2009).

The participants were allowed to talk for as long as they wanted, and the interviews lasted between 25-45 minutes. The author took notes by hand during each interview. After all of the interviews were concluded, three researchers, including the author, reviewed the notes. Based on the reoccurring themes in the participants' answers, the researchers agreed on 16 survey questions, questions 1 – 16 in Table 4.2. To these questions several standard cultural capital questions of the kind used in previous studies (Lareau & Weininger, 2003; Sullivan, 2001; Tramonte & Willms, 2009; Wildhagen, 2009; Zimdars, Sullivan, & Heath, 2009) were added, questions 17 - 24 in Table 4.2. The questions in Table 4.2 were collected together in the form of a survey. The survey was administered to the students at SWU from the spring 2014 semester to the fall 2015 semester (4 semesters total), and to the NEU from the fall 2014 semester to the fall 2015 semester (3 semesters total). The collected survey data was used to perform exploratory and confirmatory factor analyses.

Table 4.2

The Original 24 Survey Questions Assembled by Combining this Suggested by Student Interviews with Standard Cultural Capital Questions

1. From what you can remember about your childhood and adolescent years (K-12 grades), how often did your parents tell you that attending college is important?
2. From what you can remember about your childhood and adolescent years (K-12 grades), how often did your parents tell you that getting good grades is important?
3. School has always been very important to my family and me.
4. From what you can remember about your childhood and adolescent years (K-12 grades), did you have a family member who could help you when you needed help with homework?
5. From what you can remember about your childhood and adolescent years (K-12 grades), did you feel supported by your family while growing up?
6. Do you feel that you are being supported by your family while you are in college?
7. Do you have potential career(s) in mind?
8. How strongly do you feel about your career(s) in mind?
9. When you think about your career(s) in mind, how satisfied do you feel about your choice(s)?
10. Are the career(s) you have in mind similar to at least one of your parents' career(s)?
11. Think of your friends from your childhood and adolescent years (K-12 grades). Did your friends end up going to college after graduating from high school?
12. Think of your friends from your childhood and adolescent years (K-12 grades. How often do you communicate with them nowadays?
13. Think of your friends who are in college with you right now. Are their majors similar to yours?
14. Do you have friends in this organic chemistry class who you associate with often?
15. Do you have friends in this organic chemistry class who you study with often?
16. Are you friends in college interested in similar career(s) as you?
17. My family often ate dinner together as a child.
18. I was taken to concerts as a child.
19. I travelled often as a child.
20. I played musical instrument as a child.
21. I went to museums as child.
22. How many books did you own as a child?
23. What is your father's education level?
24. What is your mother's education level?

Factor Analysis

Factor analysis was performed on the student responses for this survey data. To test for reliability, in addition to examining Cronbach's α values, exploratory factor analysis was performed on the SWU dataset and confirmatory factor analysis on the NEU dataset. For both factor analyses, principal axis factoring and promax rotation methods were used. These methods were chosen because the datasets were large, and principal axis factoring accounts for co-variation (Leech, Barrett, & Morgan, 2011).

The initial exploratory factor analysis on the SWU survey data generated seven factors with Eigenvalues of 1 or higher, and with item loadings above the minimum criteria of 0.3. There were no cross loadings across these seven factors. Two questions, "Think of your friends from your childhood and adolescent years (K-12 grades). Did your friends end up going to college after graduating from high school?" (question 11 in Table 4.2) and "Think of your friends from your childhood and adolescent years (K-12 grades). How often do you communicate with them nowadays?" (question 12 in Table 2) were not included in the pattern matrix output and were dropped, leaving a total of 22 items out of the original 24 questions. After eliminating items, two of the seven factors contained only two items, i.e. smaller than the recommended three or more items per factor (Raubenheimer, 2004). The scree plot also supported reducing the number of factors from seven to five. Factor analysis was performed again with the remaining 22 items with the number of factors forced to five. The resulting pattern matrix had no cross-loadings and had a Kaiser-Meyer-Olkin (KMO) measure of sampling adequacy of .780, i.e. above the accepted recommended value of 0.7 (Kaiser, 1974). The Bartlett's test of sphericity was found to be also significant, χ^2 (276) = 8027.48, p<.001. The Cronbach's α values for each factor obtained from the exploratory factor analysis were all above 0.7, which is considered acceptable for internal consistency (Tavakol and Dennick, 2011), Table 4.3.

Confirmatory factor analysis was performed using the NEU survey data. The initial output of the confirmatory factor analysis was a seven-factor solution that was similar to the initial pattern matrix of the seven-factor solution obtained in the exploratory factor analysis on the SWU data. The two questions excluded in the exploratory factor analysis (ie high school friends attending college and communicating with high school friends) were also not found in the pattern matrix of the confirmatory factor analysis. In addition, after the removal of these items, the same two factors containing only two items emerged as observed in the exploratory analysis. Confirmatory factor analysis was therefore repeated on the 22 item set with the number of factors restricted to five. The results of this five-factor solution, KMO=.747, χ^2 (276) = 4486.50, $p<.001$, were similar to the exploratory factory analysis, with the same items grouped under the same factors. The Cronbach's α values for the factors from the confirmatory factor analysis were calculated, and two had values under 0.7, however, by less than .01, Table 4.3. Based on the close similarity between results of the exploratory and confirmatory factor analyses, it was concluded that the five-factor, 22-item instrument was reliable.

Social and Cultural Capital Factors

The complete list of survey items that comprise the instrument, separated into their respective factors, are summarized in Table 4.3. The items are also summarized again in their full text form, together with the allowed responses and factor scoring information in the Appendix D.

Table 4.3

Exploratory and confirmatory factor analysis results on the Science Capital Questionnaire (SCQ)[a]

	F1	F2	F3	F4	F5
Cronbach's alpha (α): Exploratory	.774	.708	.718	.744	.727
Cronbach's alpha (α): Confirmatory	.751	.747	.694	.783	.692
Factor 1: College Connections					
Friends in organic chemistry class to associate with	.893				
Friends in organic chemistry class to study with	.795				
Friends interested in same career(s)	.541				
Friends with similar majors	.510				
Factor 2: Traditional Cultural Capital					
Mother's education		.677			
Father's education		.655			
Going to museums as a child		.517			
Travelled as a child		.468			
Career choice similar to parent(s)		.420			
Playing musical instrument as a child		.418			
Owning books as a child		.398			
Going to concerts as a child		.369			
Factor 3: Family Resources					
Feeling supported by family growing up			.801		
Feeling supported by family in college			.737		
Eating dinner together as a family			.437		
Getting homework help by family			.342		
Factor 4: Career Plans					
Feeling strongly about potential career(s)				.933	
Feeling satisfied about potential career(s)				.734	
Having potential career(s) in mind				.466	
Factor 5: Academic Expectations					
Attending college important for parents					.772
Good grades important for parents					.771
School important for family					.483

[a] The full text for the items, and the associated allowed responses are summarized in the Appendix D.

The instrument will be referred as the Science Capital Questionnaire (SCQ). The student responses to the survey data for the spring 2014 semester at SWU and for the fall 2014 semester to the fall 2015 semester at NEU were re-analyzed according to the factors and items of the SCQ. Despite the differences in the student populations for the exploratory and confirmatory factor analyses, the different factor scores were similar at SWU and NEU. The largest factor, Factor 2, contained 8 items and was called "Traditional Cultural Capital". The items in this factor include "playing a musical instrument" and "going to museums as a child", which were included as traditional cultural capital questions (Bourdieu, 1986; Lareau & Weininger, 2003; Sullivan, 2001; Tramonte & Willms, 2009; Wildhagen, 2009; Zimdars et al., 2009). This factor also includes the parents' education level. The items in this factor are very much in line with a traditional construct for cultural capital (Lareau & Weininger, 2003), and support the notion that social hierarchy is reproduced by the members of a class who pass "high-brow culture" to other members of the same social group (Bourdieu, 1986; Lee & Bowen, 2006; Sullivan, 2001). It has been argued that cultural capital extends beyond these "high status" activities proposed by Bourdieu (Lareau & Weininger, 2003; Tramonte & Willms, 2009). More recently, concepts such as family resources and academic expectation have also included in studies of cultural capital (see, for example: Wells, 2008b). Constructs that include these concepts also emerged from the factor analysis in Factor 3, which was named "Family Resources", and Factor 5, which was named "Academic Expectations", Table 4.3. That constructs associated with both traditional and more modern interpretations of cultural capital emerged both naturally from the factor analysis was encouraging, and provided some level of construct validity.

Factor 1, which was named “College Connections”, contained items that more directly related to students’ social capital in college, and more specifically for the present context, in their organic chemistry courses. Students who scored highly in this factor have friends in the course who share similar academic and career goals. That these items cleanly combined into one factor is consistent with the notion of “communities of learners”, which have been shown to positively influence student achievement (Crawford, Krajcik, & Marx, 1999; Duschl, 2008; Gilbert, 2006), see further below.

Several of the original 24 questions were related to student career plans, since this was a major theme that came out of the interviews. One of the career-related questions, “Are you friends in college interested in similar career(s) as you?” (question 16 in Table 4.2), appeared as an item in the “College Connections” factor, and the question, “Are the career(s) you have in mind similar to at least one of your parents’ career(s)?” (question 10 in Table 4.2) appeared as an item in the traditional cultural capital factor. This factoring is perhaps not surprising since students who have friends that share similar majors and enroll in the same course are likely to have similar career plans. Similarly, students who have parents with higher academic degrees are more likely to be exposed to career plans similar to their parents. The remaining career questions appeared as items in the final factor, Factor 4, which was named “Career Plans”.

Connecting Capital to Organic Chemistry Performance: Participants

SCQ was administered and compared to student performance in general organic chemistry courses for five consecutive semesters, from spring 2014 to spring 2016 at SWU, and for four semesters, from fall 2014 to spring 2016 at NEU. Since at both institutions the courses are offered in sequence by semester, many students take the first part of the sequence during the fall semester and the second portion in the spring, and thus they are included in the SCQ/performance data comparison twice. The survey instrument was administered during the first week of the course, before any type of assessments, and the students were awarded extra credit worth 0.5% of the overall course point total for participating. Students who chose not to participate could earn the same credit by completing four short essay questions. To be included as a participant in this part of the study, students had to provide written consent to use their survey and assessment data and complete the survey instrument. The participation rate at SWU over the course of the study was 75.4%, and that at NEU was 88.4%. This part of the study was approved by the IRB at both institutions.

For the spring 2014 to fall 2015 semester at SWU, and the fall 2014 to fall 2015 semesters at NEU, the raw survey data was used in different ways to both help to generate the instrument, and also collect data for comparison with student performance. The spring 2016 data at both institutions was only used for comparison with performance data.

Assessment of Course Performance

The students' final letter grade was used to assess course performance, rather than course point total. Letter grade was selected so that students who did not complete all of the assessments, for example if they withdrew from the course, could be included. At NEU, course letter grades were assigned on a plus/minus system, and were converted into simple letter grades (ie 'A+' into 'A') to align with the grading system at SWU population. The participants were divided into three groups based on their final letter grade. Students who earned A grades were placed on one group, A, which was then assumed to include the highest performing students. Students who earned either a 'B' or a 'C' letter grade were into a second group, BC, assumed to include the intermediate performing students. At both institutions, students must receive a passing letter grade of 'C' in general organic chemistry in order for the course to fulfill the prerequisite requirement for related upper division courses. Therefore, the letter grade of 'D' was included with the other non-passing letter grades. Those students who earned 'D" and 'E' grades, or who withdrew before the end of the semester and earned a 'W' grade, were thus combined into a third group, DEW, which was assumed to include the lowest performing students.

Scoring the SCQ Factors

The complete wording of the SCQ items with their corresponding answer choices are provided in the Appendix D. The majority of the items in the SCQ had five Likert-type answers. For example, the question, "I travelled often as a child," had five different answer choices ranging from "strongly disagree" to "strongly agree." The answers were scored so that the most negative answer choice (ie "never," "strongly disagree," "no, I do not," etc.) received a score of 0, and the most positive answer choice (ie "very often," "strongly agree," "yes, I have a lot," etc) received a score of 4. The two questions asking about parents' education level had six answer choices so that all possible choices were presented, but these questions were scored on a scale of 0 – 4, where 4 represented PhD or higher professional degree. One question had four answer choices, "Do you have potential career(s) in mind?". For this question, the answer "Yes, I have one career in mind," received the maximum score of 3 while the answer, "No, I don't have any careers in mind right now," received the lowest score of 0.

Based on the scoring, the maximum score a student could get for each factor are as follows: College Connections=16; Traditional Cultural Capital=32; Family Resources=16; Career Plans=11; Academic Expectations=12. The students' scores in each of the factors were then converted into a percentage of the maximum possible score. The means and standard deviations for the student percentage scores in each factor scores are summarized by semester for both institutions in Table 4.4.

Correlating SCQ Factors and Course Performance

ANOVA was performed in order to determine whether there were differences in the various SCQ factors among the three different performance groups, A, BC, and DEW. For those semesters with significant differences among the groups, Games-Howell post-hoc tests were also performed to determine whether the differences were significant. The Games-Howell post-hoc test was chosen due to the unequal sample sizes of the groups, and because some of the SCQ factors in some of the comparisons had unequal variances. For each factor at each institution, the performance of the three groups were compared as follows A versus BC (A:BC in Appendix E and F) BC versus DEW (BC:DEW in Appendix E and F) and A versus DEW (A:DEW in Appendix E and F). A significant difference in performance in these comparisons was assumed when p is less than .05. For the significant differences, the corresponding effect size was estimated as Cohen's d, which was corrected to accommodate for the differences in sample sizes. The complete ANOVA results and corresponding effect sizes are summarized in Appendix E for SWU and Appendix F for NEU.

Table 4.4

Mean Scores and in Parentheses, Standard Deviations, for the various Capital Factors for both Institutions

	SWU					NEU			
Capital Factor	Spring 2014	Fall 2014	Spring 2015	Fall 2015	Spring 2016	Fall 2014	Spring 2015	Fall 2015	Spring 2016
College Connections	42.3 (24.1)	42.3 (22.6)	42.0 (22.0)	45.2 (22.9)	44.4 (22.1)	52.7 (20.9)	54.4 (19.4)	51.5 (19.5)	50.5 (18.0)
Traditional Cultural Capital	51.3 (18.5)	48.2 (18.5)	50.0 (18.6)	50.3 (18.5)	50.5 (15.7)	55.7 (19.5)	57.5 (18.9)	56.1 (18.8)	57.8 (19.1)
Family Resources	78.1 (19.3)	79.4 (19.8)	78.6 (18.6)	78.1 (18.5)	77.8 (18.7)	81.5 (17.1)	81.1 (16.8)	80.5 (18.1)	80.8 (15.8)
Career Plans	80.7 (15.6)	82.8 (15.0)	80.5 (16.9)	80.9 (16.7)	80.0 (17.5)	80.0 (17.2)	80.5 (15.7)	79.4 (17.3)	82.2 (15.4)
Academic Expectations	88.3 (16.5)	89.3 (15.0)	88.3 (16.7)	89.3 (14.5)	88.4 (15.8)	87.2 (16.0)	86.0 (17.2)	86.5 (16.6)	88.3 (15.2)
n	261	453	358	448	377	329	233	246	201

Results & Discussion

Summary of SCQ Factors and Their Mean Scores

The exploratory and confirmatory factor analyses discussed above provide support for the reliability of the SCQ as an instrument. The mean scores of the different SCQ factors provide some insight into the different student populations at SWU and NEU, and also provide some level of support for construct validity.

First, the instrument structure is based on the well-defined framework of Bourdieu's theory of capital, which in turn is readily understood in terms of finer grained constructs, specifically, cultural capital, social capital etc. However, the instrument was not developed by forcing these specific constructs. Instead, the analysis naturally generated factors that align very well with both the traditional cultural capital of Bourdieu and some of the more modern capitals, such as family resources (Lareau & Weininger, 2003; Wells, 2008b), which represents a high level of criterion validity (Trochim, 1999). In addition to the traditional capital factors, one of the new factors that emerged from the analysis was "College Connections". This represents a new college-science specific form of social capital, which as discussed below, has the most important connection to performance in the present study. Additional support for concurrent validity of the instrument comes from the observed differences between institutions for the different factors, in particular "College Connections".

Although the overall scores follow similar trends at both institutions, some interesting differences can be observed. The factors "Career Plans" and "Academic Expectations" were consistently the highest scoring, and had similar values at both SWU and NEU. This suggests that the students at both institutions have similarly well-developed career aspirations and also similarly high expectations of academic achievement from their families. The scores on the two capital factors "Family Resources" and "Traditional Cultural Capital," were lower than those for "Academic Expectations" at both institutions. On average, the "Family Resources" scores were 10.3% lower at SWU and 6.0% lower at NEU. Even larger differences were found for the "Traditional Cultural Capital" factor, for which scores were over 30% lower than those for "Academic Expectations" at both institutions. Finally, the "College Connections" factor scored lowest of all, across all semesters at both institutions, especially at SWU where the mean scores were generally below 45%, Table 4.4.

The mean scores for the two family cultural capital factors, "Family Resources" and "Traditional Cultural Capital" were higher at NEU compared to SWU. These results may be understandable, since NEU is a more selective private institution compared to SWU, which is a large public institution. The scores for the "College Connections" factor were also higher at NEU compared to SWU. Again, this may be a consequence of differences in the institutions, since the students at NEU predominantly live in on-campus housing (ca. 90%), whereas only a small percentage of SWU students live on-campus (ca. 20%), as reported by the respective university's institutional analysis departments. Additionally, peer-led workshops are offered to the students at NEU whereas the courses are taught in more traditional lecture style at SWU. Together, these may enable the development of stronger social interactions for students at NEU compared to SWU.

Low scores for the "College Connections" factor could be a consequence of the fact that the SCQ was administered to the students during the first week of the semester before the students had a chance to develop social connections. If this was the case then the “College Connections” factor score would presumably increase from the fall to the spring semesters, since many of the same students return to take the courses in consecutive semesters, however, this is not the case, Table 4.4. In the U.S., many of the students who take general organic chemistry are at least in their second year, and are on pre-health tracks. These results indicated that students apparently have already made their social connections before they enter the courses.

Analysis of Course Performance and Capital Factors

The ANOVA results, Appendix E and F, show which capital factors were most connected to student course performance, measured by letter grade. At both SWU and NEU, the two factors with the highest mean scores, “Academic Expectations” and “Career Plans,” showed no significant differences between the different student performance groups A, BC, and DEW, and therefore no connection to performance for essentially all semesters examined. The students in the DEW groups had similar career aspirations similarly high parental expectations of academic performance as the more successful students. The lack of correlation with performance for the “Career Plans” factor may simply be because all students are motivated to perform well since a high grade in this course is considered a requirement to gain admission into pre-professional programs, and this factor is therefore not very discriminating as shown in Chapter 2. The lack of correlation for the “Academic Expectations” factor may imply that acquiring this form of capital simply does not enable an advantage in the general organic chemistry courses. Alternatively, the scores for both of these factors are sufficiently high, Table 4.4, that any correlation with performance may simply be truncated due to ceiling effects.

The capital factor “Family Resources” was found to be statistically different for the differently performing groups at SWU for almost all of the semesters studied, particularly when comparing the A and DEW groups. Those students with lower scores in this factor tended to be the lower performing students, Table 4.5. At NEU, a significant difference in this factor for the differently performing students was only found for the 2016 spring semester. The effect sizes where differences were observed are small to moderate, and the difference between the overall mean scores in this factor for the students at the two institutions is small, Table 4.4. Nevertheless, there is still an interesting difference between institutions. The “Family Resources” factor results suggest that at the larger public university, the SWU students gain a measurable advantage from this capital, although at NEU this capital is apparently less important. A role for family-related capital in college-level learning has previously been described by Wells (2008b).

The mean scores for the “Traditional Cultural Capital” factor were also statistically different for the differently performing student groups at SWU in 3 of the 5 semesters, Appendix E, in particular for the A:DEW comparison. Students with lower traditional cultural capital tended to be lower performing. Again, the effect sizes were small to moderate. Significantly, 2 of the 3 semesters where differences were observed were fall semesters. No significant differences were observed in the spring semesters at SWU except for the 2016 spring semester. One explanation for this semester difference may simply be that students must pass the first semester chemistry course in order to enroll in the second semester course. Some of the students with lower cultural capital will have failed the first semester course and the second semester course will therefore have a slightly lower population of such students. Trends in the “Traditional Cultural Capital” factor at NEU are harder to discern. Only two of the four semesters studied showed a statistically significant difference among the performance groups, with small to moderate effect size, Appendix F. The advantage gained by the acquisition of traditional cultural capital seems to be larger SWU compared to NEU.

The largest differences among the performance groups were found in the mean scores of the “College Connections” factor, particularly at SWU, where differences were observed for all semesters with small to moderate effect size, and with a large effect size in spring 2014, Appendix E. At NEU, statistical differences were observed for each of the fall semesters, with moderate effect size, Appendix F. Students with large “College Connections” capital gained an advantage compared to those with smaller “College Connections” capital. Students with friends in the course who are on similar career paths and a stronger general personal network seem to perform better than those with a weaker personal network. The larger effects associated with this factor at SWU are also associated with low overall mean scores for this factor SWU compared to NEU. Indeed, the difference between the two institutions was largest for the “College Capital” factor, Table 4.4.

“College Capital” is a form of social capital that apparently can be important at least for the students in the general organic chemistry courses studied here. The differences between the results observed for the two institutions may be understandable in that SWU is a public institution located in a large metropolitan area, and only ca. 20% of the students live on-campus. In contrast, the vast majority of the students at NEU live on campus (ca. 90%), and take classes more as a cohort than the SWU students. In this way, the NEU students have more opportunity to increase their social capital than at

SWU. This may also explain why the “College Connections” factor is more important in the fall semesters at NEU, when students are just starting to build a social network for the semester. This study does not provide the underlying reasons why this kind of social capital is important to students in these classes, but it is unlikely to be simply that students benefit from studying together, since studying together is only one of the items in this factor. Other advantages a student can gain from more developed social interactions with peers include the sharing of responsibilities for coursework, and enhanced meta-cognition. For example, students with more friends in the course will have a better idea of how developed their content knowledge is compared to the rest of the class, and how much work they are doing compared to the rest of the class.

The results presented here results are a difficult to compare with the literature, since most of the previous work has focused on the achievements of specific social groups (Ovink & Veazey, 2011; Wells, 2008a), for example such as African-American (Torres, 2009) or first-generation (Collier & Morgan, 2008; Dumais & Ward, 2010) college students, while this current study did not separate students based on demographical characteristics. Another significant difference is that the constructs discussed here are based on a specifically developed instrument, whereas many previous studies have used proxy measures of cultural capital, for example, parental educational levels only (Adamuti-Trache & Andres, 2008; Lee & Bowen, 2006) or only family resources (Wells, 2008a).

Of course, not all forms of capital are relevant to all fields, and in the present context, the academic subject and level should be important. Using SCQ, clear differences in the student populations at the two institutions could be discerned. The NEU students seemed to gain much less advantage from the various forms of capital than the SWU students, although the social factor “College Connections” was the most important at both institutions. This result is consistent with the often discussed positive effects of student communities in science learning (see, for example: Crawford et al., 1998; Duschl, 2008; Gilbert, 2006). Peer-led team learning, which is a part of the general organic chemistry courses at NEU, incorporates this concept (Gosser & Roth, 1998; Tien, Roth, & Kampmeier, 2002; Wamser, 2006).

Limitations & Future Work

This paper represents a first attempt to describe and measure the role of cultural and social capitals in college-level science course. A new instrument is described, but in common with any new instrument, it will benefit from improvement and additional validation. For example, the “Career Goals” and “Academic Achievement” factors were not predictive of performance. Is this because these are not relevant to the population of student included in the present study, or are these factors suffering from criterion invalidity? These are the only two factors that contain only 3 items. Application of SCQ in college courses that are quite different from organic chemistry would be beneficial in testing concurrency and predictability. As discussed above, the relevance of capital is closely tied to the specific field being investigated. SCQ is already able to distinguish two different populations in the same course, it would clearly be interesting to see how the instrument would behave in very different college-level course with different populations of students. In particular, using SCQ to explore the social capital and other capitals on other student groups such as underrepresented groups, would be particularly interesting.

Conclusions

An instrument for measuring different forms of capital relevant to college-level science courses has been developed, SCQ. Reliability has been established using exploratory and confirmatory factor analysis. Support for construct validity is obtained from criterion and concurrency testing, although further validity testing is warranted. The factors generated were readily identifiable with common forms of capital defined previously by Bourdieu and others. Importantly, a new social capital factor emerged that was termed “College Connections”. SCQ was administered to students taking college-level general organic chemistry for five consecutive semesters at a large public university in the U.S. southwest, and four consecutive semesters at a smaller private university in the U.S. northeast. The mean scores for each capital factor from SCQ were compared to the students’ overall letter grades as a measure of performance. Overall, the SCQ factors accounted for small amount of variance in the organic chemistry course performance. In general, larger influences of capital factors on course performance were found for the SWU population. The factors “Academic Expectations” and “Career Plans” were found to have no influence of performance at either institution. Small effects on performance were found for the “Family Resources” and “Traditional Cultural Capital” factors, particularly at SWU. The social capital factor “College Connections” was found to have the largest influence on student performance, again, in particular at SWU, where student social connections are somewhat limited by the institution structure. The study indicates that socio-cultural factors can indeed contribute to student performance in college-level science courses and suggests further study in this area.

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Chapter 5: Why Organic Chemistry May Be a Roadblock Course for Females

Despite recent gains in the number of degrees awarded to women in science and technology fields, the decades long underrepresentation of women in science college majors continues to be an issue (Hill, Corbett, & St. Rose, 2010; National Science Foundation (NSF), 2017; U.S. Department of Commerce, 2011; Valian, 1999). Although women are often the majority college students, and are more likely to earn degrees in biology and related areas, men are more likely than women to pursue degrees in the physical sciences and engineering (Amelink & Creamer, 2010; NSF, 2017). Although more women than men are employed in health professions, women are less likely to be diagnosing health practitioners such as a physicians or dentists (NSF, 2017), and are less likely to become physician-researchers (Guelich, Singer, Castro, & Rosenberg, 2002; Newton & Grayson, 2003).

The gender gap in STEM careers can be connected to gender gaps in performance undergraduate science courses (Xie & Shauman, 2003), where gender differences are often observed (Beasley & Fischer, 2012; Boli, Allen, & Payne, 1985; Bridgeman & Wendler, 1991; Cavallo, Rozman, Blickenstaff, &Walker, 2004; Riegle-Crumb, King, Grodsky, & Muller, 2012). Science courses such as basic physics and calculus are often viewed as roadblocks to success for many pre-professional students (Barr, Gonzalez, & Wanat, 2008; Lovecchio & Dundes, 2002). In particular, organic chemistry has been described as a "gatekeeper" course for entry into the healthcare professions (Barr, Matsui, Wanat, & Gonzalez, 2010; Lovecchio & Dundes, 2002). Lovecchio & Dundes (2002) reported that of undergraduate students who left the pre-medical track due to concerns about grades, 88% of women named organic chemistry as the course that contributed to their decision, compared to 69% for men. Around 70,000 students take general organic chemistry each year. Of these, only around 10% are chemistry majors (Merritt, 2005), the majority take the course because it is a pre-requisite for applications to medical, and other health-related graduate schools. It is of interest to understand the factors that contribute to student learning and success in organic chemistry as a critical science course in the career tracks of so many undergraduates. In this chapter, a particular emphasis has been placed on describing and understanding performance differences by gender.

Literature and Theoretical Background

Theoretical Descriptions of Gender Differences in College Science Courses

A number of cognitive and non-cognitive factors have been discussed in connection to gender gaps in college science courses (see, for example, Hill et al., 2010). Early explanations for gender gaps in achievement in science and math in high school have lost support as gaps in pre-college performance and course taking have diminished (Riegle-Crumb et al., 2012; Xie & Shauman, 2003). Biological theories based on evolutionary differences in genetic and hormonal or brain structure (Baron-Cohen, 2003; Lippa, 2005; Schmidt, 2011) have also lost favor in light of observations of large variations in gender gaps across different cultures (Ceci, Williams, & Barnett, 2009; Penner, 2008), and research suggesting that interest in science is readily influenced by classroom environmental factors (Cheryan, Plaut, Davies, & Steele, 2009) or exposure to same-sex experts (Murphy, Steele, & Gross, 2007; Stout, Dasgupta, Hunsinger, & McManus, 2011). Gender gaps in STEM are also not explained by gender specific life-work preferences (Xie, Fang, & Shauman, 2015). One cognitive factor that has been extensively discussed in the context of gender gaps in STEM education is spatial ability (Halpern et al., 2007; Hyde 2005; Kimura, 2002; Spelke, 2005). Whether spatial ability skills are a pre-requisite for success in science, however, has been questioned (Ceci et al., 2009; Spelke, 2005). Specifically, it has been suggested that differences in spatial ability are readily influenced by training (Halpern et al., 2007; Hyde, 2005; Newcombe, 2010). Nevertheless, spatial ability maintains a prominent position in discussions of gender gaps in STEM education to the extent that it has been suggested as a key topic in improving science education (Gilbert, 2005).

Socio-cognitive explanations for gender gaps have been widely discussed (Bussey & Bandura, 1999). Motivation, learning and goal attainment are key factors in socio-cognitive learning theories (Bussey & Bandura, 1999; Schunk, & Usher, 2012). Self-efficacy in particular has been shown to correlate with student performance (Schunk, 1995; Usher & Pajares, 2008). Self-efficacy can be described as the belief in one's capacity to achieve specific levels of performance related to a specific task (Bandura, 1982; Zimmerman, 2000). Having low self-efficacy can negatively influence the amount of effort a student is likely to apply a particular task (Zimmerman, Bandura, & Martinez-Pons, 1992).

Performance Differences by Gender in Chemistry Courses

The literature on performance differences by gender in college chemistry course is somewhat limited and contradictory. In an early study, males were found to earn higher grades than females in an organic chemistry course, but gender was not a strong predictor of performance, which was much better predicted by academic preparedness and motivation (Garcia, Yu, & Coppola, 1993). Gender was also reported as a weak predictor of organic chemistry performance in another early study (Sevenair, Carmichael, O'Connor, & Hunter, 1987). Males performed better than females in a multi-semester study of a biochemistry course (Rauschenberger & Sweeder, 2010). However, in a 2001 study on a general chemistry, females were found to outperform males, although this difference diminished when online homework was implemented (Richards-Babb & Jackson, 2011), and Seery (2009) found no differences in performance by gender in a study of first year undergraduates in Ireland.

In more recent studies on general organic chemistry courses, gender was not found to be a significant predictor of problem solving ability (Lopez, Shavelson, Nandagopal, Szu, & Penn, 2014) or of overall performance (Jasien, 2003). Performance differences by gender were reported by Lynch and Trujillo (2011), although the sample size in that study was small (*n* less than 35). Interestingly, Lynch and Trujillo (2011) also found that even in situations where females and males performed equally well in organic chemistry, females reported lower levels of self-efficacy in comparison to males.

These results suggest that a larger scale study over multiple courses and instructors and institutions that focuses specifically on performance by gender would be useful to establish whether gender differences in organic chemistry are generally present.

Differences in Cognitive Factors by Gender: Spatial Ability

As mentioned above, spatial ability has frequently been discussed as a cognitive skill with a persistent gender gap (Barke, 1993; Halpern et al., 2007; Lawton, 2010; Maccoby & Jacklin, 1974). Because of the inherent 3-dimensional nature of molecular and crystal structures, and the way that these relate to chemical and physical properties, spatial ability has also been invoked as a key skill for chemistry learning (Bodner &

Guay, 1997; Habracken, 1996), especially in organic chemistry (Stieff, 2011). Again, somewhat contradictory results have been obtained in studies of the relationship between students' spatial ability and their performance in chemistry courses. It is important to note that multiple types of spatial ability have been described in the literature (Harle & Towns, 2010), although most studies related to chemistry performance have focused on the ability to visualize rotation, as described, for example, by the Purdue Visualization of Rotation Test (Pribyl & Bodner, 1987).

Pribyl and Bodner (1987) found a correlation between spatial ability and performance on organic chemistry questions that required problem-solving skills. In a large-scale study of general chemistry students, males were found to have higher spatial ability skills than females, although consistent gender differences in different courses could not be identified (Coleman & Gotch, 1998). These authors suggested that spatial skills can be developed with more exposure to science classes and that further research was needed. Spatial ability was found to be only a weak predictor of performance in an organic course chemistry, however (Turner & Lindsay, 2003).

Other authors found no significant gender effects on the ability to solve chemistry problems associated with spatial ability, when students with similar chemistry backgrounds are compared (Brownlow & Miderski, 2001; Brownlow, McPheron, & Acks, 2003). These authors also suggested that spatial ability skills can be learned, or at least that gender differences in spatial skills can be reduced with increased exposure to problems. Support for this proposal comes from a series of papers on spatial reasoning in organic chemistry (Stieff, 2011, 2013; Stieff, Ryu, Dixon, & Hegarty, 2012). These authors proposed that students solve organic chemistry problems requiring spatial ability in different ways. Students developed alternative strategies and heuristics to solve such problems rather than relying on visual spatial skills alone. They also suggested that regardless of gender, students can develop spatial ability skills and learn strategies to solve chemistry problems that relate to 3-dimensional structure even if they encounter difficulties deciphering the embedded spatial information within the problem (Stieff, 2013). This work suggests that context and instruction method are also important. Here, an attempt was made to characterize the role of spatial ability specifically within the context of the organic chemistry courses under study.

Differences in Socio-Cognitive Factors by Gender: Self-Efficacy

Although less frequently studied in organic chemistry courses than purely cognitive factors, some studies on socio-cognitive factors such as motivation, and self-efficacy have been reported (Black & Deci, 2000; Garcia et al., 1993; Lynch & Trujillo, 2011; Turner & Lindsay, 2003). Motivation, and in particular self-efficacy, have been suggested as factors that can result in differences in performance by gender in STEM courses (DeBacker & Nelson, 2000; Pajares, 2005; Watt, 2006). Self-efficacy in particular often correlates well with student performance in college-level science (Glynn, Brickman, Armstrong, & Taasoobshirazi, 2011; Lynch & Trujillo, 2011; Pajares, 1996; Taasoobshirazi & Glynn, 2009), and in some cases specifically in college-level chemistry courses (Lynch & Trujillo, 2011; Villafañe, Garcia, & Lewis, 2014; Zusho, Pintrich, & Coppola, 2003). Self-efficacy has also been found to be higher for male students compared to female students in core-curriculum science courses (Glynn, Taasoobshirazi, & Brickman, 2009; Zusho et al., 2003), and also two studies of organic chemistry courses (Lynch & Trujillo, 2011; Turner & Lindsay, 2003).

The Present Study

The nature of the gender gap in performance in organic chemistry, if any, is not well defined; no large-scale study has yet been reported. The primary research goal of this work, therefore, was to perform a large-scale study of student performance in general organic chemistry in order to better define the issue. From an analysis of data obtained over multiple semesters, multiple instructors and two different institutions it was concluded that female students studied generally underperform compared to their male counterparts. Spatial ability has frequently been suggested as a possible reason for gender differences in science courses, but studies on chemistry courses have had somewhat contradictory results. A second research goal was to characterize the extent to which differences in spatial ability might be responsible for the observed gender differences. In order to connect to previous work on motivation and self-efficacy, the final research goal of the study was to investigate the possible role of these factors in determining differences in student performance by gender.

Organic Chemistry Performance by Gender

Method

Participants and Study Context. Student performance data were collected from general organic chemistry students at a large public research university in the southwestern United States (SWU) and also at a medium-sized private research university in the northeastern United States (NEU). The study was granted exempt status from the IRB at both institutions. Each institution has large organic chemistry classes (ca. 300 - 500 students per semester). At both institutions, general organic chemistry is taught as a two-semester course sequence in a conventional lecture course format. The first course was taught in the fall semesters and covered introductory topics, general principles and part of the functional group chemistry that comprises the bulk of conventional general organic chemistry (see further below). The second course was taught in the following spring semesters and covered the rest of the functional group chemistry and introduced more advanced topics such as multi-step synthesis. At SWU, both courses are also offered in off-sequence semesters, i.e. the first semester course in the spring semester and the second semester course in the fall. One male and one female instructor taught the courses at SWU over the study period, with the female instructor teaching the off-sequence courses. This female instructor also taught one first semester course in the fall and one second semester course in the spring. At NEU, the courses were taught by four different instructors, three male and one female. Of those four instructors, two were teaching undergraduate courses for the first time. There was no contact or collaboration between the faculty at SWU and NEU. The courses at each institution were taught and graded independently. Although the faculty at SWU and NEU did share lecture notes, discussion handouts, and some exam materials, there were some differences in the topics that the different instructors chose to emphasize in their courses.

Data were collected at each institution over 14 consecutive semesters, from fall 2009 to spring 2016. The data from the off-sequence course sat SWU were collected from fall 2014 to spring 2016. A total of 12,744 individual student-grades were collected (8,389 at SWU and 4,355 at NEU). Of these, 6,735 of the student-grades were female and 6,009 were male. The total number of individual student participants was lower than the number of student-grades since many participated in more than one semester.

Student Performance and Demographic Data. Student demographic data were obtained from institutional records. At both institutions, student performance in each course was assessed by summing their total points on three midterm and one comprehensive final exam and then converting into a percentage of the total available points. At each institution, the exam questions were short response format and were graded by teaching assistants that were different each semester. Establishing inter-rater reliability was not attempted, instead, it is assumed that any grading differences are averaged over the many questions, semesters and graders. Performance by gender was then determined by comparing the mean percentage scores for the total number of males and females who completed the course, n_p. In order for a student to be included in this performance analysis, students had to take all of the exams in the semester they were enrolled in the course, i.e., students who withdrew from the course were not included (but see further below).

Independent samples t-tests were performed to determine if any differences in the overall percentage mean scores were statistically relevant. Cohen's *d* was also calculated to establish effect size. The Cohen's *d* included in this study was adjusted according to the sample size since the groups in comparison were unequal in size.

Normal distributions with small differences in the mean have larger differences at the tail-ends of the distributions (Nowell & Hedges, 1998). The critical factor for students on graduate school tracks is the final course letter grade. Students earning a grade of A tend to be part of the high-end tail of the points distribution and those with failing grades at the low-end tail. At both institutions, a final grade of D or E corresponds to failing the class. Student letter grades were also collected as the percentages of the male and female students who earned an A grade and also the percentages of each who earned D, E or W grades. W grades were assigned to students who withdrew from the courses. At NEU, students could be awarded plus and minus grades (e.g. A- and A+), and in the analysis, A- and A+ were counted as an A grade, and so on, to facilitate comparison to SWU, where plus/minus grades were not used. The number of students included in the performance analysis by grade, n_g, is larger than in the performance analysis by point total, n_p, because all students who started the course were included in the grade analysis, including those who withdrew from the course.

Results

Student demographic data is summarized in Table 5.1. Although the two institutions differed geographically (south west *versus* north east) and also in type (public for SWU *versus* private for NEU), the demographics of the participating students were fairly similar. The major differences were somewhat larger percentages of students self-identifying as Asian and Hispanic/Latino at SWU, and a larger percentage of students that did not identify race at NEU. At both institutions, the percentage of female students was somewhat larger than the percentage of males, Table 5.1

The mean performance scores for male and female students by semester at the two institutions are summarized in Tables 5.2 – 5.6. The scores for males were higher than for females in every semester studied for NEU, and also for the regular fall to spring courses at SWU with the exception of the spring 2014 semester, Tables 5.2-5.3 and 5.5-5.6. Males also outperformed females in the off-sequence courses at SWU, Table 5.4. The average ratio of the male mean score to the female mean score was 1.06±0.04 at NEU and 1.06±0.03 at SWU over all semesters for the courses offered in the regular sequence. This ratio for the off-sequence courses at SWU was 1.12±0.01 across all semesters. The differences in mean scores were small, but were statistically meaningful ($p \leq 0.05$) for nine of the fourteen student populations at NEU and for thirteen of the twenty student populations at SWU. The effect sizes, measured as Cohen's *d*, ranged from small to moderate ($0.2 \leq d \leq 0.5$) depending on semester and institution. The data suggests that for these students, females do underperform with respect to males in terms of points awarded for the courses.

Comparisons of male versus female students on the basis of final course grade are also shown in Tables 5.2 – 5.6. The grade comparisons are somewhat less reproducible from semester to semester because they are based on a smaller data set, from only the tail-ends of the point distributions. Nevertheless, there are some clear trends. A higher percentage of male students earned an A grade every semester, except spring 2014 at SWU and NEU. That this occurred in the same semester at each institution is presumably coincidental. Although less reproducible, the grade differences are larger than those for the mean scores. For twelve of the twenty student populations studied at SWU, the percentage of male A grades was larger than that of female A grades by more than a factor of 1.25, and exceeding 1.5 for six populations. At NEU, the male percentage was larger than the female percentage by more than 1.25 for eleven of the fourteen populations, and exceeding 1.5 for three semesters. In the fall 2011 semester at NEU, the factor was 1.83, i.e., the percentage of males who earned an A was almost twice as large as that of females for that semester. The differences in letter grades were even larger in the off-sequence courses taught at SWU, where for the spring 2016 semester the percentage of males who earned an A was twice as large as the percentage of females.

Table 5.1

Demographic Data for Student Participants Averaged Over All Semesters Studied (Fall of 2009 – Spring of 2016)

	SWU	NEU
White/Caucasian	56.4%	53.9%
Asian	17.5%	20.0%
Hispanic/Latino	17.1%	4.8%
Black/African American	3.2%	4.2%
Two or More Races	3.4%	3.3%
Native American/American Indian	0.9%	0.2%
Race Not Identified	1.5%	13.5%
Male	48.6%	44.3%
Female	51.4%	55.7%

The data show that the percentage of the female students who earn an A grade can be substantially lower that for males, at both institutions, and for all instructors. The gender differences for the A grade earners tended to be smaller in the second semester course compared to the first semester course. The student populations in the first and second semesters are somewhat different, since students who do not pass the first semester course (i.e. earn at least a C letter grade) are not allowed to take the second semester course at both institutions. The improvement in females' grades in the spring 2014 semester could therefore be due to this filtering effect. The difference in the DEW grades by gender may be even more alarming than the difference in the A grades. The percentage of students who earned failing grades (D, E or W) was higher for female students compared to male students in all but three semesters at both institutions, Tables 5.2-5.6. In spring 2015 at NEU, the percentage of females with DEW grades was almost three times larger than the percentage of males with DEW, although fewer NEU students fail or withdraw from the courses compared to SWU. On average 10.5% males and 13.1% females earned DEW grades at NEU, whereas at SWU these percentages were 22.0% and 28.3%, respectively. The percentage of female DEW grades was almost always higher at both institutions compared to that for males, and by more than a factor of 1.25 for twelve out of twenty populations at SWU and for seven out of fourteen populations at NEU. At each institution, this factor exceeded 1.5 for five populations across all semester studied.

Additional information about the DEW students is provided by the results from the off-sequence courses at SWU summarized in Table 5.4.

Table 5.2

Performance Data by Gender for the Organic I Course Taught in Fall at SWU

	2009	**2010**	**2011**	**2012**	**2013**	**2014**	**2015**	**2015**[i]
Males Mean (n_p) [a]	69.2 (151)	74.5 (210)	75.9 (215)	71.5 (219)	71.8 (190)	72.9 (223)	77.4 (211)	68.3 (146)
std dev	17.5	16.9	16.1	15.6	15.6	15.5	12.3	15.6
Females Mean (n_p) [a]	65.8 (200)	73.2 (197)	71.8 (186)	65.1 (213)	69.6 (267)	70.2 (233)	75.2 (253)	64.2 (137)
std dev	18.6	16.7	17.5	18.6	17.3	18.7	14.3	14.2
t [b]	1.73	.939	2.48	3.97	1.39	1.66	1.77	2.34
p [b]	.085	.348	.013	.001	.164	.097	.08	.02
Cohen's d [c]	0.19	0.08	0.25	0.37	0.13	0.16	0.16	0.27
Male Mean/Female Mean [d]	1.05	1.02	1.06	1.10	1.03	1.04	1.03	1.06
Males %A (n_g) [e]	28.3 (187)	32.9 (246)	36.6 (268)	33.3 (261)	36.4 (228)	31.7 (252)	34.7 (245)	32.3 (161)
Females %A (n_g) [e]	17.8 (269)	28.0 (243)	25.5 (263)	20.2 (272)	31.4 (312)	27.6 (279)	31.4 (315)	17.9 (145)
Male %A/Female %A [f]	1.60	1.18	1.44	1.65	1.16	1.15	1.11	1.80
Males %DEW (n_g) [g]	27.8 (187)	23.2 (246)	25.0 (268)	23.8 (261)	23.7 (228)	19.8 (252)	17.1 (245)	15.5 (161)
Females %DEW (n_g) [g]	34.6 (269)	26.7 (243)	37.6 (263)	36.8 (272)	26.0 (228)	30.8 (279)	27.3 (315)	12.4 (145)
Female %DEW/Male %DEW [h]	1.28	1.15	1.50	1.55	1.09	1.56	1.60	0.80

[a] Mean percentage point total determined as described in the text, n_p is the number of students who completed all exams. [b] Independent samples t-test was completed for each semester to compare student-grades by gender. [c] Effect size was calculated to compare the mean scores of males and females. The effect size accounts for unequal sample sizes. [d] The mean of this value over the eight samples is 1.05±0.03. [e] Percentage of students who received an A grade, n_g is the number of students who started the course. [f] The mean of this value over the eight samples is 1.39±0.27. [g] Percentage of students who received either a failing grade (D, E) or who withdrew from the course (W), n_g is the number of students who started the course. [h] The mean of this value over the eight samples is 1.32±0.29.i Course taught by female instructor.

Table 5.3

Performance Data by Gender for Organic II Course Taught in Spring at SWU

	2010	**2011**	**2012**	**2013**	**2014**	**2015**	**2016**	**2016[i]**
Males Mean (n_p) [a]	72.0 (147)	76.4 (193)	67.5 (209)	78.1 (208)	73.8 (195)	72.4 (186)	72.9 (192)	65.7 (94)
std dev	16.9	16.2	17.0	15.0	15.9	16.6	15.7	17.0
Females Mean (n_p) [a]	66.6 (194)	71.8 (179)	63.2 (164)	73.9 (158)	74.0 (221)	68.6 (183)	68.3 (217)	61.2 (96)
std dev	19.0	17.9	18.5	17.4	15.9	19.1	19.0	18.1
t [b]	2.72	2.61	2.31	2.47	.119	2.05	2.69	1.77
sig. [b]	.007	.010	.021	.014	.905	.041	.007	.079
Cohen's d [c]	0.30	0.27	0.24	0.26	0.01	0.21	0.26	0.26
Male Mean/Female Mean [d]	1.08	1.06	1.07	1.06	0.997	1.06	1.07	1.07
Males %A (n_g) [e]	27.6 (196)	41.9 (248)	35.9 (270)	38.3 (248)	32.2 (236)	31.1 (222)	25.2 (230)	25.7 (105)
Females %A (n_g) [e]	27.0 (252)	31.8 (233)	28.3 (219)	30.0 (203)	34.3 (251)	30.2 (225)	20.7 (261)	20.2 (104)
Male %A/Female %A [f]	1.02	1.32	1.27	1.28	0.94	1.03	1.22	1.27
Males %DEW (n_g) [g]	31.1 (196)	23.4 (248)	25.9 (270)	21.0 (248)	23.7 (236)	23.9 (222)	27.8 (230)	21.0 (105)
Females %DEW (n_g) [g]	32.9 (252)	29.2 (233)	32.0 (219)	29.1 (203)	20.3 (251)	31.1 (225)	33.7 (261)	26.9 (104)
Female %DEW/Male %DEW [h]	1.06	1.25	1.24	1.39	0.86	1.30	1.21	1.28

[a] Mean percentage point total determined as described in the text, n_p is the number of students who completed all exams. [b] Independent samples t-test was completed for each semester to compare student-grades by gender. [c] Effect size was calculated to compare the mean scores of males and females. The effect size accounts for the unequal sample sizes. [d] The mean of this value over the eight samples is 1.06±0.03. [e] Percentage of students who received an A grade, n_g is the number of students who started the course. [f] The mean of this value over the eight samples is 1.17±0.15. [g] Percentage of students who received either a failing grade (D, E) or who withdrew from the course (W), n_g is the number of students who started the course. [h] The mean of this value over the eight samples is 1.20±0.17. [i] Course taught by female instructor.

Table 5.4

Performance Data by Gender for Off-Sequence Courses Taught by Female Instructor at SWU

	Fall Semester (Organic II)		**Spring Semester (Organic I)**	
	2014	**2015**	**2015**	**2016**
Males Mean (n_p) [a]	62.6 (128)	62.2 (116)	71.4 (137)	67.7 (43)
std dev	16.6	19.0	15.9	15.7
Females Mean (n_p) [a]	56.3 (114)	56.6 (104)	63.5 (141)	59.3 (51)
std dev	17.1	16.9	15.8	16.9
t [b]	2.90	2.30	4.14	2.46
sig. [b]	.004	.022	.001	.016
Cohen's d [c]	0.37	0.31	0.50	0.51
Male Mean/Female Mean [d]	1.11	1.10	1.12	1.14
Males %A (n_g) [e]	37.4 (147)	28.6 (126)	27.2 (151)	25.5 (51)
Females %A (n_g) [e]	28.3 (127)	18.2 (121)	14.7 (156)	11.5 (61)
Male %A/Female %A [f]	1.32	1.57	1.85	2.22
Males %DEW (n_g) [g]	12.9 (147)	15.9 (126)	19.9 (151)	17.6 (51)
Females %DEW (n_g) [g]	12.6 (127)	22.3 (121)	29.5 (156)	34.4 (61)
Female %DEW/Male %DEW [h]	0.98	1.40	1.48	1.95

[a] Mean percentage point total determined as described in the text, n_e is the number of students who completed all exams. [b] Independent samples t-test was completed for each semester to compare student-grades by gender. [c] Effect size was calculated to compare the mean scores of males and females. The effect size accounts for the unequal sample sizes. [d] The mean of this value over the two semesters for fall is 1.11±0.01 and for spring is 1.13±0.01. [e] Percentage of students who received an A grade, n_g is the number of students who started the course. [f] The mean of this value over the two semesters for fall is 1.45±0.18 and for spring is 2.04±0.26. [g] Percentage of students who received either a failing grade (D, E) or who withdrew from the course (W), n_g is the number of students who started the course. [h] The mean of this value over the two semesters for fall is 1.19±0.30 and for spring is 1.72±0.33.

Table 5.5

Performance Data by Gender for the Organic I Course Taught in Fall at NEU

	2009	**2010**	**2011**	**2012**	**2013**	**2014**	**2015**
Males Mean (n_p) [a]	63.2 (135)	67.1 (151)	66.2 (155)	60.2 (154)	59.5 (142)	64.9 (147)	60.4 (121)
std dev	15.2	14.4	14.9	16.2	15.9	14.7	13.4
Females Mean (n_p) [a]	59.5 (206)	63.1 (172)	59.4 (190)	55.9 (186)	58.7 (201)	59.0 (213)	56.9 (151)
std dev	15.2	14.4	15.0	16.2	14.0	15.6	14.8
t [b]	2.17	2.49	4.18	2.45	.492	3.64	2.05
sig. [b]	.031	.013	.001	.015	.623	.001	.04
Cohen's *d* [c]	0.24	0.28	0.45	0.27	0.05	0.39	0.25
Male Mean/Female Mean [d]	1.07	1.06	1.11	1.01	1.01	1.10	1.06
Males %A (n_g) [e]	30.0 (150)	33.7 (166)	42.3 (163)	27.2 (173)	32.3 (155)	37.2 (164)	36.0 (125)
Females %A (n_g) [e]	24.0 (217)	24.0 (183)	23.1 (199)	20.7 (203)	24.7 (223)	25.2 (226)	30.9 (162)
Male %A/Female %A [f]	1.25	1.40	1.83	1.31	1.31	1.48	1.17
Males %DEW (n_g) [g]	14.0 (150)	9.6 (166)	9.8 (163)	17.9 (173)	18.7 (155)	13.4 (164)	10.4 (125)
Females %DEW (n_g) [g]	10.6 (217)	11.5 (183)	15.1 (199)	21.2 (203)	18.8 (223)	19.0 (226)	18.5 (162)
Female %DEW/Male %DEW [h]	0.76	1.20	1.54	1.18	1.01	1.42	1.78

[a] Mean percentage point total determined as described in the text, n_e is the number of students who completed all exams. [b] Independent samples t-test was completed for each semester to compare student-grades by gender. [c] Effect size was calculated to compare the mean scores of males and females. The effect size accounts for the unequal sample sizes. [d] The mean of this value over the seven samples is 1.06±0.04. [e] Percentage of students who received an A grade, n_g is the number of students who started the course. [f] The mean of this value over the seven samples is 1.39±0.22. [g] Percentage of students who received either a failing grade (D, E) or who withdrew from the course (W), n_g is the number of students who started the course. [h] The mean of this value over the seven samples is 1.27±0.34.

Table 5.6

Performance Data by Gender for the Organic II Course Taught in Spring at NEU

	2010[i]	**2011**[i]	**2012**[i]	**2013**	**2014**	**2015**	**2016**
Males Mean (n_p) [a]	59.4 (106)	55.6 (123)	61.2 (124)	57.1 (120)	62.2 (86)	63.7 (102)	62.2 (95)
std dev	17.1	13.3	14.7	15.1	14.2	15.4	15.7
Females Mean (n_p) [a]	57.6 (162)	50.5 (131)	57.8 (132)	51.6 (131)	61.8 (143)	57.5 (126)	60.8 (103)
std dev	17.3	13.2	13.1	14.8	13.0	16.7	16.7
t [b]	.865	3.06	1.94	2.93	.224	2.88	0.60
sig. [b]	.388	.002	.054	.004	.823	.004	.552
Cohen's d [c]	0.11	0.39	0.24	0.37	0.03	0.39	0.09
Male Mean/Female Mean [d]	1.03	1.10	1.06	1.11	1.01	1.11	1.02
Males %A (n_g) [e]	30.3 (122)	33.3 (135)	31.3 (134)	33.8 (133)	26.0 (104)	36.6 (112)	24.2 (99)
Females %A (n_g) [e]	24.3 (173)	25.7 (144)	19.4 (144)	19.9 (141)	30.8 (156)	24.8 (145)	20.4 (108)
Male %A/Female %A [f]	1.25	1.30	1.61	1.70	0.84	1.48	1.19
Males %DEW (n_g) [g]	8.2 (122)	4.4 (135)	7.5 (134)	13.5 (133)	9.6 (104)	2.7 (112)	7.07 (95)
Females %DEW (n_g) [g]	10.4 (173)	6.9 (144)	7.6 (144)	22.7 (141)	8.3 (156)	7.6 (145)	4.63 (108)
Female %DEW/Male %DEW [h]	1.27	1.57	1.01	1.68	0.86	2.81	0.65

[a] Mean percentage point total determined as described in the text, n_e is the number of students who completed all exams. [b] Independent samples t-test was completed for each semester to compare student-grades by gender. [c] Effect size was calculated to compare the mean scores of males and females. The effect size accounts for unequal sample sizes. [d] The mean of this value over the seven samples is 1.06±0.04. [e] Percentage of students who received an A grade, n_c is the number of students who started the course. [f] The mean of this value over the seven samples is 1.34±0.29. [g] Percentage of students who received either a failing grade (D, E) or who withdrew from the course (W), n_c is the number of students who started the course. [h] The mean of this value over the seven samples is 1.41±0.72. [i] Course taught by female instructor.

Many students who enroll in the off-sequence courses are those who already received a failing grade or withdrew in the previous semester. This population characteristic may explain the decrease in the mean percentage exam scores for both males and females in these courses compared to the regular sequence courses. This decrease was larger for females compared to males, and the differences between the final letter grades for males and females were also larger for these courses. In terms of the A grades, the mean ratio for the second semester courses taught in fall was 1.45 ± 0.18 and for the first semester courses taught in fall was 2.04 ± 0.26, with the males outperforming the females every semester. In terms of DEW grades, more females received failing grades or withdrew from the off-sequence courses than males, with the mean ratio of DEW grades being 1.19 ± 0.30 for fall and 1.72 ± 0.33 for spring. The differences in final grades between males and females were especially large for the first semester courses taught in the spring. One interpretation of these results is that gender gaps are larger for lower performing students, see further below.

It has previously been reported that a female instructor can positively influence college performance and achievement for female students (Bettinger & Long, 2005; Hoffmann & Oreopoulos, 2009). For the courses included in this study, however, there was no evidence to support this suggestion. The performance by female students compared to males was no better when a female was the course instructor, at both institutions. At NEU a female instructor taught the class for three consecutive semesters, 2010 -2012, Table 5.6. At SWU a female instructor taught all of the off-sequence courses, Table 5.4, and two of the regular sequence courses, Tables 5.2 and 5.3. The ratio of A grades by gender and the DEW grades by gender for these courses were in line with those for the male instructors.

Spatial Ability by Gender

Method: Participants and Study Context

Students' spatial ability data were collected from the students taught by the male instructor at SWU, as part of the same IRB exempt study described above. The relevant data were not available for the NEU students or for the SWU students who took the off-sequence course. A total of 4,655 students' performance data (50.4% female and 49.6% male) were analyzed, and the data were collected over 12 semesters from fall 2009 to spring 2015.

One criticism of standard spatial ability tests is that they generally use images and/or methodology that are not directly relevant to chemistry (Oliver-Hoyo & Sloan, 2014). As discussed above, previous work on the ways that students solve chemistry problems that are conventionally associated with spatial ability has shown that students often use cognitive strategies that are not directly assessed by spatial ability tests (Stieff, 2010, 2013; Stieff et al., 2012). Therefore, rather than use a standard chemistry spatial ability test (Bodner & Guay, 1997), a different approach was used to study spatial ability in general organic chemistry based on the subject material itself.

All of the organic chemistry exam questions for all 12 semesters of the regular on-sequence courses at SWU were categorized based on the types of problem normally encountered in organic chemistry as shown in Chapter 2. These categories are summarized in Table 5.7. After the questions were categorized, all of the questions belonging to a particular problem type for all semesters were combined. For each question in a problem type, item analysis was performed to measure its discrimination and difficulty index. The discrimination index was determined by comparing the scores of high and low performers on that question to the overall performance distribution. Questions with a discrimination index lower than 0.2 were not included in the analysis (Nunnally & Ator, 1964). The difficulty index was calculated as the fraction of the students who gave a completely correct response to the question (McCowan, R. & McCowan, S., 1999). The formula [1 – (*difficulty index*)] was used so that the larger value indicated higher difficulty. To determine the relationship between student performance in each problem type and the results from the item analysis, a mean percent score for each problem type over all semesters was found by combining the raw scores of all of the questions belonging to the particular problem type for all of the semesters studied. These mean scores were further grouped based on student gender.

Three of the problem types involve analysis and understanding of 3-dimensional organic molecular structures, i.e. Conformations, Chirality, and Pericyclic Reactions. Students with higher spatial ability might be expected to perform better solving problems in these three types. The other problem types can be understood and solved in two-dimensions on paper.

Results

The differences between male and female performance at SWU by problem type are summarized in Table 5.7, together with the mean difficulty index for that type. The difference in mean scores for the male and female students was not the same for all problem types. Indeed, for most of the problem types the difference in performance by gender was not statistically significant, Table 5.7. The problem types for which the difference was statistically significant were Synthesis, Mechanisms, and Reactions, with small to moderate effect sizes. These problem types were also the ones with a larger difficulty index.

The data is summarized in graphical form in Figure 5.1. The three problem types that connect to spatial ability, Chirality, Conformations, and Pericyclic Reactions were among those with small differences in mean score by gender, and which were statistically not significant. In fact, the Pericyclic Reactions type had the smallest performance difference by gender of all the problem types. In addition, the total number of problems in these three types was relatively small anyway, Table 5.7. For these reasons, the overall difference in course performance by gender is unlikely to be due to the differences in students' spatial ability. These results are consistent with previous work by Stieff (2010, 2013) and others (2012), who proposed that students develop various strategies and heuristics to solve organic chemistry problems regardless of gender. It was further proposed that these heuristics and alternate strategies enable essentially all students to solve problems requiring spatial ability equally well, even if they have different spatial ability skills.

Instead, the data show that the differences between males and females' performance were larger for those problem types that the students found to be most difficult. Since motivation and self-efficacy have been suggested as important contributing factors to performance differences by gender in STEM (DeBacker & Nelson, 2000; Pajares, 2005; Watt, 2006), then exploring these factors could provide a better explanation for the gender difference found by problem type difficulty.

Non-Cognitive Factors by Gender

Method: Instrument and Study Participants (Motivation and Self-Regulation Factors)

Students' self-reported motivation and self-regulation were measured using an Organic Chemistry Motivation Survey (OCMS), which is adapted from the Science Motivation Questionnaire-II (Glynn et al., 2011) as shown in Chapter 3. OCMS measure four factors: self-efficacy, self-determination, relevance, and grade motivation. The questions corresponding to these four factors are summarized in Table 5.8. The term relevance has several specific meanings in the education research literature (see, for example; Stuckey, Hofstein, Mamlock-Naaman, & Eilks, 2013). In the context of OCMS, relevance is defined as the extent to which the students perceive the course content to be interesting and useful to them at the time they are taking their course and also to their future careers as defined in Chapter 3. Self-determination is described as the level of control an individual has over their learning, and self-efficacy is defined as student's perceived confidence in the course material (Glynn & Koballa, 2006; Pintrich, 2004). Of the four factors, grade motivation is the only extrinsic motivation measured by the OCMS, which is the level of influence external rewards has on a student's motivation towards learning organic chemistry.

The OCMS was administered to the students at SWU and NEU during the first week of organic chemistry courses before any type of course assessments were given. At SWU, data were collected over six consecutive semesters from fall 2013 to spring 2016 in the courses taught by the male instructor. The OCMS data at NEU were collected for five semesters, fall 2013 and fall 2014 to spring 2016.

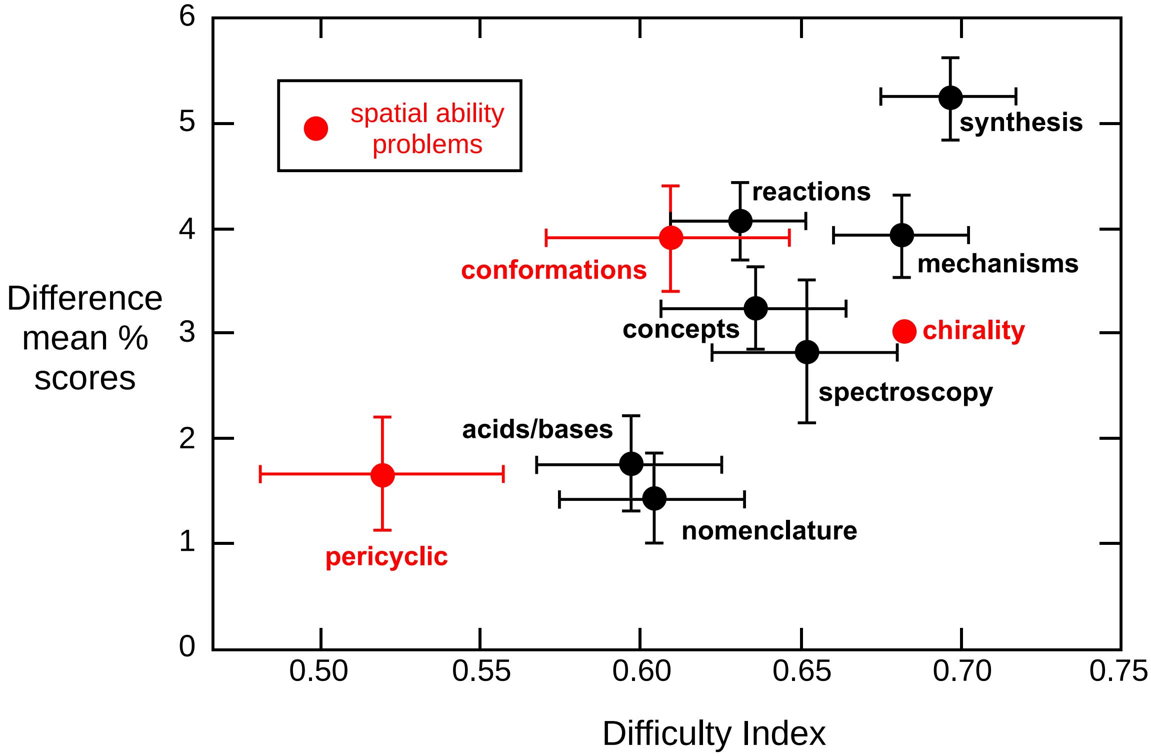

Figure 5.1. Differences in mean scores by gender per problem type versus problem type difficulty.

Table 5.7

Student Performance on Problem Types by Gender and Problem Type Difficulty

Problem Type (*No. of Problems*)	Females M_f (SEM)	Males M_m (SEM)	Mean Difference $M_m - M_f$ (SEM)	*t* (sig.)	Effect Size (Cohen's *d*[c])	Difficulty Index (SEM)
Nomenclature (34)	78.0 (1.40)	79.4 (1.52)	1.43 (0.44)	0.691 (.49)	0.17	0.604 (0.03)
Concepts (61)	71.8 (1.59)	75.0 (1.58)	3.23 (0.41)	1.44 (.15)	0.26	0.635 (0.03)
Acids/Bases (37)	73.9 (1.65)	75.6 (1.57)	1.75 (0.46)	0.769 (.44)	0.17	0.597 (0.03)
Spectroscopy (31)	71.3 (1.65)	74.2 (1.59)	2.83 (0.66)	1.24 (.22)	0.32	0.652 (0.03)
Mechanisms (110) [a]	66.3 (1.25)	70.2 (1.20)	3.93 (0.42)	2.26 (.03)	0.30	0.681 (0.02)
Reactions (125) [a]	67.4 (1.17)	71.4 (1.12)	4.06 (0.35)	2.51 (.01)	0.31	0.630 (0.02)
Synthesis (54) [a]	63.4 (1.24)	68.7 (1.26)	5.24 (0.42)	2.96 (<.00)	0.58	0.696 (0.02)
Chirality (5) [b]	60.9 (7.68)	64.0 (7.47)	3.02 (10.7)	0.282 (.79)	0.18	0.682 (0.09)
Pericyclics (25) [b]	81.0 (1.47)	82.7 (1.27)	1.66 (0.62)	0.857 (.40)	0.25	0.520 (0.04)
Conformations (24) [b]	73.4 (2.47)	77.3 (2.39)	3.90 (0.50)	1.13 (.26)	0.33	0.610 (0.04)

[a] The entries in italics refer to problem categories where the performance difference by gender is statistically significant. [b] The entries in bold refer to problem categories that are more likely to involve spatial ability. [c] Effect size was calculated to compare the mean scores of males and females. The effect size accounts for unequal sample sizes.

Survey participation was voluntary, and the students received extra credit worth 0.5% of their final course grade for completing the OCMS. For those students who wished to receive extra credit but did not want to participate in the study, essay questions were provided in lieu of the OCMS. This portion of the study was granted exempt status by the IRB at both institutions. 2,303 SWU students, 44.2% males and 55.8% females, and 1,131 NEU students, 40.8% males and 59.2% females, participated in this part of the study. At SWU, 89.6% of the students participated, and at NEU, 80.7% of the students participated.

Mean scores for each of the factors in OCMS were determined for each student population by gender, Tables 5.9 and 5.10, as discussed in Chapter 3. The differences in these scores by gender were compared using independent samples t-tests. Cohen's *d* was calculated to determine the effect size for each comparison. The Cohen's *d* calculations accounted for the sample size differences between male and female gender groups.
The OCMS factors were further to determine the extent to which each correlated with overall course performance, using multiple linear regression analysis. Even if a gender difference was found for an OCMS factor, if that factor did not connect to performance then it cannot explain the observed gender differences in performance. Course performance for this part of the study was determined by summing the student's point totals on all exams. Therefore, only the students who completed all course assessments (three midterm exams and a final exam) were included in this analysis. The sample sizes for the multiple linear regression analysis were thus smaller than the total number of students who completed the OCMS.

Table 5.8

The Four Factors of the Organic Chemistry Motivation Survey, OCMS

Factor 1: Relevance
Understanding organic chemistry will benefit me in my career.
Knowing organic chemistry will give me a career advantage.
My career will involve organic chemistry
Learning organic chemistry will help me to get a good job.
The organic chemistry I learn is relevant to my life.
Learning organic chemistry makes my life more meaningful.
I will use organic chemistry problem-solving skills in my career.
Factor 2: Self-Efficacy
I believe I can earn an A grade in organic chemistry.
I am confident that I will do well on organic chemistry tests.
I believe that I can master organic chemistry knowledge and skills.
I'm sure I can understand organic chemistry.
Factor 3: Self-Determination
I study hard to learn organic chemistry.
I spend a lot of time learning organic chemistry.
I put enough effort into learning organic chemistry.
I use strategies to learn organic chemistry well.
Factor 4: Grade Motivation
Getting a good organic chemistry grade is important to me.
It is important that I get an A grade in organic chemistry.
I think about the grade that I will get in organic chemistry.
I like to do better than other students on organic chemistry tests.

Note. In the surveys the questions were ordered randomly.

In the analysis, outliers were removed from the factor score distributions if they were above or below the standard residual range of ±3.0. A Total of 19 SWU students across six semesters and 8 NEU students across five semesters were removed to satisfy this standard residual range criterion. Based on the histogram and normality plot of residuals, the assumptions for the normality of residuals were met (Field, 2009), and for the collinearity assumptions, the variance inflation factor (VIF) and tolerance values were found to be acceptable since all values were greater than 0.25 and less than 2.0 respectively when all predictors were entered into the model (Keith, 2006).

Results

The results for the OCMS motivation factors analyzed by gender are summarized in Tables 5.9 and 5.10. The motivation factor scores were slightly higher at SWU compared to NEU, however, the trends in the OCMS factor scores were fairly similar at both institutions. Of the four factors measured, grade motivation was the highest scoring factor at both institutions, but no statistical difference was found by gender for this factor. Some gender differences were found for the factors relevance (fall 2013 at SWU; spring 2015 at NEU) and self-determination (spring and fall 2015 at NEU), but these results were not consistent across all semesters. The only factor that showed consistent and statistically significant differences (p<.001) by gender was self-efficacy. Across all semesters, the mean self-efficacy percent score at SWU was 79.0% for males and 70.4% for females, and at NEU was 72.0% for males and 58.1% for females. These large differences in self-efficacy indicated that females were much less confident in their skills and understanding of organic chemistry compared to males. At NEU, the difference

Table 5.9

Comparison of SMQ-II Results by Gender at SWU

Semester		Fall 2013		Spring 2014		Fall 2014		Spring 2015		Fall 2015		Spring 2016	
Gender (*Sample Size)*		Males (165) Females (238)		Males (*114*) Females *(147)*		Males (210) Females (246)		Males (173) Females (185)		Males (189) Females (257)		Males (168) Females (211)	
		Mean St. Dev.	Sig.	Mean St. Dev.	*Sig.*	Mean St. Dev.	*Sig.*	Mean St. Dev.	*Sig.*	Mean St. Dev.	*Sig.*	Mean St. Dev.	*Sig.*
Relevance	M	M=69.5	t=2.13	M=63.8	t=.80	M=67.9	t=1.90	M=63.6	t=.50	M=64.1	t=.60	M=61.6	t=.07
		SD=19.8	*p*=.03	SD=20.1	*p*=.42	SD=18.3	*p*=.06	SD=19.5	*p*=.62	SD=18.7	*p*=.55	SD=19.3	*p*=.94
	F	M=65.3		M=61.8		M=71.0		M=62.6		M=65.1		M=61.7	
		SD=19.4		SD=19.4		SD=15.6		SD=19.1		SD=17.4		SD=19.3	
Self-Efficacy	M	M=80.1	t=5.91	M=78.3	t=4.26	M=81.4	t=3.68	M=77.8	t=3.28	M=79.6	t=4.64	M=76.7	t=4.01
		SD=16.5	*p*<.001	SD=20.3	*p*<.001	SD=17.5	*p*<.001	SD=20.5	*p*<.001	SD=17.0	*p*<.001	SD=20.7	*p*<.001
	F	M=69.6		M=67.3		M=75.5		M=70.3		M=71.8		M=68.0	
		SD=18.2		SD=20.4		SD=16.9		SD=22.3		SD=18.0		SD=21.2	
Self-Determination	M	M=69.3	t=.72	M=67.9	t=.99	M=73.2	t=.78	M=67.2	t=.14	M=69.0	t=1.03	M=71.4	t=.39
		SD=19.1	*p*=.47	SD=21.5	*p*=.32	SD=16.9	*p*=.44	SD=20.5	*p*=.89	SD=18.7	*p*=.30	SD=18.9	*p*=.70
	F	M=68.0		M=65.4		M=74.3		M=67.5		M=70.8		M=72.1	
		SD=17.7		SD=18.1		SD=14.8		SD=19.0		SD=17.5		SD=16.4	
Grade Motivation	M	M=87.2	t=.48	M=83.9	t=.16	M=88.3	t=1.78	M=84.4	t=.50	M=87.6	t=.69	M=85.1	t=.01
		SD=14.7	*p*=.63	SD=16.1	*p*=.87	SD=13.7	*p*=.08	SD=17.7	*p*=.62	SD=14.5	*p*=.49	SD=16.0	*p*=.99
	F	M=87.8		M=84.2		M=90.3		M=85.3		M=88.4		M=85.1	
		SD=13.3		SD=13.7		SD=9.80		SD=13.9		SD=11.5		SD=14.2	

Table 5.10

Comparison of SMQ-II Results by Gender at NEU

Semester		Fall 2013		Fall 2014		Spring 2015		Fall 2015		Spring 2016	
Gender (*Sample Size*)		Males (46) Females (86)		Males (126) Females (196)		Males (94) Females (138)		Males (103) Females (142)		Males (92) Females (108)	
		Mean St. Dev.	Sig.	Mean St. Dev.	*Sig.*	Mean St. Dev.	*Sig.*	Mean St. Dev.	*Sig.*	Mean St. Dev.	*Sig.*
Relevance	M	M=64.3 SD=19.1	$t=.80$ $p=.43$	M=56.7 SD=20.3	$t=1.56$ $p=.12$	M=58.5 SD=18.2	$t=2.10$ $p=.04$	M=51.2 SD=20.7	$t=.16$ $p=.88$	M=55.7 SD=18.9	$t=.23$ $p=.82$
	F	M=61.7 SD=16.8		M=53.1 SD=20.3		M=53.2 SD=19.7		M=50.8 SD=21.1		M=55.0 SD=20.6	
Self-Efficacy	M	M=73.4 SD=17.1	$t=4.46$ $p<.001$	M=70.8 SD=19.6	$t=5.47$ $p<.001$	M=75.8 SD=19.4	$t=6.08$ $p<.001$	M=68.5 SD=21.2	$t=4.87$ $p<.001$	M=71.3 SD=22.1	$t=4.28$ $p<.001$
	F	M=59.2 SD=17.5		M=58.2 SD=20.5		M=59.7 SD=20.1		M=54.9 SD=21.8		M=58.6 SD=19.7	
Self-Determination	M	M=68.9 SD=14.5	$t=.53$ $p=.59$	M=67.5 SD=17.6	$t=1.08$ $p=.28$	M=73.1 SD=18.2	$t=2.37$ $p=.02$	M=64.2 SD=18.0	$t=2.70$ $p=.008$	M=68.0 SD=15.8	$t=.87$ $p=.39$
	F	M=67.4 SD=14.9		M=69.5 SD=16.0		M=67.8 SD=16.1		M=70.3 SD=17.0		M=70.1 SD=17.7	
Grade Motivation	M	M=87.1 SD=15.4	$t=.05$ $p=.96$	M=84.9 SD=13.1	$t=.14$ $p=.89$	M=86.6 SD=11.0	$t=3.19$ $p=.002$	M=85.5 SD=16.2	$t=.06$ $p=.95$	M=84.9 SD=16.3	$t=.80$ $p=.43$
	F	M=87.2 SD=12.0		M=84.7 SD=13.5		M=81.1 SD=15.4		M=85.4 SD=13.9		M=83.0 SD=15.7	

between males and females was particularly large.

Even though self-determination, like self-efficacy, is considered important for self-regulated learning, this factor was not found to be significantly different between males and females for the majority of the semesters studied. In fact, females scored higher in this factor compared to males in four out of six semesters at SWU and three out of five semesters at NEU, although the differences were too small to be significant.

The results of the multiple linear regression analysis of significant predictors are summarized in Appendix G and H. For five out of six semesters at SWU and for four out of five semesters at NEU, self-efficacy was the highest predictor of organic chemistry performance. In fact, at SWU, self-efficacy was the only significant predictor for three out of six semesters studied. On average, self-efficacy scores accounted for 14.9% of performance variance at SWU and 14.7% of variance at NEU across all semesters. The extent of performance variance described by the self-efficacy scores increased from the fall to the spring semesters at SWU and NEU. For example, the self-efficacy score alone explained 23.2% of the overall performance variance at SWU in spring 2016 while the same factor only accounted for 7.6% variance in the fall semester. This trend is not surprising since the students who participated in the fall were those enrolled in the first semester course whereas those who participated in the spring were in the second semester course. Second semester students have already been exposed to a semester of organic chemistry, whereas the first semester students have not yet received any assessment feedback to gauge their skills and understanding of organic chemistry.

The other OCMS factors were not consistently predictive as self-efficacy at both institutions. In fall 2013, self-determination factor was the highest predictor at SWU and

NEU, but this result was not reproduced in other semesters and was ruled as coincidence. The factors, relevance and grade motivation, were found to be significant for one semester at SWU and two semesters at NEU, however, the extent of the variance explained by these factors were small, especially at SWU. Across the semesters studied, the other OCMS factors contributed additional 1.1-2.4% at SWU and 1.6-6.0% at NEU to the regression model above self-efficacy, but for many of the semesters, these other factors were found to be non-significant.

Discussion

Female underperformance compared to males in general organic chemistry has been confirmed for a large population of students, over multiple semesters, multiple instructors and at two different institutions. The effect on letter grade was larger than the effect on points total, in some semesters the percentage of male students earning an A was twice as high as the percentage of female students. The reverse holds true for failing grades, where a higher percentage of females fail compared to males. This previously unrecognized disproportionate outcome in a critical science course, particularly the difference in final letter grades, is likely to have significantly negative implications for women pursuing STEM careers, particularly those on pre-health tracks (Lovecchio & Dundes, 2002).

This performance gap persists even if the instructor was female for the courses included in this study. The performance difference could also not be attributed to differences in spatial ability, a cognitive factor that is frequently suggested as having a gender gap.

The study of motivation factors showed that self-efficacy had the largest difference between males and females for all semesters studied at both institutions. Self-efficacy was also the factor that was most predictive of overall course performance for the majority of the semesters examined. These results strongly suggest that socio-cognitive factors play a role in the observed gender effects. This proposal is consistent with previous studies that correlate self-efficacy performance in college-level science courses (Glynn et al., 2011; Lynch & Trujillo, 2010; Pajares, 1996; Taasoobshirazi & Glynn, 2009), specifically with chemistry (Lynch & Trujillo, 2011; Villafañe et al., 2014; 2015; Zusho et al., 2003), and with studies that provide evidence that self-efficacy is connected to performance differences by gender other in STEM courses (DeBacker & Nelson, 2000; Pajares, 2005; Watt, 2006).

The OCMS was administered in the first week of class, and the results showed that even coming into the organic chemistry course females tended to have lower self-efficacy than males. Even though their understanding of the content and their ability to solve problems had not yet been assessed, females tended to be less confidence in their abilities in organic chemistry than males. Self-efficacy represents student's level of belief that they can perform, in the present case in an organic chemistry course (Bandura, 1977; Pajares, 1996; Schunk, 1995). Students with lower self-efficacy have been found to be less effective users of deep cognitive strategies and to self-regulate less efficiently than students with high self-efficacy (Pintrich, & Schunk, 2002; Schunk, & Usher, 2012; Zimmerman, 2000; Zimmerman et al., 1992). In turn this suggests that strategies to increase self-efficacy (see, for example: Zimmerman et al., 1992) should be useful in order to address the gender performance gap uncovered in this work. It is important to also consider the fundamental basis for this incoming lowered self-efficacy in females.

Socio-cultural theories provide a context to understand important socio-cognitive factors such as self-efficacy (Ceci et al., 2009). Gender gaps in science achievement have previously been related to societal attitudes and expectations, particularly of parents and teachers (Fredricks & Eccles, 2002; Jacobs, Chhin, & Bleeker, 2006; Jacobs, Davis-Kean, Bleeker, Eccles, & Malanchuk, 2005; Lavy & Sand 2015; Riegle-Crumb & Humphries 2012). Expectation theory suggests that cultural stereotypes result in implicit bias towards individuals in negatively stereotyped groups (Ridgeway, 2014), and studies of stereotype and identity threat (Steele, 1997; Steele, James, & Barnett, 2002) demonstrate a link to academic performance in STEM (Good, Aronson, & Harder, 2008; Shapiro & Williams, 2012; Spencer, Steele, & Quinn, 1999; Steele & Aronson, 2005). It is further proposed that studies of socio-cultural factors such as stereotype threat would also be useful in order to guide strategies to ameliorate the gender gap identified in this work, and possibly in other college STEM environments.

Conclusions

A potentially important gender gap has been uncovered where females underperform in general organic chemistry courses compared to males. This trend was observed across multiple semesters, instructors and at 2 institutions. Although the performance differences by gender were small when exam scores were compared, much larger differences were found when the final letter grades were examined. In some semesters, the percentage of males who earned an A grade was twice as large as the percentage earned by females. This gender difference could not be attributed to students' spatial ability, and was not ameliorated by students having a female instructor. Measurements of student motivation and other self-regulating factors using an instrument that was specifically designed for general organic chemistry showed that self-efficacy was not only the factor with the largest difference by gender (females had lower self-efficacy), but was also the factor that correlated best with overall course performance. These results point to the importance of social-cognitive factors in determining achievement in general organic chemistry, and suggest possible strategies to further investigate possible social and cultural origins of the observed gender effect.

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Chapter 6: Conclusions & Future Directions

The overall goal of this dissertation was to explore the relationships between organic chemistry course performance and various cognitive, socio-cognitive, and socio-cultural factors. Because of the limited literature on social factors on organic chemistry performance, more emphasis was placed on examining the influences of social and cultural variables, rather than cognitive variables. In particular, the role of cultural and social capital has not previously been properly explored in any college-level chemistry course. All of the studies described here involved analysis of data from a large number of students, taught by different instructors, from two different research universities across multiple academic years. The majority of the prior literature on organic chemistry course performance was limited by small sample sizes. Addressing multiple and complimentary factors in large-scale studies represents a unique approach to the study of a college-level science course.

The first project, described in Chapter 2, took a different approach to examining the cognitive skills that students use in solving different types of organic chemistry problems. Instead of focusing on problem-solving in one specific area, as in previous work, this study provided a new categorization scheme for all of the different kinds of organic chemistry problems encountered in most courses. Differences in student performance by problem type were found, with types that required higher cognitive load being more predictive of overall course performance. However, student performance on high cognitive load problems was different when student groups were compared in terms of non-cognitive factors, for example, whether they were pre-health or not. These results indicated that student performance in organic chemistry is likely to be influenced by factors beyond cognitive ability. These results suggested a shift of research focus towards an examination of the social factors related to course performance.

Results on students' motivation and self-regulation related to organic chemistry were summarized in Chapter 3. The Science Motivation Questionnaire - II (SMQ-II) (Glynn, Brickman, Armstrong, & Taasoobshirazi, 2011) was adapted for use in general organic chemistry. Factor analysis was used to refine the survey, and the resulting four-factor instrument was named Organic Chemistry Motivation Survey (OCMS). When students' motivation scores from OCMS were analyzed, self-efficacy was found to account for 27-52% of the variance in course performance (depending upon semester and institution), while the remaining factors contributed only 0-5.0% to the regression model. Considering that the self-efficacy factor consisted of only four items, it is remarkable that it could account for such a large percentage of the variance in performance.

Sociocultural theories switch the focus of cognition and motivation from individual students to their social and cultural environment, i.e., how social and cultural factors influence student performance and achievement. Almost no studies have previously been reported on general organic chemistry from the perspective of sociocultural learning theories. As described in Chapter 4, concepts that explicitly influence student's social and cultural experiences are cultural and social capital, but there has been no discussion of these concepts in the context of organic chemistry course performance. Since no standardized instrument existed to measure students' cultural and social capital in college-level science courses, the bulk of Chapter 4 was devoted to explaining how the Science Capital Questionnaire (SCQ) was developed, and how it was assessed for reliability and validity. The SCQ was used to measure various types of capital of organic chemistry students. A college-level specific form of social capital, named “College Connections,” was found to be the most predictive of course performance. The differences in the SCQ results at two different academic institutions were consistent with obvious structural and cultural differences at the institutions, which represents some level of validity for the new instrument.

In Chapter 5, various aspects of the previous studies were combined to address a specific problem in organic chemistry – differences in performance by gender. After discovering large differences in course grades at two institutions (females were found to fail the course twice as frequently as males in some semesters), the approaches described in Chapters 2 and 3 were used to explore possible factors contributing to this important issue. Students’ spatial ability were examined by comparing their scores on problem types that required such skills to those that do not, and it was found that spatial ability cannot be the origin of the observed gender differences. Students’ motivation and self-regulation were studied using the OCMS. Females were found to have significantly lower self-efficacy than males, and self-efficacy also showed the strongest correlation with course performance. These results again highlight the importance of non-cognitive factors on student performance and suggest that the origin of gender differences in organic chemistry lies, at least in part, in their beliefs about student’s ability to perform in organic chemistry.

One of the overall goals of this thesis was to provide large-scale studies on the effects of social factors on organic chemistry performance. The studies included in this thesis are some the largest studies described to date on organic chemistry student populations, which provide high statistical power for the results found.

The results from the studies presented in the previous chapters suggest several possible directions for future research. Self-efficacy was found to be highly related to course performance in Chapters 3 and was the significant factor in explaining gender differences in organic chemistry performance in Chapter 5. In the introductory chapter, an argument was made about connecting education research, and practice, to existing learning theory. One obvious next step would be to return to Bandura's self-efficacy theory and use this as a guide to design interventions or adjustments to curricula to help to increase the students' self-efficacy.

Bandura suggests that self-efficacy is influenced by the following factors: mastery experiences, vicarious experiences, social persuasion, and physiological responses (Bandura, 1982). Mastery experiences provide the learner with opportunities to test their skills at a given task. Unsuccessful attempts at a task can harm a student's self-efficacy, which in turn can lead to avoidance (Bandura, 1982). Students can also learn by observing other people, termed as vicarious experiences. In particular, interactions with people the students both see as succcessful, and also as people they can identify with, has been shown to be an effective way of increasing self-efficacy (Zeldin & Pajares, 2000). Students' self-efficacy can be also influenced by other people's feedback and support. For example, positive feedback has been shown to help women gain self-efficacy (Betz & Schifano, 2000; Zeldin & Pajares, 2000), while negative feedback can have detrimental effects (Zeldin, Britner, & Pajares, 2008). Students' interpretations of their own physiological responses can affect their self-efficacy if the responses are unfavorable (Rittmayer & Beier, 2009).

Several attempts have been made to incorporate these factors into intervention methods to help students' self-efficacy in STEM (Rittmayer & Beier, 2009; Zeldin & Pajares, 2000). Interventions targeting mastery experiences have been shown to increase STEM self-efficacy in general (Betz & Schifano, 2000; Cordero, Porter, Israel, & Brown, 2010; Dunlap, 2005; Hernandez, Schultz, Estrada, Woodcock, & Chance, 2013), and previous research has shown that women were more likely than men to attribute their success in STEM to vicarious experiences and social persuasion (Zeldin & Pajares, 2000; Zeldin, Britner, & Pajares, 2008). In order to improve females' vicarious experiences in STEM, several studies have used role models to help female students establish their STEM identities (Drury, Siy, & Cheryan, 2011; Herrmann et al., 2016; Steele, 1997; Stout, Dasgupta, Hunsinger, & McManus, 2011; Weisgram & Bigler, 2006). In particular, Herrmann et al. (2016) found significant improvements in female students' general chemistry course grades when the experimental group was exposed to a letter written by a female role model. The positive results from this particular study concerning college-level chemistry students suggest that similar intervention methods might be useful for the students in organic chemistry courses. In addition to providing vicarious experiences, it has been suggested that role models should also incorporate elements of social persuasion (Rittmayer & Beier, 2009; Seymour & Hewitt, 1997; Zeldin & Pajares, 2000) to provide female students with positive, realistic support to increase STEM self-efficacy.

In addition to interventions to increase students' self-efficacy in organic chemistry, perhaps more important future work on self-efficacy should be directed towards exploring the fundamental reasons why some students (e.g., female students in

Chapter 5) enter the course with low self-efficacy. Self-efficacy is a socio-cognitive concept, which, by definition, is shaped by an individual's social and cultural observations, interactions, and experiences (Bandura, 2001). Therefore, it would be useful to further examine what types of social experiences and interactions lead to lower self-efficacy of students. For female and underrepresented students, an example of a possibly important social pressure is stereotype threat (Aronson, Quinn, & Spencer, 1998; Spencer, Steele, & Quinn, 1999; Steele, 1997). Individuals experiencing stereotype threat can be negatively impacted in terms of their performance, which can eventually lead to disengagement from the particular environment or topic (Picho & Brown, 2011; Steele, 1997). Picho and Brown (2011) discussed various key factors (e.g. group identification, stigma consciousness, and negative affect) that could influence an individual's level of stereotype threat. For example, a previous study showed that female students who strongly identified with their gender group were more likely to feel stereotype threat in situations where stereotypes against women are known to exist (Schmader, 2002). In another study, women reported higher levels of negative affect under stereotype threat conditions, which in turn negatively affected their performance on a math exam (Cadinu, Maass, Rosabianca, & Kiesner, 2005). However, a systemic study that examines all of these stereotype threat factors together in the context of organic chemistry courses has not yet been performed. Therefore, future studies that focus on these factors and their relationships to organic chemistry performance as well as self-efficacy would be useful.

Another important future research direction would be further validation of the SCQ, and the implementation of this instrument in other college-level STEM populations. Using the instrument to study two different populations of organic chemistry students at SWU and NEU provided some level of validity, but further testing and refinement of the instrument would be useful to encourage wider adoption. For example, a mixed-methods study that incorporates a qualitative approach to validation would be useful (Creswell, Clark, & Vicki, 2011). In addition, using the SCQ in other STEM courses and comparing these results to those reported in Chapter 4 would be helpful in determining which capital factors are the most important for college students in STEM disciplines in general. Other possible populations to study would be the organic chemistry students enrolled in community colleges. As discussed in Chapter 4, students' social capital (College Connections factor) was the most predictive of organic chemistry performance. It would be beneficial to further study if social capital also predicts student performance in other STEM courses or in smaller classroom settings.

This work ultimately resulted in two new instruments to measure socio-cognitive and sociocultural factors in what is considered to be an important roadblock college-level science course using large populations of organic chemistry students. It would be of particular interest to expand these studies, particularly the sociocultural aspects, to other large college science courses.

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APPENDIX A

CHAPTER 2: EXAMPLES OF ORGANIC CHEMISTRY PROBLEM TYPES

Example Questions from Fall 2009 First Semester Course

Question 1 (14 pts.) Give the IUPAC name for the following. Specify stereochemistry as appropriate.

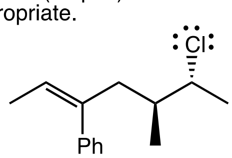
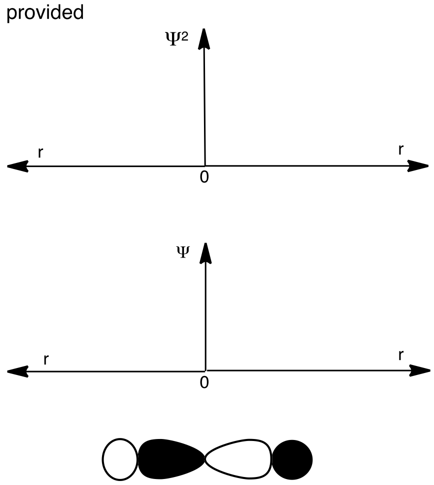


Figure A1. Nomenclature (1) problem type.

Question 2 (18 pts.) Given the pictorial representation of the 3p atomic orbital shown below:
a) Give a plot of the magnitude of the wavefunction (Ψ) versus distance from the nucleus on the axes provided, **AND IDENTIFY ANY NODES ON THIS PLOT**
b) Give a plot of the magnitude of the wavefunction squared (Ψ^2) versus distance from the nucleus on the axes provided



3p A.O. wavefunction picture

Figure A2. Bonding/Concepts (2) problem type.

Question 1 (22 pts.) Which of the following two structures would you expect to be the strongest Bronsted acid? Give an explanation for your choice. Your explanation should include drawings of the structures of the corresponding conjugate bases, as appropriate (ignore other possible structure isomers).

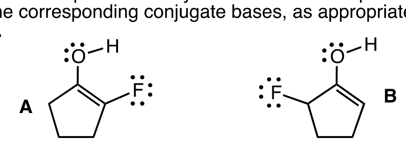
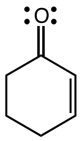


Figure A3. Acidity/Basicity (3) problem type.

Question 7 (22 pts.) Between structure **A** and **B**, which should have a **LOWER** frequency IR absorption for the C=O bond? Give an explanation that includes drawings of relevant minor resonance contributors.

A



B

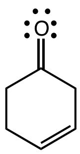
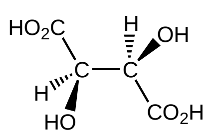


Figure A4. Spectroscopy (4) problem type.

Question 2 (12 pts.)
a) Assign the configuration, R or S, for each asymmetric (chiral) center for (-) tartaric acid
b) Draw a structure of (+) tartaric acid



(-) tartaric acid

(+) tartaric acid

Figure A5. Chirality (5) problem type.

Question 11 (60 pts.) For the each of the following reactions, give a full curved-arrow pushing mchanism. At each step indicate the Lewis acid and base (LA/LB) and also Bronsted acid and base (BA/BB) as appropriate.

a)

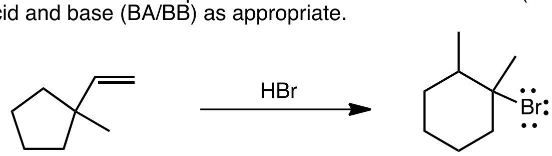
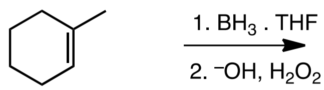
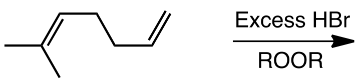
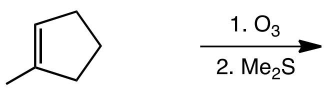


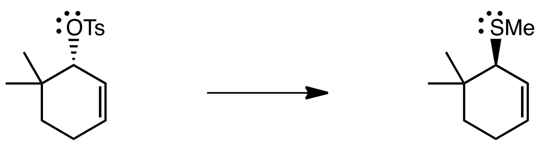
Figure A6. Mechanism (6) problem type.

Question 7 (77 pts.) For the following reactions:
a) Give the missing major **ORGANIC PRODUCT or REAGENTS/CONDITIONS** as appropriate
b) **Show stereochemistry** where appropriate
c) **Briefly explain whether a solution of the product would be optically active**

a)


b)


c)


d)


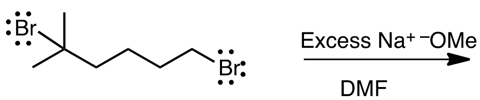
e)


Figure A7. Reagents/Products (7) problem type.

Question 4 (22 pts) For the following structure
a) draw **both chair conformations**
b) determine the **energy difference** between the two chair conformations
c) indicate the **lower energy chair**

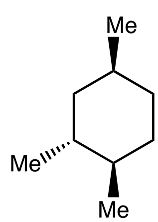


Figure A8. Conformations (10) problem type.

Example Questions from Spring 2010 Second Semester Course

Question 3 (12 pts.) Give the IUPAC name for the following compound. Be sure to use cis/trans, E/Z or R/S where appropriate.

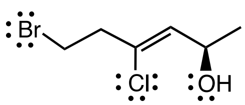
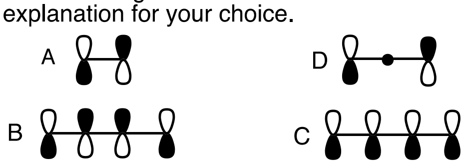


Figure A9. Nomenclature (1) problem type.

Question 2 (10 pts.) Rank the energies of an electron in each of the following π-molecular orbitals. Give a BRIEF explanation for your choice.



___ < ___ < ___ < ___

lowest energy ... highest energy

Figure A10. Bonding/Concepts (2) problem type.

Question 4 (14 pts.) Which is the stronger Bronsted acid, A or B? Give a BRIEF explanation, including the drawings of all relevant structures and ALL resonance contributors as appropriate.

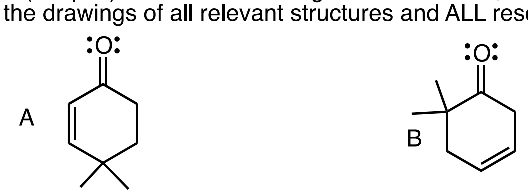
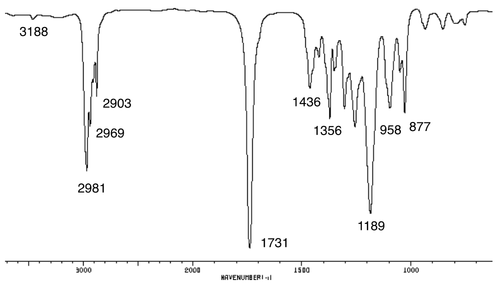


Figure A11. Acidity/Basicity (3) problem type.

Question 13 (25pts) Provided are spectra for a compound with molecular formula $\mathbf{C_6H_{12}O_2}$

a) Give the degrees of unsaturation ________________

b) On the infrared spectrum, indicate the peaks that identify the functional groups in the molecule (including C(sp^3)-H). Indicate **BOTH the functional group**, and where appropriate, **the specific BOND** in the functional group that corresponds to the peak**.**



c) draw the structure and clearly indicate which hydrogens correspond to which signals **in the proton nmr spectrum (only)**

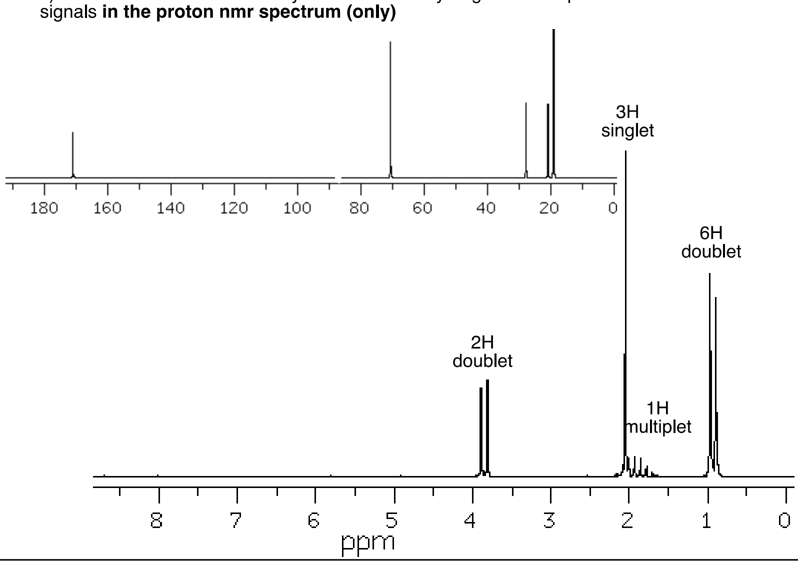


Figure A12. Spectroscopy (4) problem type.

Question 12 (20 pts.) Give a curved arrow-pushing mechanism for the following reaction

- **You can give an "abbreviated mechanism, i.e. you may use $+H^+$ and $-H^+$**
- **IT IS NOT NECESSARY TO INDICATE THE LEWIS/BRONSTED ACID/BASE AT EACH STEP**
- **<u>BUT, draw all resonance structures for the intermediates</u>**
- **Add non-bonding electrons and C–H bonds as necessary**

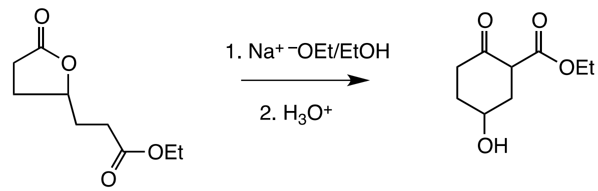
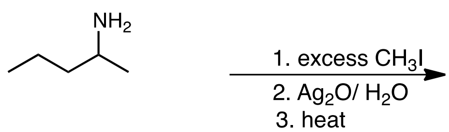
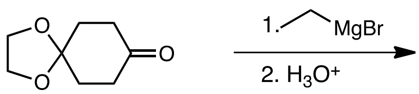
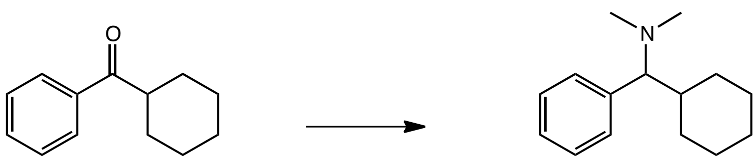


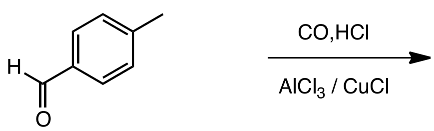
Figure A13. Mechanism (6) problem type.

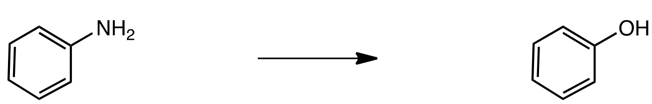
Question 8 (72 pts)
Provide the missing products, reagents/conditions or reactants, as required. **Do not forget to include absolute and relative stereochemistry as appropriate**.

a) 

b) 

c) 

d) 

e) 

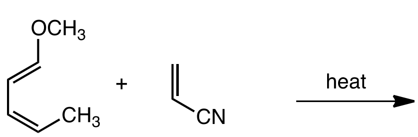
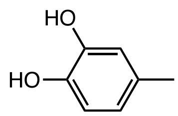
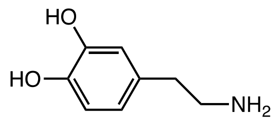
f) 

Figure A14. Reagent/Products (7) problem type**.**

Question 16 (40 pts.) In each case, synthesize the (target) molecules on the right from the starting molecules the left. this can not be done in one reaction. Give reagents and conditions and the intermediate molecules at each step. Do not show any mechanisms or transient intermediates.

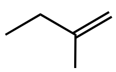
a)





dopamine

b)



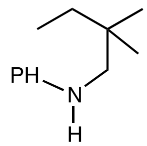
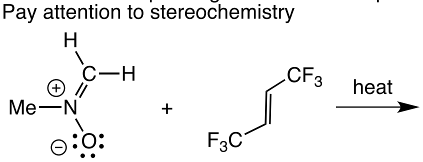


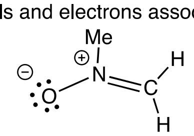
Figure A15. Synthesis (8) problem type.

Question 9 (18 pts)

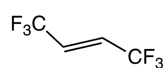
a) Give the curved arrow-pushing and the allowed product for the following cycloaddition reaction. Pay attention to stereochemistry



b) ON TOP of the structures as indicated, draw the requested F.M.O.s and give the total number of π-molecular orbitals and electrons associated with the π-system for each structure.



draw the HOMO



draw the LUMO

total # of π-M.O.s for this structure = _______

total # of electrons in the π-system for this structure = _______

total # of π-M.O.s for this structure = _______

total # of electrons in the π-system for this structure = _______

Figure A16. Pericylic Reactions (9) problem type.

APPENDIX B

CHAPTER 3: DETAILED STUDENT DEMOGRAPHIC DATA

Table B1

Demographic Data for the Student Participants, Averaged Over All Semesters Studied at SWU and NEU

	SWU	NEU
White/Caucasian	55.9	49.0
Asian	21.1	17.1
Hispanic/Latino	14.0	4.8
Black/African American	3.0	4.5
Two or More Races	3.6	4.8
Native American/American Indian	0.4	0
Race Not Identified	1.8	19.7
Male	46.8	43.9
Female	53.2	56.1

Note. The data include participants from spring 2014 to spring 2016 at SWU and fall 2014 to spring 2016 at NEU.

APPENDIX C

CHAPTER 3: DETAILED MOTIVATION AND CORRELATION TO PERFORMANCE DATA

Table C1

Motivation and Correlation with Performance Data, Averaged Over All Semesters Studied at SWU (Spring 2014 to Spring 2016: 5 Semesters) and at NEU (Fall 2014 to Spring 2016: 4 Semesters)

	SWU		NEU	
	Averaged Score [a]	Correlation Coefficient [b]	Averaged Score [c]	Correlation Coefficient [d]
Relevance	61.6	0.26	52.2	0.27
Self-Determination	70.7	0.41	68.3	0.29
Self-Efficacy	68.4	0.65	57.6	0.62
Grade Motivation	84.2	0.35	82.8	0.28

Note. The data were collected from spring 2014 to spring 2016 at SWU and fall 2014 to spring 2016 at NEU.

[a] Average of the mean scores for semesters Spring 2014 – Spring 2016 from data in Table 3 in Chapter 3. [b] Average of the correlation coefficients for semesters Spring 2014 – Spring 2016 from data in Table 5 in Chapter 3. [c] Average of the mean scores for semesters Fall 2014 – Spring 2016 from data in Table 3 in Chapter 3. [d] Average of the correlation coefficients for semesters Fall 2014 – Spring 2016 from data in Table 5 in Chapter 3.

APPENDIX D

CHAPTER 4: SCQ QUESTIONS, CHOICES, AND SCORING GUIDE

The SCQ instrument as administered as a survey consisting of the 22 questions given here, with the response options indicated, and in parentheses, the scoring for each response option. The two original questions that were removed in the factor analysis and not included in the SCQ are given at the end.

1. What is your father's education level?
    a. High school/GED equivalent OR less(0)
    b. Associate's Degree (1)
    c. Bachelor's Degree (2)
    d. Master's Degree (3)
    e. Professional Degree (M.D., J.D., etc.) (4)
    f. Ph.D. (4)

2. What is your mother's education level?
    a. High school/GED equivalent OR less(0)
    b. Associate's Degree (1)
    c. Bachelor's Degree (2)
    d. Master's Degree (3)
    e. Professional Degree (M.D., J.D., etc.) (4)
    f. Ph.D. (4)

3. From what you can remember about your childhood and adolescent years (K-12 grades), how often did your parents tell you that attending college is important?
    a. Very Often (4)
    b. Often (3)
    c. Sometimes (2)
    d. Very Few (1)
    e. Never (0)

4. From what you can remember about your childhood and adolescent years (K-12 grades), how often did your parents tell you that getting good grades is important?
    a. Very Often (4)
    b. Often (3)
    c. Sometimes (2)
    d. Very Few (1)
    e. Never (0)

5. Are the career(s) you have in mind similar to at least one of your parents' careers?
    a. Very similar (4)
    b. Similar (3)
    c. Neither similar or dissimilar (2)
    d. Somewhat dissimilar (1)
    e. Not similar at all.(0)

6. Think of your friends who are in college with you right now. Are their majors similar to yours?
    a. All of them have a similar major to mine. (4)
    b. Most have a similar major to mine. (3)
    c. Some have similar majors to mine while the others do not. (2)
    d. Very few of them are similar to my major (1)
    e. I have no friends who share my major (0)

7. Do you have friends in this Organic Chemistry class who you associate with often?
    a. Yes, I have a lot. (4)
    b. Yes, I have many. (3)
    c. Yes, I have some. (2)
    d. Yes, I have a few. (1)
    e. No, I do not. (0)

8. Do you have friends in this Organic Chemistry class who you study with often?
    a. Yes, I have a lot. (4)
    b. Yes, I have many. (3)
    c. Yes, I have some. (2)
    d. Yes, I have a few. (1)
    e. No, I do not. (0)

9. Are your friends in college interested in similar career(s) as you?
    a. Very similar (4)
    b. Similar (3)
    c. Neither similar or dissimilar (2)
    d. Somewhat dissimilar (1)
    e. Not similar at all. (0)

10. My family often ate dinner together as a child.
    a. Strongly Agree (4)
    b. Agree (3)
    c. Neither Agree or Disagree (2)
    d. Disagree (1)
    e. Strongly Disagree (0)

11. School has always been very important to my family and me.
    a. Strongly Agree (4)
    b. Agree (3)
    c. Neither Agree or Disagree (2)
    d. Disagree (1)
    e. Strongly Disagree (0)

12. From what you can remember about your childhood and adolescent years (K-12 grades), did you have a family member who could help you when you needed help with homework?
    a. Yes, all the time. (4)
    b. Yes, most of the time. (3)
    c. Yes, sometimes. (2)
    d. Yes, on a few occasions. (1)
    e. No, not at all. (0)

13. From what you can remember about your childhood and adolescent years (K-12 grades), did you feel supported by your family while growing up?
    a. Very supported (4)
    b. Supported (3)
    c. Neither supported or unsupported (2)
    d. Somewhat unsupported (1)
    e. Not supported at all (0)

14. Do you feel that you are being supported by your family while you are in college?
    a. Very supported (4)
    b. Supported (3)
    c. Neither supported or unsupported (2)
    d. Somewhat unsupported (1)
    e. Not supported at all (0)

15. I was taken to concerts as a child.
    a. Strongly Agree (4)
    b. Agree (3)
    c. Neither Agree or Disagree (2)
    d. Disagree (1)
    e. Strongly Disagree (0)

16. I travelled often as a child.
    a. Strongly Agree (4)
    b. Agree (3)
    c. Neither Agree or Disagree (2)
    d. Disagree (1)
    e. Strongly Disagree (0)

17. I played a musical instrument as a child.
    a. Strongly Agree (4)
    b. Agree (3)
    c. Neither Agree or Disagree (2)
    d. Disagree (1)
    e. Strongly Disagree (0)

18. I went to museums as a child.
    a. Strongly Agree (4)
    b. Agree (3)
    c. Neither Agree or Disagree (2)
    d. Disagree (1)
    e. Strongly Disagree (0)

19. How many books did you own as a child?
    a. None or very few (0-10 books) (0)
    b. About one shelf (11-25 books) (1)
    c. About one bookcase (26-100 books) (2)
    d. About two bookcases (101-200 books) (3)
    e. Three or more bookcases (201 books or more) (4)

20. Do you have potential career(s) in mind?
    a. Yes, I have one career in mind. (3)
    b. Yes, I have a few careers (2-3) in mind. (2)
    c. Yes, I have many careers (4 or more) in mind. (1)
    d. No, I don't have any careers in mind right now. (0)

21. How strongly to you feel about your career(s) in mind?
    a. Very strongly (4)
    b. Strongly (3)
    c. Neutral (2)
    d. Somewhat strongly (1)
    e. Not sure (0)

22. When you think about your career(s) in mind, how satisfied do you feel about your choice(s)?
    a. Very satisfied (4)
    b. Satisfied (3)
    c. Neither satisfied or dissatisfied (2)
    d. Somewhat unsatisfied (1)
    e. Not satisfied at all (0)

The following two questions were included as part of the exploratory and confirmatory factor analysis but were removed and were not included in SCQ. Their reponse options and scoring are indicated as above.

23. Think of your friends from your childhood and adolescent years (K-12 grades). Did your friends end up going to college after graduating from high school?
    a. Almost everyone (if not all) went off to college. (4)
    b. Most of my friends went off to college. (3)
    c. Some went off to college and the others did not. (2)
    d. Very few went off to college and the majority did not. (1)
    e. No one went off to college except for me. (0)

24. Think of your friends from your childhood and adolescent years (K-12 grades). How often do you communicate with them nowadays?
    a. Very frequently (0)
    b. Often (1)
    c. Sometimes (2)
    d. A few times (3)
    e. Not at all (4)

APPENDIX E

CHAPTER 4: SCIENCE CAPITAL QUESTIONNAIRE ANOVA RESULTS FOR SWU

Table E1

ANOVA Results for SWU, Showing Comparisons between High Performing (A), Intermediate Performing (BC) and Lower Performing (DEW) Student Groups by Capital Factor, Semester and Institution (Spring 2014 to Spring 2016)

	Spring 2014 (n=261)			Fall 2014 (n=453)			Spring 2015 (n=358)		
	F	η_p^2	***p***	***F***	η_p^2	***p***	***F***	η_p^2	***p***
Factor 1:	12.74	.09	.00	9.43	.04	.00	6.92	.04	.00
College		***p***	***d***		***p***	***d***		***p***	***d***
Connections	A:BC	.02	.38	A:BC	.04	.27	A:BC	.06	--
	BC:DEW	.01	.51	BC:DEW	.05	.29	BC:DEW	.17	--
	A:DEW	.00	.96	A:DEW	.00	.56	A:DEW	.00	.36
	F	η_p^2	***p***	***F***	η_p^2	***p***	***F***	η_p^2	***p***
Factor 2:	1.55	.01	.21	11.94	.05	.00	2.48	.01	.09
Traditional		***p***	***d***		***p***	***d***		***p***	***d***
Cultural	A:BC	--	--	A:BC	.00	.35	A:BC	--	--
Capital	BC:DEW	--	--	BC:DEW	.07	--	BC:DEW	--	--
	A:DEW	--	--	A:DEW	.00	.61	A:DEW	--	--
	F	η_p^2	***p***	***F***	η_p^2	***p***	***F***	η_p^2	***p***
Factor 3:	4.13	.03	.02	7.46	.03	.00	3.52	.02	.03
Family		***p***	***d***		***p***	***d***		***p***	***d***
Resources	A:BC	.10	--	A:BC	.02	.28	A:BC	.10	--
	BC:DEW	.47	--	BC:DEW	.22	--	BC:DEW	.75	--
	A:DEW	.04	.50	A:DEW	.00	.48	A:DEW	.04	.36
	F	η_p^2	***p***	***F***	η_p^2	***p***	***F***	η_p^2	***p***
Factor 4:	.72	.01	.49	.30	.00	.74	10.02	.05	.00
Career		***p***	***d***		***p***	***d***		***p***	***d***
Plans	A:BC	--	--	A:BC	--	--	A:BC	.95	--
	BC:DEW	--	--	BC:DEW	--	--	BC:DEW	.00	.53
	A:DEW	--	--	A:DEW	--	--	A:DEW	.00	.57
	F	η_p^2	***p***	***F***	η_p^2	***p***	***F***	η_p^2	***p***
Factor 5:	4.37	.03	.01	2.63	.01	.07	.15	.00	.86
Academic		***p***	***d***		***p***	***d***		***p***	***d***
Expectations	A:BC	.76	--	A:BC	--	--	A:BC	--	--
	BC:DEW	.06	--	BC:DEW	--	--	BC:DEW	--	--
	A:DEW	.16	--	A:DEW	--	--	A:DEW	--	--

Note. When at least one of these comparisons was statistically valid, the comparisons are enclosed in a box for easy identification. The effect sizes for the comparisons are given by Cohen's *d*. The remaining results are shown on the next page.

	Fall 2015 (n=448)			Spring 2016 (n=377)	
F	η_p^2	***p***	***F***	η_p^2	***p***
5.81	.03	.00	13.86	.07	.00
	p	***d***		***p***	***d***
A:BC	.44	--	A:BC	.33	--
BC:DEW	.02	.32	BC:DEW	.00	.69
A:DEW	.01	.48	A:DEW	.00	.50
F	η_p^2	***p***	***F***	η_p^2	***p***
7.25	.03	.00	6.22	.03	.00
	p	***d***		***p***	***d***
A:BC	.00	.40	A:BC	.10	--
BC:DEW	.44	--	BC:DEW	.12	--
A:DEW	.00	.55	A:DEW	.00	.51
F	η_p^2	***p***	***F***	η_p^2	***p***
3.64	.02	.03	1.48	.01	.23
	p	***d***		***p***	***d***
A:BC	.34	--	A:BC	--	--
BC:DEW	.19	--	BC:DEW	--	--
A:DEW	.03	.37	A:DEW	--	--
F	η_p^2	***p***	***F***	η_p^2	***p***
.81	.00	.44	.98	.01	.38
	p	***d***		***p***	***d***
A:BC	--	--	A:BC	--	--
BC:DEW	--	--	BC:DEW	--	--
A:DEW	--	--	A:DEW	--	--
F	η_p^2	***P***	***F***	η_p^2	***p***
.92	.00	.40	.91	.01	.40
	p	***d***		***p***	***d***
A:BC	--	--	A:BC	--	--
BC:DEW	--	--	BC:DEW	--	--
A:DEW	--	--	A:DEW	--	--

APPENDIX F

CHAPTER 4: SCIENCE CAPITAL QUESTIONNAIRE ANOVA RESULTS FOR NEU

Table F1

ANOVA Results for NEU, Showing Comparisons between High Performing (A), Intermediate Performing (BC) and Lower Performing (DEW) Student Groups by Capital Factor, Semester and Institution (Fall 2014-Spring 2016)

	Fall 2014 (*n*=329)			Spring 2015 (*n*=233)			Fall 2015 (*n*=246)		
	F	η_p^2	***p***	***F***	η_p^2	***p***	***F***	η_p^2	***p***
Factor 1:	7.63	.05	.00	.08	.00	.93	6.73	.05	.00
College		***p***	***d***		***p***	***d***		***p***	***d***
Connections	A:BC	.16	--	A:BC	--	--	A:BC	.24	--
	BC:DEW	.02	.41	BC:DEW	--	--	BC:DEW	.05	--
	A:DEW	.00	.71	A:DEW	--	--	A:DEW	.00	.65
	F	η_p^2	***p***	***F***	η_p^2	***p***	***F***	η_p^2	***p***
Factor 2:	.12	.00	.89	.00	.00	.99	5.71	.05	.00
Traditional		***p***	***d***		***p***	***d***		***p***	***d***
Cultural	A:BC	--	--	A:BC	--	--	A:BC	.05	.35
Capital	BC:DEW	--	--	BC:DEW	--	--	BC:DEW	.31	--
	A:DEW	--	--	A:DEW	--	--	A:DEW	.00	.61
	F	η_p^2	***p***	***F***	η_p^2	***p***	***F***	η_p^2	***p***
Factor 3:	.99	.01	.37	1.20	.01	.30	2.69	.02	.07
Family		***p***	***d***		***p***	***d***		***p***	***d***
Resources	A:BC	--	--	A:BC	--	--	A:BC	--	--
	BC:DEW	--	--	BC:DEW	--	--	BC:DEW	--	--
	A:DEW	--	--	A:DEW	--	--	A:DEW	--	--
	F	η_p^2	***p***	***F***	η_p^2	***p***	***F***	η_p^2	***p***
Factor 4:	2.55	.02	.08	.30	.00	.74	.81	.02	.60
Career		***p***	***d***		***p***	***d***		***p***	***d***
Plans	A:BC	--	--	A:BC	--	--	A:BC	--	--
	BC:DEW	--	--	BC:DEW	--	--	BC:DEW	--	--
	A:DEW	--	--	A:DEW	--	--	A:DEW	--	--
	F	η_p^2	***p***	***F***	η_p^2	***p***	***F***	η_p^2	***P***
Factor 5:	5.60	.03	.00	1.48	.01	.23	.29	.00	.75
Academic		***p***	***d***		***p***	***d***		***p***	***d***
Expectations	A:BC	.01	.39	A:BC	--	--	A:BC	--	--
	BC:DEW	.99	--	BC:DEW	--	--	BC:DEW	--	--
	A:DEW	.05	--	A:DEW	--	--	A:DEW	--	--

Note. When at least one of these comparisons was statistically valid, the comparisons are enclosed in a box for easy identification. The effect sizes for the comparisons are given by Cohen's *d*. The remaining results are shown on the next page.

Spring 2016 (*n*=201)		
F	η_p^2	***p***
2.48	.02	.09
	p	***d***
A:BC	--	--
BC:DEW	--	--
A:DEW	--	--
F	η_p^2	***p***
6.02	.06	.00
	p	***d***
A:BC	.00	.60
BC:DEW	.72	--
A:DEW	.45	--
F	η_p^2	***P***
3.37	.03	.04
	p	***d***
A:BC	.01	.45
BC:DEW	.97	--
A:DEW	.44	--
F	η_p^2	***p***
.83	.01	.44
	p	***d***
A:BC	--	--
BC:DEW	--	--
A:DEW	--	--
F	η_p^2	***p***
.50	.01	.61
	p	***d***
A:BC	--	--
BC:DEW	--	--
A:DEW	--	--

APPENDIX G

CHAPTER 5: LINEAR REGRESSION MODEL FOR SWU

Table G1

Multiple Linear Regression Models with Significant Organic Chemistry Motivation Survey (OCMS) Predictors for SWU (Fall 2013-Spring 2016)

	Fall 2013 (*n*=351)				Spring 2014 (*n*=228)				Fall 2014 (*n*=401)			
Model	Factor	ΔR^2	β	sig.	Factor	ΔR^2	β	sig.	Factor	ΔR^2	β	sig.
1	Self-Determination	.082	.216	<.001	Self-Efficacy	.192	.438	<.001	Self-Efficacy	.060	.232	<.001
2	Self-Efficacy	.024	.170	.002					Relevance	.011	-.152	.005
3									Self-Determination	.013	.136	.018

Note. The *sig*. values within the table denote the significance of the β. The linear regression models were all significant <.001.

Spring 2015 (n=306)				Fall 2015 (n=387)				Spring 2016 (n=332)			
Factor	ΔR^2	β	sig.	Factor	ΔR^2	β	sig.	Factor	ΔR^2	β	sig.
Self-Efficacy	.185	.430	<.001	Self-Efficacy	.076	.275	<.001	Self-Efficacy	.232	.409	<.001
								Self-Determination	.015	.143	.010

APPENDIX H

CHAPTER 5: LINEAR REGRESSION MODEL FOR NEU

Table H1

Multiple Linear Regression Models with Significant Organic Chemistry Motivation Survey (OCMS) Predictors for NEU (Fall 2013 & Fall 2014-Spring 2016)

	Fall 2013 (n=120)				Fall 2014 (n=302)				Spring 2015 (n=212)			
Model	Factor	ΔR^2	β	sig.	Factor	ΔR^2	β	sig.	Factor	ΔR^2	β	sig.
1	Self-Determination	.092	.303	<.001	Self-Efficacy	.063	.251	<.001	Self-Efficacy	.216	.430	<.001
2									Self-Determination	.016	.131	.039
3												

Note. The *sig*. values within the table denote the significance of the β. The linear regression models were all significant <.001.

Fall 2015 (n=232)				Spring 2016 (n=188)			
Factor	ΔR^2	β	sig.	Factor	ΔR^2	β	sig.
Self-Efficacy	.081	.236	<.001	Self-Efficacy	.226	.316	<.001
Grade Motivation	.023	.159	.016	Grade Motivation	.060	.229	.001
				Relevance	.021	.168	.019

APPENDIX I

PERMISSION FROM CO-AUTHORS FOR CHAPTERS 2 & 3

Chapters 2 and 3 of this document have been previously published with co-authors in *Chemical Education Research and Practice*. The co-authors (Ian Gould, Deena Gould, Nathan Barrows, Nicholas Hammond, Robert Atkinson, Hagit Ben-Daat, & Mary Zhu) are aware and have granted permission to include these two journals in this culminating document.

APPENDIX J

CHAPTER 2: IRB APPROVAL LETTER ON PROBLEM TYPE STUDY AT SWU

EXEMPTION GRANTED

Ian Gould
Chemistry and Biochemistry
480/965-7278
igould@asu.edu

Dear Ian Gould:

On 10/25/2013 the ASU IRB reviewed the following protocol:

Type of Review:	Initial Study
Title:	Statistical Analysis of Student Performance across Various Types of Organic Chemistry Questions
Investigator:	Ian Gould
IRB ID:	STUDY00000163
Funding:	None
Grant Title:	None
Grant ID:	None
Documents Reviewed:	None

The IRB determined that the protocol is considered exempt pursuant to Federal Regulations 45CFR46 (4) Data, documents, or specimens on 10/25/2013.

In conducting this protocol you are required to follow the requirements listed in the INVESTIGATOR MANUAL (HRP-103).

Sincerely,

IRB Administrator

Note. Ian Gould is the author's research advisor and is the chair of the author's defense committee. All IRB approvals were submitted by the research advisor, and the author is listed as the co-investigator under the STUDY # 00000163.

APPENDIX K

CHAPTERS 3, 4, & 5: IRB APPROVAL LETTER FOR MOTIVATION (OCMS), SCIENCE CAPITAL (SCQ), AND GENDER STUDY FOR SWU

APPROVAL: EXPEDITED REVIEW

Ian Gould
Molecular Sciences, School of
480/965-7278
igould@asu.edu

Dear Ian Gould:

On 9/22/2015 the ASU IRB reviewed the following protocol:

Type of Review:	Initial Study
Title:	Motivation and Cultural Capital of Organic Chemistry Students (Modification Fall 2015)
Investigator:	Ian Gould
IRB ID:	STUDY00003040
Category of review:	(7)(b) Social science methods, (7)(a) Behavioral research
Funding:	None
Grant Title:	None
Grant ID:	None
Documents Reviewed:	• motivationconsentF2015.pdf, Category: Consent Form; • surveyF2015.pdf, Category: Measures (Survey questions/Interview questions /interview guides/focus group questions); • RecruitscriptF2015.pdf, Category: Recruitment Materials; • motivationmodificationIRBF2015.doc, Category: IRB Protocol;

The IRB approved the protocol from 9/22/2015 to 9/21/2016 inclusive. Three weeks before 9/21/2016 you are to submit a completed Continuing Review application and required attachments to request continuing approval or closure.

If continuing review approval is not granted before the expiration date of 9/21/2016 approval of this protocol expires on that date. When consent is appropriate, you must use final, watermarked versions available under the "Documents" tab in ERA-IRB.

In conducting this protocol you are required to follow the requirements listed in the INVESTIGATOR MANUAL (HRP-103).

Sincerely,

IRB Administrator

Note. Ian Gould is the author's research advisor and is the chair of the author's defense committee. All IRB approvals were submitted by the research advisor, and the author is listed as the co-investigator under the STUDY # 00003040. This is the most recent approval letter for the extension of the studies included in chapters 3, 4, and 5.

APPENDIX L

CHAPTER 5: IRB APPROVAL LETTER FOR GENDER DATA ON COURSE TAUGHT BY MALE INSTRUCTOR AT SWU

EXEMPTION GRANTED

Ian Gould
Chemistry and Biochemistry
480/965-7278
igould@asu.edu

Dear Ian Gould:

On 6/10/2014 the ASU IRB reviewed the following protocol:

Type of Review:	Initial Study
Title:	Exploring the Effects of Gender and Race/Ethnicity Differences on Student Performance in Organic Chemistry
Investigator:	Ian Gould
IRB ID:	STUDY00001188
Funding:	None
Grant Title:	None
Grant ID:	None
Documents Reviewed:	• Gender Race Ethnicity IRB2.doc, Category: IRB Protocol;

The IRB determined that the protocol is considered exempt pursuant to Federal Regulations 45CFR46 (1) Educational settings on 6/10/2014.

In conducting this protocol you are required to follow the requirements listed in the INVESTIGATOR MANUAL (HRP-103).

Sincerely,

IRB Administrator

Note. Ian Gould is the author's research advisor and is the chair of the author's defense committee. All IRB approvals were submitted by the research advisor, and the author is listed as the co-investigator under the STUDY # 00001188.

APPENDIX M

CHAPTER 5: IRB APPROVAL LETTER FOR GENDER DATA ON COURSE TAUGHT BY FEMALE INSTRUCTOR AT SWU

ASU Knowledge Enterprise Development

EXEMPTION GRANTED

Ian Gould
Molecular Sciences, School of
480/965-7278
igould@asu.edu

Dear Ian Gould:

On 9/20/2016 the ASU IRB reviewed the following protocol:

Type of Review:	Initial Study
Title:	Gender Performance in Organic Chemistry in Pillai Classes
Investigator:	Ian Gould
IRB ID:	STUDY00004877
Funding:	None
Grant Title:	None
Grant ID:	None
Documents Reviewed:	• SmithaIRB.doc, Category: IRB Protocol;

The IRB determined that the protocol is considered exempt pursuant to Federal Regulations 45CFR46 (1) Educational settings on 9/20/2016.

In conducting this protocol you are required to follow the requirements listed in the INVESTIGATOR MANUAL (HRP-103).

Sincerely,

IRB Administrator

Note. Ian Gould is the author's research advisor and is the chair of the author's defense committee. All IRB approvals were submitted by the research advisor, and the author is listed as the co-investigator under the STUDY # 00004877.

APPENDIX N

CHAPTERS 3, 4, & 5: IRB APPROVAL LETTER FOR MOTIVATION (OCMS), SCIENCE CAPITAL (SCQ), AND GENDER STUDY FOR NEU

OFFICE FOR HUMAN SUBJECT PROTECTION

Research Subjects Review Board

UNIVERSITY of ROCHESTER

Letter of Initial Approval

RSRB: RSRB00059063 **Principal Investigator:** Nicholas Hammond

Study Title: Correlation of Motivation, Cultural Capital, and Gender with Performance in Organic Chemistry

Initial Approval: 9/16/2015

Approval Expires : 9/15/2016

Length of Review: 1 year

Level of Risk:

- Minimal Risk - Adults

Review Level: Expedited

Expedited Category(ies):

- 5 - materials that have been/will be collected solely for non-research purposes
- 7 - individual or group characteristics or behavior

Regulatory Findings Regarding Consent and HIPAA:

- Waiver of Documentation of Consent granted
- HIPAA: Does not apply to this activity

List of Materials Approved by the RSRB: Protocol dated: 9/3/2015, Information letter dated: 9/3/2015, Class Script

Additional Remarks: Seperate IRB approval from Arizona State University pending (Ian Gould)

This study was reviewed and approved under the OHSP and UR policies, and in accordance with Federal regulation 45 CFR 46 under the University's Federalwide Assurance (FWA00009386).

This approval is contingent upon the research being conducted in compliance with the approved study protocol including all requirements and/or determinations of the RSRB. Consent must be obtained and documented in the manner approved by the RSRB (unless a waiver of consent is specified above). Only the most currently approved version of consent forms and recruitment materials bearing an RSRB approved watermark may be used when obtaining consent and recruiting subjects. Consent forms/recruitment letters must be printed on department letterhead.

As the Principal Investigator, you are responsible for ensuring compliance with Policy 901 Investigator Responsibilities. Click here for the Summary of Responsibilities for Investigators Conducting Non-FDA Regulated Research. Also, any unanticipated problems involving risks to subjects or others (including unexpected deaths, hospitalizations or serious injuries, breach of confidentiality, loss of privacy) must be reported according to Policy 801 Reporting Research Events.

All study documentation, including RSRB approved materials, should be maintained as required by applicable regulatory requirement(s). This includes all pages of the signed consent form for at least three years after the research is completed (six years if protected health information was collected as part of the research), or for a longer term if required by FDA regulations or other contractual agreements.

Steven Lamberti, RSRB Chair 9/16/2015

Saunders Research Building · 265 Crittenden Blvd, Suite 1.250 · Box CU420628 · Rochester, NY 14642-0628
585. 273.4127 · 585.273.1174 *fax*

Note. Nicholas Hammond is author's research collaborator at NEU. Separate IRB had to be submitted at University of Rochester for the studies included in chapters 3, 4, & 5. This is the most recent modification approval letter from the IRB.