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Understanding the Relationship Between Organic Chemistry Misconceptions and Students' Chemistry Self-efficacy in Higher Education Organic Chemistry Courses

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DEDICATION

I dedicate this dissertation to my husband and son, Robert and Franklin Dudley. Through their constant support and love, I was reminded to always take chances, make mistakes, and get messy.

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ABSTRACT

Understanding the relationship between organic chemistry misconceptions and students' chemistry self-efficacy in higher education organic chemistry courses

by Lauren A. Dudley

Organic chemistry is accepted as a crucial part of science higher education funneling students into many career opportunities such as pharmaceuticals, biotechnology, and medical industries. Students attempting organic chemistry courses in higher education are among a plethora of majors including biology, chemistry, health science, and engineering. However, organic chemistry as a course has stayed fairly stagnant for the past 50 years. Students in this course typically resort to rote-memorization and often regard the course itself as insurmountable. To answer the decreasing retention rates seen across the United States, the research revolving around organic chemistry knowledge and teaching methodologies has increased in the past twenty years. Furthermore, self-efficacy in chemistry has been established as a pivotal aspect for students to be successful in chemistry; yet little effort has been made to understand if a relationship exists between foundational knowledge in organic chemistry and a student's chemistry self-efficacy. In an effort to help fill this gap in the literature, this dissertation investigates the relationship between chemistry-oriented misconceptions held by university students and their organic chemistry self-efficacy during the first semester organic chemistry course. Specifically, 97 university students were surveyed using validated instruments regarding their foundational knowledge of chemistry based on NGSS standards, their chemistry self-efficacy, and demographic information. The results indicated that at the beginning of the semester, the more chemistry-oriented misconceptions students held, their chemistry self-efficacy was significantly lower. The students who had attempted organic chemistry at least once

before were also highly correlated with more misconceptions. At the end of the semester, the number of misconceptions were again negatively correlated with student self-efficacy. These findings may have implications for organic chemistry instructors to set more foundational curriculum at the beginning of the semester to work through misconceptions as they could pose a roadblock to self-efficacy enhancement and ultimate success in the course.

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Chapter 1: Introduction

In this Chapter, I describe the problem of the having misconceptions in organic chemistry and how they relate to student self-efficacy. I outline the purpose of this study and discuss the importance of this work. After explaining the research questions and defining key terms, this Chapter concludes with a review of the limitations, delimitations, and conceptual assumptions of this dissertation.

Organic chemistry is a prominent element within the science, technology, engineering, and mathematics field (STEM) according to the scientific community (*American Chemical Society: Organic Chemistry*, 2022). However, organic chemistry as a course has remained relatively unchanged for the past 50 years (Cooper et al., 2019). There are widespread perceptions among students that organic chemistry is difficult, irrelevant, and ineffective for their ultimate goals (Cooper & Klymkowsky, 2013; Healy, 2019). Most students taking organic chemistry are in their second year of college, attaining a biology, chemistry, biochemistry, or health science degree. The variety of student goals leads to an issue for educators to make the subject content specific for those goals. Organic chemistry as a curriculum was set in 1959 with the publication of *Organic Chemistry* by Morrison and Boyd (Cooper et al., 2019). Although earlier texts presented descriptions of reactivity and synthesis, Morrison and Boyd integrated curved arrow mechanisms as the model for how and why reactions occur (Cooper et al., 2019). Since this introduction more than 50 years ago, little has changed in terms of what is incorporated into the textbook and how it is organized. The vastness of content currently provided in organic chemistry textbooks lead most students to an insurmountable number of stumbling blocks including rote memorization (King et al., 2019). Yet, it is accepted by the scientific community that organic chemistry, with its focus on reactivity of carbon-based compounds, is an integral part of the science field (Crandell et al., 2019; King et al., 2019).

Although the significance of organic chemistry is accepted by the scientific community, there is a widespread perception of students that organic chemistry is challenging and irrelevant to most student goals (Crandell et al., 2019; King et al., 2019; Zoller, 1990). Students not only enter organic chemistry with elevated anxiety, but they also have difficulty connecting prior knowledge to organic chemistry topics due to the abstract, visual nature of organic chemistry specifically in curved arrow mechanisms (Crandell et al., 2019, 2020; Healy, 2019). The connections between high school chemistry and first year, general chemistry in higher education may be the key to connecting the transition and ultimate success in organic chemistry (Austin et al., 2018; Crandell et al., 2019; Kirbulut, 2014). Numerous studies have noted that misconceptions or lack of understanding in foundational topics presented in previous chemistry courses pose a significant roadblock to student success in organic chemistry (Fischer et al., 2019; Lindsay et al., 2017; Stone et al., 2018).

Student's self-efficacy has been correlated with improved grade outcomes (Gibbons & Raker, 2019; Hong et al., 2021; Quinlan et al., 2021). As noted in the current research, persistence and grade outcomes are correlated to the self-efficacy of students in STEM. One study expressed a wide relationship across all STEM related subjects of self-efficacy and achievement (Gibbons & Raker, 2019). Self-efficacy in this study predicted a student's grade outcome more than any other measures (e.g., previous exams or format of lecture). The impact of self-efficacy on grade outcomes is an established area of study. However, the conceptual knowledge that influences student self-efficacy is under researched with only a few known studies occurring in the past ten years (Kallia & Sentance, 2019; Kustos & Zelkowski, 2013; Sen

& Yilmaz, 2012). From these studies there seems to be a relationship between misconceptions and self-efficacy in STEM fields. The relationship of misconceptions and self-efficacy is of particular interest relative to student success in organic chemistry due to the conflicting perceptions between the scientific community and students in organic chemistry.

The Problem and Its Explication

The scientific community accepts organic chemistry curriculum as beneficial and important as a precursor for many careers in science such as medical fields, biochemical fields, and the pharmaceutical industry (Cooper et al., 2019). Despite the fact that the scientific community values organic chemistry for most STEM students, students overwhelmingly despise it and identify it as the gateway course to their future goals (Villafañe et al., 2016). STEM in higher education has traditionally been given a major focus in the United States in the past three decades (U.S. Department of Education, 2020). From innovations to pharmaceuticals, chemistry is a foundation for the interconnected disciplines that bring knowledge, understand, and evaluate data, and solve problems. Chemistry purports to address societal needs and solve the global problems that we face (Hwang & Taylor, 2016).

Unfortunately, many students struggle in chemistry with a majority being women and underrepresented minorities (URM) – both educational and occupational settings (Hwang & Taylor, 2016). Students from these groups perform worse than their peers in chemistry courses, and therefore are less prepared in higher education which is a major reason why they are not equally represented (Hwang & Taylor, 2016). According to a report from the American College Testing (ACT), students overall report difficulties in chemistry and fail to meet the requirements by college (2015). This study focused on identifying the major misconceptions in student knowledge that could prevent success in organic chemistry.

Areas of Concern

Between 1975 and 2015, the percentage of high school graduates making an immediate transition to college increased from 51% to 69% (National Science Board, 2018). This increase has also been seen in chemistry courses throughout the past 15 years (Merritt, 2005). It was reported by Merritt (2005) that over 61,200 students in the United States took organic chemistry during their undergraduate career in 2004, an increase of 11.4% from the previous year. This increase was seen consistently throughout the three-year survey that occurred during 2002 to 2004. Merritt suggested this increase will continue as students enrolling in science related graduate and undergraduate programs increases. Merritt, in this 2005 report, noted that there is usually a 10-fold larger enrollment in organic chemistry courses relative to the number of majors. This indicated to Merritt that there was a relevant interest in biology and pre-medical studies as well as traditional chemistry majors.

However, this influx of student population does not follow the degrees awarded. The United States has seen a decline in the number of STEM undergraduate degrees given since 1980 (Love et al., 2014). This suggests that although there is an increase in students taking chemistry, ultimately, there is a decline in the successful completion of the degree itself. It has been suggested that 40% of undergraduates who begin their studies as a STEM major ultimately do not succeed in its completion (Schreffler et al., 2019). Previous studies have recognized that negative experiences in chemistry are the leading cause of students changing their career paths (Barr et al., 2010; Lockie & van Lanen, 2008; Villafañe et al., 2014).

The daunting reputation and abstract nature of chemistry courses facilitate the idea that they are one of the most challenging courses for students to complete (Cooper et al., 2013; Grove et al., 2008; Horowitz et al., 2013). URM and women are at higher risk of leaving science and medical careers during their undergraduate studies (Barr et al., 2010; Lynch & Trujillo, 2011). Challenges encountered in chemistry may be an extension of the overemphasis on rote memorization, misconceptions in foundational knowledge from high school, and impacted lecture courses. These factors may ultimately hinder the cultivation of self-efficacy in students (Elbulok-Charcape et al., 2019).

Purpose of the Study

The first goal of this study is to review the research that has been conducted which examines organic chemistry misconceptions and its relationship to student organic chemistry self-efficacy. There is a paucity of research in this area involving the relationship between topics taught in prior chemistry courses and the influence on organic chemistry self-efficacy. However, it will become evident that little research has been conducted involving the relationship between topics taught in prior chemistry courses and the influence on organic chemistry self-efficacy. This study will (a) examine if there is a relationship between the most prevalent chemistry misconceptions and student organic chemistry self-efficacy, (b) explore the nature of those relationships throughout the first semester of an organic chemistry course, and (c) identify the most prevalent misconceptions held by students in organic chemistry courses.

Importance of the Study

This study is important not only because organic chemistry courses are widely accepted as being a critical component for so many undergraduate majors, but also because student success in organic chemistry is particularly lacking (Fischer et al., 2019). As such, it is imperative to understand how previous knowledge is constructed and organized for students entering organic chemistry to fully understand how misconceptions could influence their future success.

Definitions

The definitions for key terms central to this dissertation are as follows:

Curriculum – A curriculum is defined by the Merriam-Webster dictionary website (2022) as "a set of courses constituting an area of specialization." For the purposes of this study, the specialization is organic chemistry.

Misconceptions – Although the Merriam-Webster dictionary website (2022) stated a misconception is "a wrong or inaccurate idea or conception," I will expand this definition to not only include incorrect knowledge, but also include that misconceptions may be a belief system of propositions logically linked together (Fischer et al., 2019). The belief system obstructs the student's ability to gain deeper understandings of the scientific topic.

Organic chemistry – According to the American Chemical Society website (2022), organic chemistry "is the study of the structure, properties, composition, reactions, and preparation of carbon-containing compounds. Most organic compounds contain carbon and hydrogen, but they may also include any number of other elements (e.g., nitrogen, oxygen, halogens, phosphorus, silicon, sulfur). Originally limited to the study of compounds produced by living organisms, organic chemistry has been broadened to include human-made substances (e.g., plastics)." For this study, the topics will include the first semester organic chemistry topics.

Science – The National Academy of Sciences (2008) stated that science is "the use of evidence to construct testable explanations and predictions of natural phenomena, as well as the knowledge generated through this process."

Scientific community – The definition of scientific community found in Nature (2022) is a "community and society [that] encompasses research and material which directly concerns, or is relevant to, members of the community of scientists in particular or society at large."

Self-efficacy - Psychologist Albert Bandura (1977) has defined self-efficacy as people's beliefs in their capabilities to exercise control over their own functioning and over events that affect their lives. One's sense of self-efficacy can provide the foundation for motivation, well-being, and personal accomplishment. In this study, self-efficacy will be directly related with the student's ability to successfully answer a question or complete an assignment in organic chemistry.

University – According to the Merriam-Webster website (2022), a university is "an institution of higher learning providing facilities for teaching and research and authorized to grant academic degrees. Specifically, it is one made up of an undergraduate division which confers bachelor's degrees and a graduate division which comprises a graduate school and professional schools each of which may confer master's degrees and doctorates." For this study, the undergraduate division is of interest.

Research Questions

This dissertation explores one primary question and three secondary questions.

Primary Question:

1. To what extent does a relationship exist between chemistry-oriented misconceptions held by university students and their organic chemistry self-efficacy?

Secondary Questions:

1. What are the most prevalent chemistry-oriented misconceptions held by undergraduate students beginning a first-semester organic chemistry course?
2. Is there a relationship between the strength of the most prevalent chemistry-oriented misconceptions and the level of self-efficacy at the beginning of the course?
3. Is there a relationship between the strength of the most prevalent chemistry-oriented misconceptions and the level of self-efficacy at the end of the course?

Delimitations

I have identified potential threats to the internal and external validity of this study. First, this study is limited by the population of the participants. Because participation was voluntary, there may be some self-selection that takes place and students who have extremely low self-efficacy in science or organic chemistry may chose not to participate. In addition, I collected data from four-year universities in Southern California. The population may not be representative of university students as a whole in California or the United States of America.

Second, the instrument used in this study was a combination of different parts of existing instruments. I utilized the Misconceptions Oriented Standards-based Assessment Resources for Teachers of High School Physical Sciences (MOSART HS PS). This instrument was developed out of the need for rigorous assessment tools probing for teacher and student understandings of high school level physical science concepts in both chemistry and physics, which is well validated (Sadler et al., 2013). I also included the Chemistry Attitudes and Experiences Questionnaire (CAEQ) as well. This instrument was used to identify college chemistry student attitudes, self-efficacy, and learning experiences during their first year which is also well validated (Dalgety et al., 2003). Because I employed these instruments to address a specific population outside of the original scope of their development, the reliability and validity of each instrument may no longer hold. I addressed these issues in Chapter 5.

Limitations

Due to the diverse nature of the participant population and the origins of their foundational knowledge, which may be from various high school backgrounds, it may be that unmeasured factors could influence the results of this proposed study. These factors may also influence the participants self-efficacy during the semester. The correlation between chemistry-oriented misconceptions and student self-efficacy may not be the only correlation that exists in the sample population; however, the impact of misconceptions may allow for some predictions on future enhancements in organic chemistry.

Participants may also guess on the misconception portion of the assessment. Although the guessing strategy may be mitigated with the proposed DDMC assessment, participants could still guess on the assessment.

Outline of the Remainder of the Dissertation

The remainder of this dissertation includes four additional Chapters. Chapter 2 consists of a literature review examining factors associated with understanding the theoretical framework underlining this study. Both conceptual change and social learning theories are identified and explained in light of organic chemistry and science courses in higher education. Conceptual change theory will explain the foundation and advancement of misconceptions. Social learning theory will introduce the concept of self-efficacy and its impact on student success. Chapter 3 outlines the methods proposed to conduct this study, including a discussion of the development of the instrument used and data analysis strategies that will be employed. Chapter 4 outlines the results of the dissertation. Chapter 5 completes the dissertation with an analysis of the findings. This Chapter will also include a discussion on how the results add to the greater knowledge of organic chemistry, science education and self-efficacy. Finally, limitations and future research goals will be presented.

Chapter 2: Literature Review

The purpose of this Chapter is to investigate the theories that offer a framework for understanding the relationship between chemistry-oriented misconceptions and student self-efficacy in higher education through a review of the literature. First, a background of the current environment in science higher education will be addressed. This information will provide a foundation and reasoning for the theoretical framework to be built upon. Both conceptual change theory and social learning theory will be discussed as pivotal aspects of addressing the relationship between misconceptions and student self-efficacy in higher education science. Specifically, historical contexts, important models, and relevant literature will be presented, which is pertinent to higher education science.

In the final section of this Chapter, I will propose a strategy to investigate the relationship between misconceptions and student self-efficacy in higher education science by discussing the few research studies found that examine these issues. Other non-science or non-higher education environments will also be presented here due to a paucity of current higher education science research. The understanding of student-held misconceptions in science courses, as it relates to student self-efficacy, is an important topic for instructors in higher education in order to develop curriculum, evaluate educational environments, and gauge effectiveness in assessments.

Literature Inclusion Criteria

As previously mentioned, this is a selective review of the literature. To access the literature, I searched several databases including EBSCO, ERIC, Web of Knowledge - ISI Thomson Scientific, and JSTOR. I initially limited the search to work published between 2002 and 2022 to capture the most recent data. I used search terms including the following: organic chemistry, chemistry, science, foundational misconceptions, foundational knowledge, self-efficacy, conceptual change, social learning, higher education, undergraduate, university. Publications were only included if they investigated student self-efficacy in a science course or tracked misconceptions during the science course. I focused my review on undergraduate students whenever possible, however, one study does follow a high school science setting.

Selective Literature Review of Factors Related to Science Misconceptions and Self-efficacy

In this Chapter, I review the literature involving conceptual change and social learning theories as they relate to science education, primarily chemistry in higher education. This Chapter will begin with the current outlook and environment in science education and its impacts on organic chemistry students. Following this topic, Conceptual change theory will provide the foundation for understanding the growth of misconceptions while social learning theory discusses the importance of self-efficacy to student success. Next, I will describe the current use of these theories in the field of chemistry research and will conclude with a review of the research that has attempted to bridge the gap between the two theories.

Current Outlook and Environment in Science Education

Science courses in higher education are known for being difficult, unreachable classes, with students commonly resorting to rote memorization and experiencing challenges in successfully completing courses (King et al., 2019). The daunting reputation and abstract nature of chemistry courses facilitate the idea that they are one of the most challenging courses for students to complete (Cooper et al., 2013; Grove et al., 2008; Horowitz et al., 2013) and many students do not complete these courses. Chemistry courses specifically have an average attrition rate of 40% across universities (Cooper, 2018; Cooper & Klymkowsky, 2013; King et al., 2019). Attrition rates are even higher for URM, such as culture, race, and ability minority groups (Elbulok-Charcape et al., 2019; Villafañe et al., 2014). For this reason, researchers in the past decade have focused their attention on the social emotional role of education, specifically in higher education science courses (Flaherty, 2020). Creating a social emotional learning (SEL) environment allows students to view their education as part of their real-life experience (Weissberg & Cascarino, 2013). Weissberg and Cascarino identified the struggle is that educators and researchers already see the impact of SEL on students in all grades, but progress is slow to adopt it nationwide. SEL not only promotes the development of interpersonal skills, but it also prepares academically proficient students (Weissberg & Cascarino, 2013). The development of SEL in higher education chemistry courses will produce according to the authors a good student, a valuable citizen, and ultimately affect the success of students in the course. There are both short-term and long-term benefits with this corporation.

Previous studies have recognized that adverse experiences in organic chemistry are the leading cause of students changing their career paths (Barr et al., 2010; Rocabado et al., 2019). Barr et al. (2010) conducted a qualitative study at both public and private institutions investigating students who reportedly left their premedical studies for other majors primarily due to chemistry courses. Out of the 1,036 students from three cohorts studied, two groups were identified as likely to lose interest in their premedical courses. Women and students from underrepresented groups identified chemistry courses as the primary factor for their loss of interest and ultimate change in major. This study posited that if chemistry courses have this adverse effect on students, regardless of the university's size, it is necessary to reevaluate the role of science courses in the premedical curriculum. Barr reported that the results showed 71% of the students indicated that chemistry courses were the most discouraging course in their studies. Organic chemistry was explicitly cited as being the most discouraging by 38% of the student population surveyed. Thus, retention is an issue with chemistry courses in higher education.

The main concern focuses on URM and women being at higher risk of abandoning science and medical careers during their undergraduate studies (Barr et al., 2010; Lynch & Trujillo, 2011). Challenges encountered in chemistry may be an extension of the overemphasis on rote memorization and impacted lecture courses that hinder class participation (Elbulok-Charcape et al., 2019). Pedagogical reforms in the last ten years which have attempted to mitigate these challenges include Process Oriented Guided-Inquiry Learning, Peer-Led Team Learning, and flipped classrooms (Alden, 2018; Bokosmaty et al., 2019; Rau et al., 2017; Webber & Flynn, 2018). These pedagogical reforms have shown promise for improving the attitudes, grade outcomes, and retention for higher education chemistry courses; however, at this time, research in the area of enhancing organic chemistry courses has been focused primarily on grade outcomes and lecture format (Austin et al., 2018; Gibbons & Raker, 2019). Furthermore, the research has reflected mixed results: studies finding some statistical significance (e.g., GPA, DFW rates) and others finding no significance at all (e.g., overall average of final course grades).

One example of mixed results has been seen in research encompassing the flipped classroom approach (Antunes et al., 2012; Baepler et al., 2014; Bokosmaty et al., 2019; Seery, 2015). Flipped classrooms are a trend making its way through science education (Seery, 2015). The characterization of flipped classrooms is not readily defined; however, they all rely on allowing learners to engage with a portion of the lecture material before physical class time (Seery, 2015). Seery noted this methodology, which allowed an active learning environment during class time rather than outside, enabled the instructor to guide students as they applied the material. Direct instruction being moved out of the classroom was, according to Seery, key to a dynamic learning space. Seery also mentioned the approach to flipped methods is fluid in terms of execution. However, it was found there was generally an increased amount of engagement and popularity among chemistry students regardless of the approach. This indicated to Seery participation in flipped classrooms increased due to the movement of direct instruction outside of lecture time.

Studies have set out to identify a relationship between flipped classrooms to grade outcomes as well (Antunes et al., 2012; Baepler et al., 2014; Bokosmaty et al., 2019). The overall results of Antunes et al. (2012), Baepler et al. (2014), and Bokosmaty et al. (2019) showed some improvement in grade outcomes with varying success. That is some years their flipped method worked to lower failure rates, and some years it did not. It has been noted that these irregular results repeat themselves within the last few years of literature in this area. Although engagement may increase, statistical significance in increasing grade outcomes with this pedagogical approach are limited.

Adding in aspects of SEL, studies that focused on student support and self-efficacy have seen more positive outcomes (Fischer et al., 2019). According to Hansen-Thomas and Chennapragada, the way this occurs is with multicultural education, which has been linked to SEL (Hansen-Thomas & Chennapragada, 2018). The importance of multicultural education within higher education chemistry involves (a) identifying and incorporating cultural backgrounds of students within teaching strategies, (b) being open to different methods of communication employed by the students, (c) facilitating connections between existing knowledge and academic goals, and (d) utilizing and prioritizing cultural diversity for academic success (Hansen-Thomas & Chennapragada, 2018). Ultimately, the use of these methodologies has been shown to help all students learn and engage with the material more effectively. SEL research presents a novel approach to understanding when misconceptions are interfering with student acquisition of knowledge. Focusing on student misconceptions and the relationship to student self-efficacy may be a novel approach to addressing these challenges in higher education science courses. By understanding how misconceptions are formed and how the develop within a specific chemistry course, educators can better enhance the SEL approach to a learning environment.

What are Misconceptions?

The amount of research being conducted investigating students' conceptual learning, frameworks, and misconceptions in science has increased rapidly (Bongers et al., 2019; Lawson, 1994). While it is still an expanding field, there is consistency in the definition of misconceptions (Barbera, 2013; Kien-Kheng et al., 2016; Wilson-Kennedy et al., 2020). Misconceptions are incorrect or naïve preconceptions that students have about a given concept or topic (Chen, Sonnert, Sadler, & Sunbury, 2020). In addition to the incorrect knowledge, misconceptions may be a belief system of propositions logically linked together (Fischer et al., 2019). The belief system obstructs the student's ability to gain deeper understandings of the scientific topic (Fischer et al., 2019).

Conceptual change often happens throughout the life of growing children (Ormrod, 2020). Yet, when presented in the classroom, learners of all ages hold onto certain misconceptions even after instruction indicates contradictions (Vosniadou et al., 2011). A student’s prevailing beliefs affect their acceptance of new information (Ormrod, 2020). This may be due to the aptitude of students to interpret new information in light of what they already know or the failure to identify inconsistencies in new and prior beliefs.

In conceptual change theory, misconceptions are shown to undergo multiple stages of development (Lawson, 1994). As more knowledge is developed, students can experience dissatisfaction with the currently held belief system, identify new and plausible concepts, and accommodate new concepts. As defined through the work of Piaget, this process is known as assimilation and accommodation (Lawson, 1994). This process, however, does not always occur successfully in student experiences, and when it does not, correct interpretations of scientific concepts are not developed (Cooper et al., 2013; Nakhleh, 1992; Scalise et al., 2006). The misconception creates a cognitive disequilibrium that can be difficult to mitigate.

What is Self-efficacy?

Self-efficacy is defined as "the conviction that one can successfully execute the behavior required to produce the outcomes" (Bandura, 1977, p. 193). Students who believe they can do well in formative or summative assessments in chemistry are also regarded as having high self-efficacy. Self-efficacy was introduced in social learning theory by Bandura in 1977. Bandura's study set out to understand human behavior and therapeutic procedures rather than learning. This theory implied that self-efficacy, the level, and strength thereof, can be changed by psychological means. Bandura proposed that students gain self-efficacy through four principal sources: performance accomplishments, verbal persuasion, vicarious experiences, and physiological states. The more effective the experience of these sources, the more likely students will increase their self-efficacy. This idea of Bandura's generated the framework to aid in the improvement of self-efficacy in teaching-related experiences.

Bandura (1977) postulated that students who have personal mastery experiences gain self-efficacy. Successes increase expectations, and efficacy can increase further — failures lower expectations and stunt the efficacy. Nevertheless, once a high efficacy is developed in one task, it can, according to Bandura's study, "generalize to other situations in which performance was self-debilitated" (p.195). The more participant modeling, performance exposure, and self-instructed performance students experience in a course, the more likely they have opportunities to increase their self-efficacy (Bandura, 1977; Bartimote-Aufflick et al., 2016; van Dinther et al., 2011).

Identifying a Link Between Misconceptions and Self-efficacy

There is a paucity of literature regarding the link between conceptual change theory and social learning theory (Cordova et al., 2014; Kallia & Sentance, 2019). It is known in higher education science courses that student misconceptions exist as a significant problem (Nakhleh, 1992; Özmen, 2004; Seery & Donnelly, 2012; Taber, 2010; Zoller, 1990). The inequity and attrition rates currently facing higher education science courses may be mitigated by investigating the commonly held misconceptions and their relationship to self-efficacy. In order to understand misconceptions and self-efficacy and the role they play in higher education science courses, conceptual change theory, and social learning theory should be explored.

Conceptual Change Theory

Learning scientific concepts is a cumulative process (Kallia & Sentance, 2019; Özmen, 2004; Taber, 2010). Each new piece of knowledge is constructed on previously established foundations (Özmen, 2004). Preexisting, incorrect knowledge or misconceptions can interfere with students' learning (Zoller, 1990). Conceptual change theory posits that students construct knowledge through their experiences keeping in mind that prior knowledge, experiences, and social context all influence the acquisition of new knowledge (Özmen, 2004). However, when a misconception is part of a larger theory or worldview, the mitigation of that misconception may be difficult (Ormrod, 2020). The process of replacing a theory or belief system with another is known as conceptual change. This can include changing a strongly unified set of concepts rather than an isolated idea (Ormrod, 2020).

History – Piaget and Knowledge Acquisition

Embedded within cognitive developmental psychology, conceptual change was initially proposed through the work of Jean Piaget (Carey, 1985). By observing children, Piaget focused on how knowledge is acquired (Lawson, 1994). In these observations, knowledge can be represented as a coherent, unified framework of theory-like nature (Ozdemir & Clark, 2007). Conceptual change is often attributed to Piaget's work. However, it is also a major asset to Kuhn's concept of a paradigm shift (Kuhn, 1962). The root of conceptual change lies in constructivism.

Constructivism

Constructivism argues that learning builds upon previous knowledge that students hold (Bodner et al., 2001; Bodner, 1986). The process of obtaining knowledge and meaning occurs from the interaction between a student's experiences and their own ideas or cognition. Constructivism has been formed from two main perspectives: cognitive and social. Jean Piaget falls into the cognitive constructivism side, whereas, Lev Vygotsky, on the other hand, concentrates on the social aspects of learning through experiences. John Dewey overlaps the boundary between the two perspectives and has many ideas that match with each side (Bodner et al., 2001). The commonality between these three foundational psychologists is that all three believed that the learning theories at the time did not accurately portray the actual learning process. At this time, behaviorism and humanism were the primary learning theories. Piaget suggested that learning is most effective when a student is actively engaged in obtaining knowledge rather than passively receiving knowledge (Piaget, 1976).

The construction of knowledge, according to Piaget, occurs through a process of accommodation and assimilation. Accommodation involves reframing one’s mental representation of the external world to fit a new experience (Piaget, 1976). Assimilation is the process by which a person acquires the social and psychological characteristics of a group (Piaget, 1976). The three psychologists all noted there is an already existing framework of knowledge that must accept the new experiences of students (Bodner, 1986; Bodner et al., 2001).

Conceptual Change

In conceptual change theory, if a learner can solve problems within the existing conceptual schema, then the learner does not change the current held belief system (Kuhn, 1962; Ozdemir & Clark, 2007); however, if the learner does not successfully solve problems, the current conception may experience many outcomes. This includes a transition on the scale of moderate changes or even complete dissatisfaction and abandonment in order to accept a different conception (Kuhn, 1962; Ozdemir & Clark, 2007). Sinatra pointed out that Piaget's childhood development theory was analogous to evolution with children's ability to adapt to specific environmental pressures and affordances; however, certainly not an actual evolutionary process because, among other issues, children are actively making choices (2008). The major distinction is that in learning, the child is actively making decisions. Assimilation and accommodation are two steps in the acquisition of knowledge (Lawson, 1994; Sinatra et al., 2008). It is within these concepts that misconceptions can be better understood.

Assimilation and Accommodations

Assimilation can be defined as the process of adding new information to the learner's current conception or framework (Bodner, 1986; Lawson, 1994; Sinatra et al., 2008). This process relies on the additive process where the learner may have little or no prior knowledge on the subject (Sinatra et al., 2008). At this point, two outcomes could occur. The learner could (1) assimilate the knowledge, fully accept the new information into their knowledge, or (2) identify a conflict with what they already know. What the student does next (in the event of a conflict) is what Piaget calls the accommodation process. When a learner is presented with a conflicting concept (a misconception is presented), disequilibrium occurs (Sinatra et al., 2008). In the disequilibrium state, learners could completely ignore the disequilibrium and retain their misconception, modify their misconception slightly to accept the disequilibrium, or accommodate them (Sinatra et al., 2008).

Accommodation involves altering the learner's framework of knowledge to change their current incorrect conceptions (Lawson, 1994). Accommodation must occur in order to acquire knowledge (Ozdemir & Clark, 2007). This radical change leads to a conceptual change and the ability to displace the misconception (Carey, 1985; Taber, 2010).

Social Constructivism

Learning can also be viewed as a social process. Lev Vygotsky developed social constructivism. Vygotsky's work on Social Development Theory proposed that the social interactions made by a student preceded development, consciousness, and cognition (Wertsch, 1993). This was in opposition to Piaget's assumption that learning is separate from social aspects and interactions. Vygotsky proposed that cognition and development are the product of socialization and social behaviors (Wertsch, 1993). The major tenets in Vygotsky's theory focus on (1) how social interactions play a fundamental role in the process of cognitive development, (2) what the role is of the more knowledgeable other (MKO) who may be a teacher, peer, or mentor who has a better understanding than the learner, and (3) what learning can be done in the zone of proximal development (ZPD) which is the distance between the learner's ability to perform a task with guidance versus independently (Wertsch, 1993). All three of these tenets argue that learning is a function of activities, context, and culture of inquiry under social interactions. Vygotsky emphasized the importance of social interaction as a critical component of learning (Wertsch, 1993). This social interaction could aid in the assimilation and accommodation process, but it also may be a link to behavioral and cognitive theories. Vygotsky tied various aspects of inquiry together into a unique approach that does not separate the individual from the sociocultural environment.

Overall, social constructivists understand that learning occurs not only in the cognitive sense but also when engaging in social activities (Repice et al., 2016; Wertsch, 1993). By interacting with other learners from different skill levels, backgrounds, and proficiency, learners can exchange knowledge successfully and be appropriated on an individual level.

Combating Misconceptions

In order to promote conceptual change, educators must not only help students learn new skills but also help them let go of their existing beliefs that contain misconceptions (Ormrod, 2020). Educators need to first determine what beliefs and misconceptions students currently hold if they want students to be successful in mitigating misconceptions (Ormrod, 2020). Misconceptions in higher education science classes often develop throughout the foundational courses (the first two years of coursework for undergraduate majors) when the cumulative learning is most apparent (Taber, 2010). Also at play during this time is the transition from high school to college, where the learning environment is remarkably different (Cooper et al., 2012). Due to the vast nature of scientific concepts, there are misconceptions reported on most topics and across several education levels (Cooper et al., 2013; Esselman & Block, 2019; Popova & Bretz, 2018). When learners are presented with an alternative conception, they typically make sense of it, linking existing understandings to the new material (Taber, 2010). Research suggests that misconceptions may arise from a learner's intuitive understanding of the world as well as the influence of others (Taber, 2010).

The fundamental concepts presented during foundational courses are typically abstract in higher education science courses (Nakhleh, 1992). If these concepts are not constructed appropriately in the learners at the very beginning, they may not be able to fully understand more complex concepts that build on these foundations (Nakhleh, 1992). Numerous studies have shown the value of correcting learner misconceptions (Esselman & Block, 2019; Sinatra et al., 2008; Smithrud & Pinhas, 2015). However, foundational learners with strong misconceptions often abandon the intervention altogether or revert to their original misconceptions after the intervention is over (Chen, Sonnert, Sadler, Sasselov, et al., 2020). It has been suggested that intuitive misconceptions cannot be undone (Chen, Sonnert, Sadler, Sasselov, et al., 2020). Rather, there is a coexistence of the new conception with the original misconception. This could suggest the inability to fully accommodate when presented with disequilibrium information (Carey, 1985; Lawson, 1994).

Social Learning Theory

Social learning theory has often been described as the bridge between behaviorism and cognitive theory (Rumjaun & Narod, 2020). Each of these theories describes a certain view of learning. In behaviorism, the focus is on a change in external behavior (Bandura, 1985; Rumjaun & Narod, 2020). This change occurs when there is repetition and reinforcement of the behavior to achieve rote learning. Cognitive learning theory works to identify the mental processes that aid in learning (Schunk & Pajares, 2005). This bridge provides a comprehensive approach to understanding the process of learning in higher education science courses (Rumjaun & Narod, 2020). As mentioned previously, learning science is a cumulative process. Along with the construction of scientific concepts, learners must also engage in problem solving, projects, and inquiry-based assessments to construct the meaning of the concepts or phenomena in science (Rumjaun & Narod, 2020). Social learning theory seeks to integrate behavioral change in order to effectively acquire knowledge through observation, imitation, and modeling (Bandura, 1985).

History – Bandura and Self-efficacy

Bandura proposed that self-efficacy has a causal link to the outcome of behavior (Bandura, 1985). The model suggested by Bandura (1985) described self-efficacy beliefs exerting their influence on cognitive, motivational, emotional, and decisional processes. These beliefs play a significant role in the self-regulation of motivation through metacognition and outcome expectations. As defined by Bandura, self-efficacy identifies the belief in one's ability to execute a task successfully (1985). Bandura went further to identify that people tend to engage in activities based on their self-efficacy. The more competent a person feels about a task, the more likely they will reengage in that task (Bandura, 1985). In the context of higher education science courses, the task is knowledge acquisition and ultimately success in the course. Self-efficacy in higher education science courses has been investigated over the past few decades (Flaherty, 2020). Overall, the more participant modeling, performance exposure, and self-instructed performance students experience in a course, the more likely they have opportunities to increase their self-efficacy (Gibbons & Raker, 2019).

Reciprocal Determinism and Self-efficacy

The concept of a person's behavior, cognition, and environment all influencing each other is known as reciprocal determinism. Bandura introduced reciprocal determinism to combat unidirectional environmental determinism and other one-directional theories (Bandura, 1978). The causal processes explained in social learning theory involve a continuous reciprocal interaction between behavioral, environmental, and cognitive influences. Previous theories had identified the environment as the sole influencer on behavior (Bandura, 1978; Ghee & Khoury, 2008). The environment operates in one direction as the dominant ruler of a person's view of reality. These theories failed to explain why or how individuals imitate the action of others even when they are not environmentally reinforced to do so. Bandura identified an issue with environment being a sole influencer and instead advocated for the reciprocal model.

A person's thinking, or cognition, can also influence their behavior and environment through a self-regulatory process (Aydın, 2015; Ghee & Khoury, 2008). Cognitive factors can influence which external events are observed, how they are understood, and whether they will have enduring impacts on a person. Ghee and Khoury (2008) investigated the reciprocal determinism in science and math students attending an elementary school. In this study, students who felt positive about math or science, perceived themselves to perform better in these subjects, and those who perceived themselves to perform poorer were also more likely to feel negative about these subjects. Also, when students reported lower levels of math anxiety, they also held positive evaluations of their affective-behavioral perceptions of math and science.

Bandura (1978) proposed that a person can cognitively decide to change their immediate environment and can create conditional incentives for themselves in order to change their own behavior. The environment does influence behavior, according to Bandura, but a person's cognition and behavior can also influence the social environment through daily transactions with others (Gibbons & Raker, 2019; Williams & Williams, 2010). Bandura postulated that a person's behavior is influenced by both the environment and learning experiences. Behavior and cognition are causations of past events and experiences (Bandura, 1978).

Strengthening Self-efficacy

Reciprocal determinism in self-efficacy has been the focus of research in science courses in order to aid in strengthening self-efficacy (Bautista, 2013; Ghee & Khoury, 2008; Williams & Williams, 2010). Bautista (2013) hypothesized that cognition could transform the individual learner through imitation, modeling, and feedback of environmental, individual, and social stimuli, specifically in an online physics class via online scaffolding. Noting Bandura's Social Learning Theory, Bautista postulated that a learner in an online community of inquiry that focused on a self-regulated, constructive learning environment would perform better than their traditional (online, lecture) course. In the self-regulated, constructive learning environment, online discussions were utilized to leverage the learning behaviors of the students. There was an exceptionally high positive correlation between a student's experiences in online discussions and their performance in classroom interaction, formative assessment, and summative evaluations. Bautista concluded that social learning within the vicarious interactions on the online platform aided in student learning and that science instruction needs to provide challenging sections of social inquiry to inspire engagement.

Efficacy-enhancing teaching, inspired by Bandura's development of self-efficacy, utilizing performance accomplishments, vicarious experiences, verbal persuasion, and physiological states, has also been evaluated (Cheung, 2014; Fernandez, 2017; Hayat & Shateri, 2019; Quinlan et al., 2021). The Cheung (2014) project investigated a variety of teaching methods to see if there was an improvement in a student's chemistry self-efficacy. Cheung employed numerous instructional strategies and employed surveys to gauge students' responses. These strategies included: learning from classmates, verbal persuasion, meditation teaching, and friendly learning environments. The objectives of this research study were to align Bandura's original four sources of self-efficacy with that of a chemistry learning environment. Coined by Cheung, efficacy-enhancing teaching referred to instructors repeating successes of students during lectures, providing opportunities for students to observe and engage in peer problem solving, and frequent positive feedback from instructors. The peer model was at the forefront of Cheung's method to create a vicarious experience for students. This provided students the opportunity to build positive peer relationships. Cheung was successful in effectively improving students' chemistry self-efficacy by implementing the teaching methodologies stated above.

Student engagement has been extensively researched in science education (Armbruster et al., 2009; Baepler et al., 2014; Cash et al., 2017). The different pedagogical approaches have been centered on student self-efficacy and motivation. Student's self-efficacy has been correlated with improved grade outcomes (Boz et al., 2016; Flaherty, 2020; Galyon et al., 2011; Mau, 2003). Galyon et al. (2011) investigated the link between self-efficacy and GPA, class performance, and grade outcomes in a human anatomy course. Although not a chemistry course, the methodologies utilized in the Galyon study can cross disciplines (Gibbons & Raker, 2019). Within groups of the Galyon study, as the students gained more confidence in the material, their participation and GPA increased over the norms. The correlation for the Galyon study was mirrored in a similar study utilizing organic chemistry students by Gibbons in 2019. In this study, Gibbons expressed a wide relationship across all science-related subjects of self-efficacy and achievement. This suggests that scientific concepts in one subject, such as chemistry, influences another, biology, or physics, for example. Building up self-efficacy in chemistry could therefore impact other science courses as well that are built on similar foundational concepts. Specifically referencing the Galyon paper, Gibbons noted the longitudinal research design increased the support for self-efficacy being tied to achievement (2019). Gibbons and Galyon both reported that self-efficacy more strongly predicted a student's grade outcome than any other measures (e.g., previous exams or format of lecture) when measured at the end of the semester. This suggested to Gibbons that the impact of self-efficacy on grade outcomes is a potential causality rather than just an association, as seen in prior pre-measure design research. Self-efficacy did, nevertheless, fluctuate during a semester course; however, as shown by Gibbons, self-efficacy can be defined as a choice indicator. Students must choose to increase their self-efficacy, which is related to motivation. Ultimately, students with high self-efficacy choose better study strategies and participate in more self-regulation that affects their grade outcomes (Gibbons & Raker, 2019; Raker et al., 2019).

Self-concept

There is a difference that should be noted separating the idea of "self-concept" and "self-efficacy." In 2019, Gibbons stated, "self-efficacy" is the outcome, and "self-concept" is a "person's perceptions of [them]self" (p.600). A student's self-concept is created by an internal and external frame of reference. That is, internally when they do self-evaluations and externally when they work and compare their knowledge with peers. Self-concept is based on past achievements and how that knowledge influences future achievement. Self-efficacy is future-oriented (Bandura, 1977, 1984; Gibbons & Raker, 2019). Both have been shown in research to support an increase in achievement (Bong, 1998; Marsh, 1990; Shavelson et al., 1976). Gibbons identified the need for further research into the association between self-efficacy, self-concept, and achievement, especially in chemistry (2019). Gibbons utilized A cross-lagged, reciprocal causation model to evaluate these three concepts in an organic chemistry course. The goal of this study was to determine if self-efficacy or self-concept was more influential in achievement as well as the classroom environment.

The results of the Gibbons (2019) study indicated that achievement predicted future self-belief measures, and a student's initial self-concept was able to predict achievement measures (e.g., future exams). Gibbons explained the results provided insight into self-concept as a past-oriented notion. Students used their prior achievements in chemistry to influence their current beliefs and their choices for the future. Positive experiences in chemistry predicted a student will engage in chemistry more in the future (Gibbons & Raker, 2019). Because self-efficacy is future-oriented, it could be seen that self-concept predicted self-efficacy (Gibbons & Raker, 2019; Raker et al., 2019; Srinivasan et al., 2018); however, the results of the Gibbons (2019) study did not suggest any relationship between self-efficacy and achievement.

Gibbons' (2019) attributed this result to an error in the students' self-regulation behaviors being a factor. A student may report a high self-efficacy, yet they are unaware of their incompetence. This is related to the Dunning-Kruger effect in psychology: "Not only do these people reach erroneous conclusions and make unfortunate choices, but their incompetence robs them of the metacognitive ability to realize it" (Kruger & Dunning, 1999, p. 1121). The Dunning-Kruger effect is prevalent in chemical education research as students with false high self-efficacy usually predict their grade outcomes to be higher than what is accurate (Gibbons & Raker, 2019). Research suggested this group of students with false self-efficacy may benefit from alternative pedagogical approaches (Casselman et al., 2017; Gibbons & Raker, 2019; Kruger & Dunning, 1999). The most effective approaches are those that allow the learner to confront their current conceptions. This echoes the process of assimilation and accommodation. To avoid the Dunning Kruger effect, students may need to have more opportunities to combat their misconceptions in order to successfully assimilate and accommodate new correct knowledge. Thus, it would be useful to explore if holding strong misconceptions could produce false self-efficacy or affect self-efficacy.

The Use of Metacognition to Increase Self-Efficacy

One potential mechanism for improving self-efficacy is metacognition, the ability of a student to notice and regulate their learning (Willson-Conrad & Kowalske, 2018). Reciprocal determinism discussed the importance of regulating learning through the interdependency of cognition, behavior, and environmental factors. Through the research of Willson-Conrad and Kowalske (2018), high school chemistry students who regularly self-evaluate, regulate, and think about their learning perform better on formative and summative assessments. Although this research was focused on high school students, the foundational knowledge and experiences obtained in high school has been noted to be influential in later courses which includes higher education (Bleicher et al., 2003). Willson-Conrad and Kowalske (2018) specifically found students who gauged their intake of material and did frequent tasks such as planning, making meaningful connections in material, and self-evaluation were more successful. Willson-Conrad and Kowalske studied the perceptions of students throughout the semester, focusing on the summative exam process. Their goal was to investigate self-efficacy and how chemistry students studied for exams through phenomenological, qualitative analysis rather than focus solely on the grade outcomes. The qualitative approach allowed Willson-Conrad and Kowalske to develop themes from the student stories, and a major theme was self-efficacy. By categorizing the different experiences of students' exam process, Willson-Conrad and Kowalske could see clear correlations between students' self-efficacy and exam performance. Students in the highest performing groups participated in study groups, attended office hours regularly, and had specific study strategies (e.g., practiced multiple types of questions, utilized an exam-taking routine, organized their studying to manage stress). The high-performing students also engaged in office hours to reevaluate the exam with their professor. Willson-Conrad and Kowalske highlighted that instructors could utilize these results to understand the perception of students and the role of exams in chemistry courses. The more instructors understand the role of exams in the eyes of the student, the more instructors can initiate metacognitive strategies within a classroom.

Metacognitive monitoring studies in higher education courses, some of which are chemistry-related, provide further inquiries to successful learning (Thomas & Anderson, 2013; Wang, 2015). Both Thomas and Anderson (2013), as well as the Wang (2015) study, effectively changed the environment of the classroom and students' perceptions of learning to a more positive attitude and reported increased awareness during lecture courses. Thomas and Anderson (2013) focused on the teacher's ability to alter specific students' metacognitive skills. They utilized classroom environment instruments, such as the Metacognitive Orientation Learning Environment Scale – Science (MOLES-S) and the Self-efficacy, Metacognition Learning Inventory – Science (SEMLI-S), to gauge the extent to which the classroom environment nurtured the students' metacognitive abilities. These Likert scale surveys were designed by Thomas in previous articles (Thomas, 2003, 2004). Thomas and Anderson (2013) found that an instructor can change the learning environment to enhance student perceptions by explicitly addressing metacognitive dimensions within the classroom. During four weeks of instruction, Thomas and Anderson collected what they called pre-intervention data. These data represented the baseline classroom environment without any metacognition language or influence. Following this, students were presented with specific scripted lectures that were designed to probe metacognition. The instructor used metaphors to allow students to make abstract connections with the material. According to the results, these metacognitive metaphors inspired students to change their perceptions of the course and showed a benefit for their overall feelings of the material presented (Thomas & Anderson, 2013). The metacognitive exercises embedded in the educational environment allowed students to engage with their own understanding and conceptions.

Gender and Ethnicity

The field of science, technology, engineering, and mathematics (STEM) has been known to contain embedded inequities and significant gender differences across higher education and careers (Sadler et al., 2012). The disparities for women and underrepresented groups choosing STEM majors in higher education has been the focus of numerous studies (Brotman & Moore, 2008; Mau, 2003). Brotman and Moore identified that female attitudes towards science were less positive than males and the disparities increased with age (2008). Mau also confirmed females were less likely to pursue a STEM degree in higher education (2003). The gendered career patterns have been seen in most disciplines of STEM workforces as well (National Science Foundation, 2009). With the gendered nature of STEM education and the workforce, this research aims to encounter some of the visible forms of inequalities that exist in STEM education.

Hwang and Taylor emphasized that underrepresented students perform below their peers in STEM subjects partly due to the traditional views of STEM and the curriculum focus (Hwang & Taylor, 2016). Hwang and Taylor clarify, the traditional focus of a chemistry course emphasizes broad and abstract concepts rather than real-life applications. Embedded within STEM higher education is a binary system of language that engages and reinforces a binary system not only by use of men and women, but also competition and collaboration, as well as active and passive themes (Parson, 2016). These systems create inequality, where men are held to a lower standard and women, are given unattainable ones.

Inequities in chemistry education reach across race, gender, and class (Morales-Doyle, 2017). These inequities are seen when schools with limited access and funding are primarily serving students from underrepresented races and low-income classes (Morales-Doyle, 2017). Morales-Doyle notes that inequities across these identities remain prevalent and under-researched. He calls for curriculum reform for more justice-centered pedagogy in the sciences. A justice centered advanced chemistry class in an urban high school allowed students to succeed academically while focusing on environmental and social issues identified in the community. The reform presented by Morales-Doyle can be addressed by understanding the discourse currently being presented in chemistry courses in higher education. Chemistry is a higher education course that brings with it negative connotations of URM students having to conform to the curriculum rather than the curriculum serving all students (Morales-Doyle, 2017, Kokka, 2018).

Future Ideas and Conclusion

Echoing this theme of metacognition, as previously mentioned, assimilation and accommodation, constructivist environments, and self-efficacy require students to confront their own conceptions (Posner et al., 1982). It is in the merging of conceptual change theory and social learning theories that the process of learning can be better understood.

There have been numerous studies investigating either self-efficacy and misconceptions in higher education (Nakhleh, 1992; Seery, 2015; Taber, 2010) or in primary and secondary science topics (Bermúdez et al., 2012; Sen & Yilmaz, 2012). These studies have shown a student with higher amounts of misconceptions in a given topic correlate with a more negative attitude, lower self-efficacy, or lower performance on that topic. For example, Bermudez et al (2012) identified that adolescents (13 – 18 years of age) with higher scores in HIV misconceptions also showed more negative attitudes and self-efficacy about the topic and knowledge related to HIV. At present, little has been shown linking self-efficacy outcomes with misconceptions in higher education science (Cordova et al., 2014; Kallia & Sentance, 2019).

Specifically, in higher education, many topics have been shown to hold common misconceptions, yet the current scope of literature has focused on interventions to mitigate the misconception (Kallia & Sentance, 2019). Kallia and Sentance explored the connection between computer programming misconceptions and student self-efficacy in a secondary education setting (2019). If previous positive experiences can influence self-efficacy, misconceptions may be a barrier to obtaining positive experiences and increases in self-efficacy. It was posited by Kallia and Sentance that students with higher self-efficacy typically have low to no misconceptions. In this study, Kallia and Sentance also identified that some students showed high self-efficacy with high misconceptions. This was also identified in a similar study conducted in a higher education psychology course (Cordova et al., 2014). This could suggest the Dunning-Kruger effect is a crucial factor to consider when attempting to combat and understand the conceptual change that occurs in learning.

It appears there is a valid connection between increasing motivation and metacognition, which leads to self-efficacy and, finally, grade outcomes (Casselman et al., 2017; Cordova et al., 2014). Perhaps metacognition and activities that increase motivation allow learners to regularly address their misconceptions and confront the process of assimilation and accommodation more frequently. Along with this, most research in lecture methodologies, such as flipped style or active learning, show an increase of awareness of students and overall grade outcomes (Seery, 2015). Seery (2015) noted students in the flipped classroom increased participation. Taking this one step further, it was also shown that student peer relationships are active in these flipped settings.

As seen with Elliot and Dweck's work, in *Handbook of Competence and Motivation*, the positivity of peer relationships directly affects motivation within a classroom (2005). Gauging the peer relationships within flipped or active learning (whether they are positive or negative) may be the key to understanding the overall performance of students year to year (Elliot & Dweck, 2005). Again, this points to ways to enhance knowledge assimilation and accommodation in order to increase self-efficacy. If positive student relationships are enhanced in active learning and flipped environments which directly affect student knowledge and challenge misconceptions, then self-efficacy increases should follow.

Due to the paucity of research on the relationship of higher education science misconceptions and student self-efficacy, the following areas of future research may provide a greater grasp of the role understanding student prior knowledge plays in affecting self-efficacy and ultimate success within the course. Future research should probe (1) what are the common student-held misconceptions in higher education science courses, (2) is there a change in these misconceptions throughout the semester, (3) is there a relationship between students' misconceptions and self-efficacy throughout the course, and (4) can self-efficacy be improved through the mitigation of misconceptions. By understanding both the process of conceptual change and social learning theories, educators can grasp what roadblocks exist for student success in higher education science courses. In order to investigate the construction of foundational knowledge needed for organic chemistry students, the study proposed here will investigate the most common misconceptions of students in organic chemistry and identify if there is a relationship to student self-efficacy.

Chapter 3: Methodology

The purpose of this Chapter was to investigate the relationship between chemistry-oriented misconceptions held by university students and their organic chemistry self-efficacy. In order to accomplish this goal, students enrolled in a first-semester organic chemistry course at various 4-year institutions will be surveyed. The instrument included a combination of two established surveys, both of which are validated and found reliable in the topic presented. One probed chemistry-oriented misconceptions, and the other gauged student self-efficacy in organic chemistry.

This Chapter explains the development of the survey instrument by describing the background and creation of each portion of the instrument. The desired participant group is also described here, along with the procedures proposed to gather the data. The final section of this Chapter provides an explanation of the data analysis strategies to explore the relationship between chemistry-oriented misconceptions held by university students and their organic chemistry self-efficacy.

The Instrument

To investigate if there is a relationship between two variables, a quantitative methodology, rather than a qualitative methodology, was employed. In order to identify if a relationship does exist, a correlation study was desired (Urdan, 2017). A survey instrument was also valuable for this topic so that a larger sample of students may be surveyed. In order to enhance the ability to generalize the results of this project, there is a precedence to have a larger sample size, as seen in current literature within the topic of chemistry self-efficacy (Chen, Sonnert, Sadler, & Sunbury, 2020; Villafañe et al., 2016).

Using a survey instrument provided quantitative data that can then be assessed for a statistical relationship. Multiple inventories exist that address individual or minor combinations of chemistry concepts (Lawrie et al., 2019). These concept inventories have been utilized to evaluate instructional interventions, curriculum changes, or academic development (Cooper & Klymkowsky, 2013; Lawrie et al., 2019; Toledo & Dubas, 2016). To effectively investigate multiple concepts in chemistry, the instrument chosen for this study covered current foundational topics in chemistry covered by the NGSS standards which students would have developed since high school (Sadler et al., 2010).

There have been numerous studies investigating self-efficacy in chemistry students (Aydin & Uzuntiryaki, 2009; Dalgety, 2006; Uzuntiryaki & Aydin, 2009). The surveys currently available in the literature focus on learning chemistry theory, applying the theory, and chemistry skills both in a lecture and laboratory setting. The two instruments chosen for this study are the Chemistry Concepts Inventory (CCI) developed by the Misconceptions Oriented Standards-based Assessment Resources for Teachers of High School Physical Sciences (MOSART HS PS) project (Sadler et al., 2013) and a subsection of the Chemistry Attitudes and Experiences Questionnaire (CAEQ) (Dalgety et al., 2003). These instruments were chosen due to their focus on the topics of my research questions as well as their reliability and validity.

The Misconception Survey

The assessment of student conceptions of science has been a complex issue that has interested educators in science (Barbera, 2013; Lawrie et al., 2019; Sadler, 1998). Yet most of the assessments are either standardized with poor reliability (Harlen, 2005; Koretz et al., 1994) or have a set up where students can answer correctly by the process of elimination (Sadler et al., 2010). For this reason, it was essential to explore "distractor-driven" multiple-choice (DDMC) tests for this project rather than standardized chemistry tests such as the American Chemical Society (ACS) exams.

The Rationale for Distractor Driven Assessments

Dating back to Piaget's early cognitive research on children's ideas and traditional structure clinical interview, DDMC instruments are constructed through knowledge of currently held misconceptions assessed through interviews, open-ended written tests, and psychometrics (Sadler et al., 2010). These DDMC assessments are unique and different from traditional multiple-choice tests in that they offer students a single correct answer and one or more misconceptions identified by researchers (Osborne & Freyberg, 1985). The statistical performance of DDMC items is very different than traditional, standardized multiple-choice questions in that a single wrong answer (an attractive misconception) is chosen by a majority of students who answer the item incorrectly (Sadler et al., 2010). This is the distractor that is not typically found in a standardized multiple-choice test.

Typically, the guessing strategy results in a probability of 0.20 correct on a five-item multiple-choice assessment. However, with a DDMC assessment, when a student holds a particular misconception, the probability of choosing the distractor will increase above 0.20. In a standardized test that does not include these popular misconceptions as distractors, students are more likely to guess the correct answer by process of elimination. According to Sadler et al. (2010) without the distractors, multiple-choice items will do very little to inform educators of the students' actual ideas. Standardized assessments cannot adequately measure the degree to which the students have fully accepted the scientific concept because they are not being tempted by their misconceptions. By presenting the distractor, you offer the students a choice that can more clearly reflect their understanding of a concept. The development of DDMC assessment items, however, is more difficult to create yet holds more analytical weight due to the need to integrate popular, current misconceptions (Sadler et al., 2010).

MOSART HS PS Assessment Development

The Misconceptions Oriented Standards-based Assessment Resources for Teachers of High School Physical Sciences (MOSART HS PS) was developed out of the need for rigorous assessment tools probing for teacher and student understandings of high school level physical science concepts in both chemistry and physics (Sadler et al., 2013). This assessment (Appendix A) was developed based on the need to diagnose misconceptions that impede the learning of science concepts (Sadler, 1998). As mentioned earlier, the development of DDMC assessments created by the MOSART HS PS project relies on psychometrics to produce valid items that can be used to evaluate student misconceptions (Sadler et al., 2013).

Built upon qualitative research and psychometrics, DDMC assessments like the MOSART HS PS project captures alternative conceptions identified from rich qualitative interviews but gives them the power of quantitative assessments (Sadler, 1998). This measure of conceptual change has its strengths and weaknesses as any methodology does, according to Sadler (1998). The weakness of using interviews is that these methodologies are time-consuming and rely on relatively few subjects and are difficult to generalize to a larger population. Yet qualitative methodology has been the most productive way of investigating ideas in science; multiple-choice assessments built on current qualitative research can provide a foundation for appropriate generalizations (Sadler, 1998).

The authors of the MOSART HS PS project developed the instrument for a National Science Foundation (NSF) funded project whose original goal was to construct evidence-based measures of student understanding of high school-level physical science concepts in chemistry and physics (Sadler et al., 2013). The assessment reflects the content of the National Research Council (NRC) Science Education Standards and Framework and the Next Generation Science Standards (NGSS). While other instruments focus on one or a few concepts at a time, the MOSART HS PS project instrument is unique in that it utilizes the foundation of high school standards to develop an instrument to holistically assess areas of misconceptions based on current qualitative evidence.

MOSART HS PS Assessment Validation

According to Sadler (1998), items on the DDMC assessment are constructed, tested, and refined using classical test theory (CTT) or item response theory (IRT). CTT analyzes performance based on the total score of a participant (Novick, 1966). Although historically utilized in quantitative analysis of multiple-choice tests of student conceptions, CTT limits the generalization of results if the test population differs. Student scores are also test dependent and cannot be accurately compared to other forms of assessment. IRT is a probabilistic measurement model (Hambleton & Swaminathan, 1985). In IRT, several different statistical models are utilized to identify the student's individual test item score and that of the overall measure of the ability that the test was designed to evaluate. IRT aims to explain the relationship between unobservable attributes (the items themselves) and their observable outcomes (student performance). Using CTT and IRT for the development of the MOSART HS PS assessment offers a foundation for making predictions based on test outcomes and is more suited to generalizing those outcomes to larger populations (Sadler, 1998).

Chemistry Topics

For this project, there are 660 items in total from the MOSART HS PS project, of which 40% contain misconception distractors. The authors of the MOSART HS PS project also have a

30-item research test that has been utilized for pre- and post-testing of students (Sadler et al., 2013). This assessment has all the NGSS chemistry Disciplinary Core Ideas (DCI) covered and has been tested on 3,552 students in 113 classrooms. The NGSS chemistry DCIs are fundamental in understanding more complex ideas within or across science disciplines (Sarna et al., 2013). Utilizing the MOSART HS PS assessment for this project would allow for analysis of foundational, general chemistry knowledge, which has been shown important for organic chemistry success (Cooper & Klymkowsky, 2013; Cooper et al., 2012; Crandell et al., 2019).

Specifically, the MOSART HS PS assessment probes at three NRC standards of importance to organic chemistry foundations: (1) Properties and Changes in Properties of Matter, (2) Motions and Forces, and (3) Transfer of Energy (Sadler et al., 2013). Currently, topics presented in the research of student misconceptions in higher education chemistry courses include bonding structure changes, mechanisms, and thermodynamics of covalent bond reactions (Cooper et al., 2012; Crandell et al., 2019; Fischer et al., 2019; Stowe & Cooper, 2017). These complex topics in organic chemistry can be built on the solid foundation of properties of matter, kinetics (motion), and thermodynamics (transfer of energy) (Crandell et al., 2019, 2020). Therefore, as the MOSART HS PS assessment has been validated with high school students and is built on the foundational topics already seen as gatekeepers to deeper understandings in organic chemistry, this project predicts it is reasonable to utilize this assessment.

The Self-efficacy Survey

Dalgety, Coll, and Jones (2003) developed the Chemistry Attitudes and Experiences Questionnaire (CAEQ) to identify college chemistry student attitudes, self-efficacy, and learning experiences during their first year. Their larger study aimed at observing the factors that influence student enrollment choice. However, the authors identified their main impetus for developing the CAEQ was to investigate how secondary education influenced students' experiences in higher education. It was for this purpose that the CAEQ was chosen for this study. Dalgety, Coll, and Jones created the CAEQ to focus on basic, foundational knowledge that college students would have some previous experience in high school (Dalgety et al., 2003). Both high school chemistry and general chemistry teach basic concepts to undertake further chemistry courses. The CAEQ was formed on the idea that secondary school learning experiences influence those in higher education, specifically in attitudes towards chemistry and chemistry self-efficacy (Hill et al., 1990). The CAEQ consists of three sections (i.e., attitude towards chemistry, chemistry self-efficacy, and learning experiences).

Original Work on Self-efficacy

The development of CAEQ began with identifying issues with the most popular instruments that were utilized to measure student attitude toward science – the Scientific Attitudes Inventory II (SAI II) (Moore & Foy, 1997) and the Test of Science Related Attitudes (TOSRA) (B. J. Fraser, 1978). SAI II probed more towards science attitudes and the scientific culture that students experience, whereas the TOSRA focused on group work experiences in high school (Dalgety et al., 2003). For a higher education chemistry course, the SAI II and TOSRA would be inappropriate. Research into student perceptions and learning preferences heavily influenced the development of this instrument (Coll et al., 2002; B. Fraser & Goh, 2015; Nair & Fisher, 1999).

Dalgety et al. recognized student self-efficacy depends on the precise definition of their subject disciplines (2003). Their first steps were to define chemistry, attitudes towards chemistry, and chemistry self-efficacy. The term chemistry, in the CAEQ, focuses on chemistry culture and the patterns for thinking, feeling, and acting that are acquired through the process of learning chemistry theory, skills, and values. Chemistry self-efficacy is described as a student's judgment of their own capabilities to perform actions required to successfully accomplish specific types of outcomes. This definition is based on the work of Albert Bandura (1977). The outcomes designed here relate to the three main learning environments presented to students in higher education chemistry – lectures, practical classes (laboratory), and tutorials.

Validity and Reliability

The CAEQ development was informed by Trochim's concept of construct validity (1999). According to Trochim, an instrument has high construct validity if it has both translation and criterion validity. Translation validity is concerned with the link between item design and administration. If the theoretical constructs are well defined, and the items are good translations of the theoretical constructs, then the instrument is deemed to possess translational validity (Trochim, 1999). Criterion validity considers operationalism and whether the operationalism gives conclusions that are expected based on the theoretical constructs. In order to address validity, Dalgety et al. utilized a sound theoretical framework involving social learning theory, inclusive definitions, and evaluated student perceptions in high education chemistry through investigation of the literature (2003).

A panel of experts and a cohort of students representative of the intended population of college science participants were identified in the development of the CAEQ. Using a semi-structured interview protocol, the panel of experts learned the viewpoints of chemistry faculty and chemistry graduate students to develop the items in the CAEQ. A specialist in the teaching of non-English-speaking-background students reviewed the instrument to understand the readability for students for whom English is a second language. Data was collected from three scales of the instrument (attitude, self-efficacy, and learning experiences). Participants enrolled in a New Zealand first-year chemistry course from varying institutions were surveyed at the beginning and end of the semester (Dalgety et al., 2003). Each administration was subjected to factor analysis and statistical discriminant validity that suggest the CAEQ has high discriminant validity. To assess the reliability of the subscales, the authors conducted a Cronbach alpha which resulted in an average reliability of 0.74 at the beginning of the semester and 0.84 at the end of the semester. Dalgety et al. identified the reliability is similar to the TOSRA and other self-efficacy scales in other disciplines (2003).

Construct validity for the CAEQ was further examined by investigating the correlations of chemistry majors and nonmajors (Dalgety et al., 2003). The chemistry majors showed significantly more positive attitudes towards chemistry and a higher chemistry self-efficacy than nonmajors. Predictive validity was examined by correlations of the estimated mean response for learning experiences (third subscale) with the attitude and self-efficacy subscales (first and second accordingly). Using Pearson's correlation coefficient, all correlations were significant ($p < .01$). The CAEQ, therefore, has high predictive validity in that it was able to show learning experiences are influenced by attitude and self-efficacy and vice versa. Overall, the CAEQ has high translation and criterion validity. It is likely that the CAEQ will provide data from which valid conclusions can be drawn based on the theoretical constructs of the subscales.

The subsection which investigates chemistry self-efficacy will be the portion of the CAEQ that will be utilized in this project. There are a total of 17 items measuring different aspects of chemistry self-efficacy (i.e., learning chemistry theory, applying chemistry theory, learning chemistry skills, and applying chemistry skills) (Dalgety et al., 2003). For this study, items relating to chemistry laboratory skills and theory should not be utilized since this study is not investigating the laboratory portion of chemistry. The five items that were chosen probe at students' self-efficacy beliefs regarding applying chemistry knowledge in the lecture portion of organic chemistry.

Narrowing the Focus and Rationale

Current research has analyzed this subsection by itself and confirmed the validity and reliability (Villafañe et al., 2014). In order to explore diverse students' trends in chemistry self-efficacy in a first-year preparatory chemistry course for science majors (Villafañe et al., 2014), five of the CAEQ statements from the self-efficacy subsection were chosen (Appendix A) to investigate Chemistry self-efficacy (CSE) (Villafañe et al., 2014). The CSE survey was administered five times during the semester course. Villafañe et al. (2014) reported an internal consistency reliability using a Cronbach's alpha coefficient for each of the five CAEQ questions chosen to range from 0.79 to 0.87. The authors confirmed these values show good internal consistency reliability for the subset chosen. A Confirmatory Factor Analysis was also performed on the CSE survey for each of the five times it was administered by the researchers. Fit indices for each administration displayed a reasonable fit for the 1-factor solution. Authors reported the CFI ranged from 0.88 to 0.96, and the SRMR values ranged from 0.04 to 0.06 (Villafañe et al., 2014). This analysis shows it is reasonable to interpret the results from the CSE survey as measuring one construct – that of chemistry self-efficacy belief regarding applying chemistry knowledge to the tasks in a lecture course.

Demographic Information

Science courses in higher education are known for being difficult, inaccessible classes, with students commonly resorting to rote memorization and experiencing challenges in successfully completing courses (Grove et al., 2008). Chemistry courses specifically have an average attrition rate of 40% across universities (Grove et al., 2008). The daunting reputation and abstract nature of chemistry courses facilitate the idea that they are one of the most challenging courses for students to complete (Cooper et al., 2013; Grove et al., 2008; Horowitz et al., 2013). These attrition rates are even higher for underrepresented minority groups (URM), students whose culture, race, and gender identify as minority groups (Elbulok-Charcape et al., 2019; Villafañe et al., 2014). For this reason, research in the past decade has focused its attention on the social and emotional role of education, specifically in higher education science courses (Flaherty, 2020).

As referenced in Chapter 2, it has been observed that gender and ethnicity may play a role in student success and retention (Kokka, 2018; Morales-Doyle, 2017; Rocabado et al., 2019). Therefore, demographic information was added at the end of this instrument. Students were asked to report their gender, ethnicity (underrepresented status), and experience in organic chemistry. This experience question probed at understanding whether the participant was taking organic chemistry for the first time or if they had unsuccessfully attempted the course before. These demographic questions were asked at the end of the survey. There are seven questions attributed to analyzing the participant's "under-represented" status. These questions probe at ethnicity, first-generation status, and Pell Grant eligibility (Appendix A).

Combination

This study will employ the instrument in this order: 30 MOSART HS PS items, the five CAEQ items, and the three demographic topics. The MOSART HS PS items were placed at the beginning of the survey to probe the knowledge of students first. The CAEQ items following the entire MOSART HS PS items allowed students to assess their own self-efficacy once presented with the foundational chemistry topics. Demographic information was assessed last. It is possible that the order of the instrument will have unforeseen effects.

One reason for assessing the misconceptions prior to self-efficacy is to identify the Dunning-Kruger effect in this project. The Dunning-Kruger effect is prevalent in chemical education research as students with false high self-efficacy usually predict their grade outcomes to be higher than what is accurate (Gibbons & Raker, 2019). Researchers suggested this group of students with false self-efficacy may benefit from alternative pedagogical approaches (Casselman et al., 2017; Gibbons & Raker, 2019; Kruger & Dunning, 1999). These alternative approaches allow the learner to confront their current conceptions in an attempt to resolve misconceptions.

To score the questions appropriately, I used the following system:

- For questions 1-30, a score of a correct or incorrect answer = zero points; a score of choosing the misconception option = 1 point. The sum of the MOSART HS PS items was labeled a participant's "misconception score"
- For the CAEQ questions 31-35, a score of strongly disagree = one point, disagree = two points, undecided = three points, agree = four points, and strongly agree = five points. The sum of the CAEQ items was labeled a participant's "self-efficacy score"

Participants and Procedure

I surveyed 97 participants, adults enrolled in organic chemistry first-semester courses during the Fall 2022 semester from a variety of public and private institutions. The sample consisted of participants who are enrolled in an organic chemistry first-semester course at a four-year university in Southern California. Organic chemistry typically occurs in the second-year studies for biology, chemistry, and health science majors as well as any other students pursuing graduate degrees in the medical field (e.g., PT, PA, pharmacy). Organic chemistry students have been chosen here due to the high attrition rates currently being seen across the nation (Grove et al., 2008; Horowitz et al., 2013). Focusing on student misconceptions and the relationship to student self-efficacy may be a novel approach to addressing these challenges in higher education science courses.

The study was conducted through in-person campus visits in which students received consent information (Appendix B). The survey was delivered and completed on Qualtrics using iPads. Data were collected during the first two weeks of the fall 2022 semester (August – September) as well as the last two weeks of fall 2022 semester (December). Both collections contained identical survey questions and order. The data collection timing was chosen to assess misconceptions prior to the organic chemistry content (pre-semester) as well as after (post-semester). By surveying during the first two weeks of the semester, I was more likely to probe the knowledge and self-efficacy of participants obtained in previous chemistry courses (e.g., high school chemistry and general chemistry). Reissuing the survey again at the end of the semester, aided in assessing if their foundational knowledge or self-efficacy changed throughout the semester.

Working with the department chairs at the universities, I emailed students enrolled in organic chemistry participation dates and times. These times varied for convenience of the participants. Completing the survey took 20 minutes and any student that participated at the beginning of the semester was invited back to complete the survey again in December. Identifiable data was collected to link the two survey dates and then deidentified during data analysis. Participation was voluntary and any student could choose not to complete the survey once they had begun it. Participants could also choose not to return for the second survey at the end of the semester. There was no course credit or compensation for participation.

Data Collection and Treatment

Data were collected using Qualtrics which allowed for automated data entry into excel. Data were entered into Excel using identifiable information (e.g., first and last name) in order to match the pre- and post-semester survey results. Then, data were deidentified for analysis. Of the 97 surveys, all pre-semester surveys were complete where every question was answered. When analyzing the post-semester surveys, only 47 surveys were completed.

All computer files of data and data analysis were stored on the cloud server, Google Drive, which Chapman University provides students. In excel, misconception scores and self-efficacy scores for both pre- and post-semester data were calculated. Additionally, gender, underrepresented status, and experience in organic chemistry were dichotomized. Gender was able to be dichotomized as none of the participants identified as non-binary or other genders.

In order to identify the participant make-up with regard to misconceptions and self-efficacy, I used the survey data to calculate standard central tendency measures (means, standard deviations). Then, I used statistical analyses to determine whether there were any relationships among the number of misconceptions held by the participants and their self-efficacy. I also investigated relationships between gender, underrepresented status, and experience in organic chemistry. Specifically, I utilized a Spearman's Rho correlation coefficient and a multiple regression analysis to explore the relationships between the variables. The results are described in the next Chapter.

Chapter 4: Results

This study explored the relationships among student held organic chemistry misconceptions and their organic chemistry self-efficacy at the beginning and the end of a fall semester of organic chemistry. To properly evaluate these relationships, university students enrolled in organic chemistry first semester completed a survey with the following components:

- 30 distractor driven multiple choice questions probing misconceptions within foundational chemistry topics with scores ranging from 0 to 30 (higher score indicated more misconceptions).
- Five Likert-scaled questions addressing chemistry self-efficacy with scores ranging from 5 to 25 (higher score indicates higher self-efficacy in chemistry courses).
- Three demographic sections (e.g., gender, underrepresented status, and experience in organic chemistry).

In this Chapter, I report the results of this study. The Chapter begins with a narrative of the participants and follows with a description of how the data were evaluated and the justification for the analyses. Then, I address the research questions described in Chapter 1.

Characteristics of the Participants

At the beginning of the fall 2022 semester, 97 students were surveyed. Of the 97 participants, 48% (n = 47) returned for the post-semester survey. The demographics of the participants for both pre- and post-semester are presented below in Table 4.1 and 4.2 respectively. The pre-semester sample included more females (69%) than males and identified largely as not underrepresented (77%) and experiencing their first time taking organic chemistry (88%). The post-semester sample included more females (71%) than males and identified largely as not underrepresented (89%) and experiencing their first time taking organic chemistry

(91%). None of the participants identified as non-binary or unidentified. Therefore, gender became a dichotomous variable. To attain racial status, the seven questions (Appendix A) followed multiple definitions of "underrepresented" identities. If students identified as underrepresented in any of these definitions, they were reported so in Table 4.1.

Table 4.1

Demographic Characteristics of Participants Pre-semester

Characteristic	n	%
Gender		
Female	67	69.1
Male	30	30.9
Representation Status		
Not underrepresented	75	77.3
Underrepresented	22	22.7
Experience		
First time in organic chemistry	85	87.6
Second time in organic chemistry	12	12.4

Table 4.2

Demographic Characteristics of Participants Post-semester

Characteristic	n	%
Gender		
Female	32	71.1
Male	13	28.9
Representation Status		
Not underrepresented	40	88.9
Underrepresented	5	11.1
Experience		
First time in organic chemistry	41	91.1
Second time in organic chemistry	4	8.9

In order to address the secondary research question regarding the most prevalent chemistry-oriented misconceptions held by undergraduate students beginning a first-semester organic chemistry course, the percentage of participants who selected the misconception was tabulated for each NGSS Standard. Table 4.3 reports the misconceptions that were most prevalent. In both the pre- and post-semester, the NGSS Standard PS1_A iii was the most common to be identified as a misconception. This standard relates to the structure and properties of matter in relation to how particles bond (combine) to form matter.

Table 4.3

Analysis of Common Misconception Items

NGSS Standard	NGSS Description	% Misconceptions Pre-semester	% Misconceptions Post-semester
PS1_A	Structure and Properties of Matter		
i	Atomic Structure	15.88	17.33
ii	Periodic Table Arrangement	7.73	8.15
iii	Bonding	25.00	52.22
iv	Energy	7.73	5.56
PS1_B	Chemical Reactions		
i	Reactivity of redox reactions	13.40	13.89
ii	Equilibrium	16.49	15.56
iii	Conservation of Mass	24.74	18.89
PS1_C	Nuclear Processes		
i	Isotopic Decay	23.02	20.74
PS3_D	Energy in Chemical Processes		
i	Conservation of Energy	6.19	5.56

Assessing the Normality

In order to assess which statistical analyses were appropriate to employ, it is imperative to assess the normality of the data. It is also important to discuss how the data meet the assumptions of each statistical test. After the discussion of normality, I present the results of the chosen statistical tests.

The mean, median and standard deviations of the misconception scores and self-efficacy scores for pre-semester surveys are tabulated in Table 4.4. Scores are listed in Table 4.4 as a percentage of the total possible. Three groups were created to assess for student differences in pre- and post-semester surveys. If participants only took the pre-semester survey and did not return for the post-semester survey, they were included in the “pre only” group. Any participant that attended both data collection in the pre- and post-semester sessions were identified as “pre” and “post” groups. A t-test was utilized to assess if there were any differences in the pre- and post- groups misconception score, self-efficacy score, and correct score. Table 4.4 shows there were no significant changes in the scores for pre- or post-semester outcomes.

Table 4.4

Means, Standard Deviations, and standard error for Misconception Assessment and Self-Efficacy Assessment

	MOSART Misconception Score			Self-Efficacy Score			MOSART Correct Score		
	Pre only	Pre	Post	Pre only	Pre	Post	Pre only	Pre	Post
mean	0.15	0.15	0.14	0.87	0.77	0.79	0.72	0.74	0.75
SD	0.08	0.11	0.08	0.21	0.12	0.11	0.17	0.17	0.15
N	52	45	45	52	45	45	52	45	45
SE	0.05	0.05	0.05	0.05	0.06	0.06	0.06	0.07	0.06
T-test			0.30			0.16			0.34

Figure 4.1 shows the averages and standard deviations for the means presented in table 4.4.

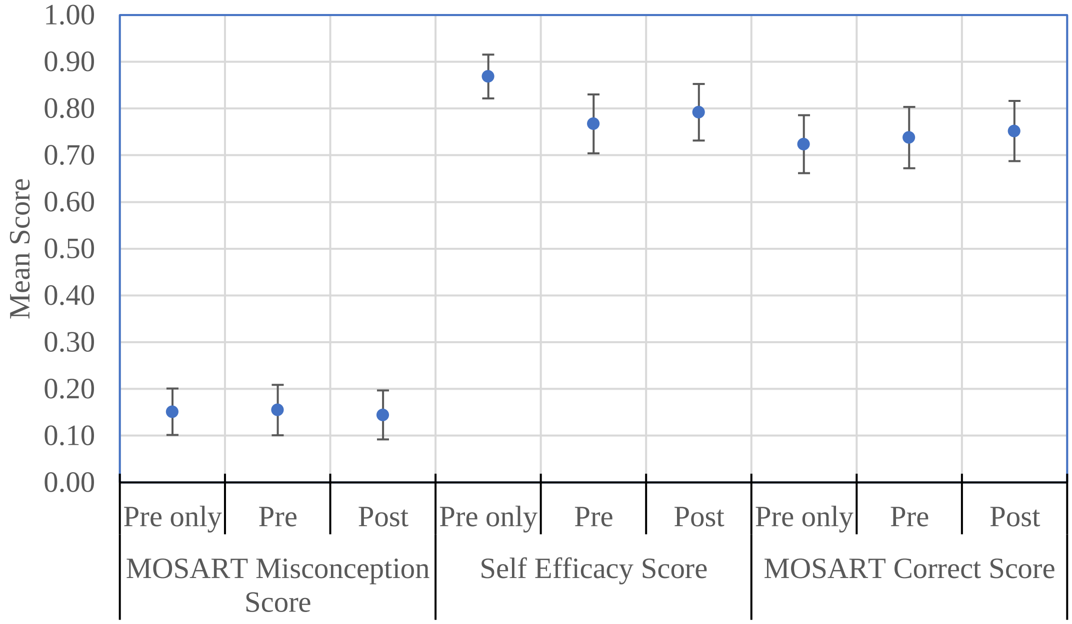
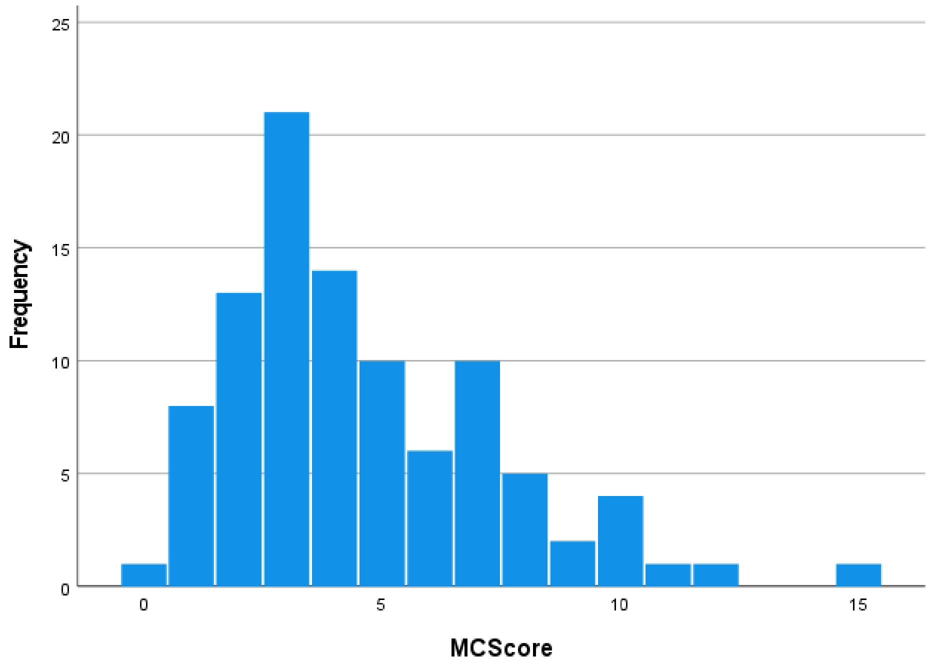


Figure 4.1: *Means and standard errors of the mean for Misconception Assessment and Self-Efficacy Assessment.*

The pre-semester scores on the MOSART HS are shown below in Figure 4.1. Skewness and kurtosis, the symmetry of the distribution of the scores and the shape of the distribution in terms of its peakedness respectively, of the MOSART HS Scores (skewness = 1.044, kurtosis = 1.188) fall within the acceptable range of normality, which is ± 1 or ± 2 (Pallant, 2016). Although a Kolmogorov Smirnoff test, which tests for normality, indicated that the misconception score (statistic = 0.170, $p < 0.001$) distribution violates normality.



Mean = 4.59
Std. Dev. = 2.813
N = 97

Figure 4.2: *Histogram of pre-semester misconception scores*

The pre-semester scores on the CAEQ are shown below in Figure 4.2. Skewness and kurtosis, the symmetry of the distribution of the scores and the shape of the distribution in terms of its peakedness respectively, of the CAEQ scores (skewness = -0.753, kurtosis = 0.297) fall within the acceptable range of normality, which is ± 1 or ± 2 (Pallant, 2016). Although a Kolmogorov Smirnoff test, which tests for normality, indicated that the self-efficacy scores (statistic = 0.139, $p < 0.001$) distribution violates normality.

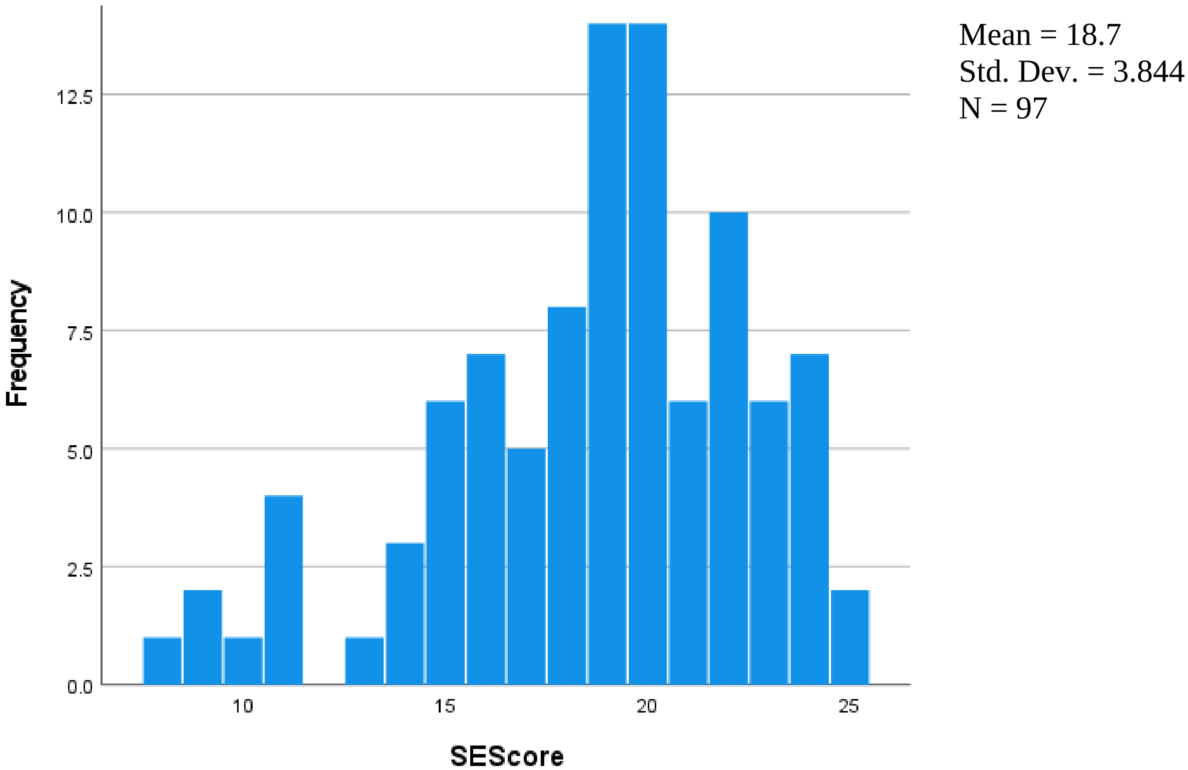


Figure 4.3: *Histogram of pre-semester self-efficacy scores*

The post-semester scores on the MOSART HS are shown below in Figure 4.3. Skewness and kurtosis, the symmetry of the distribution of the scores and the shape of the distribution in terms of its peakedness respectively, of the MOSART HS Scores (skewness = 0.252, kurtosis = -0.917) fall within the acceptable range of normality, which is ± 1 or ± 2 (Pallant, 2016). The Kolmogorov Smirnoff test, which tests for normality, indicated that the misconception score (statistic = 0.138, p =0.031) has a normal distribution.

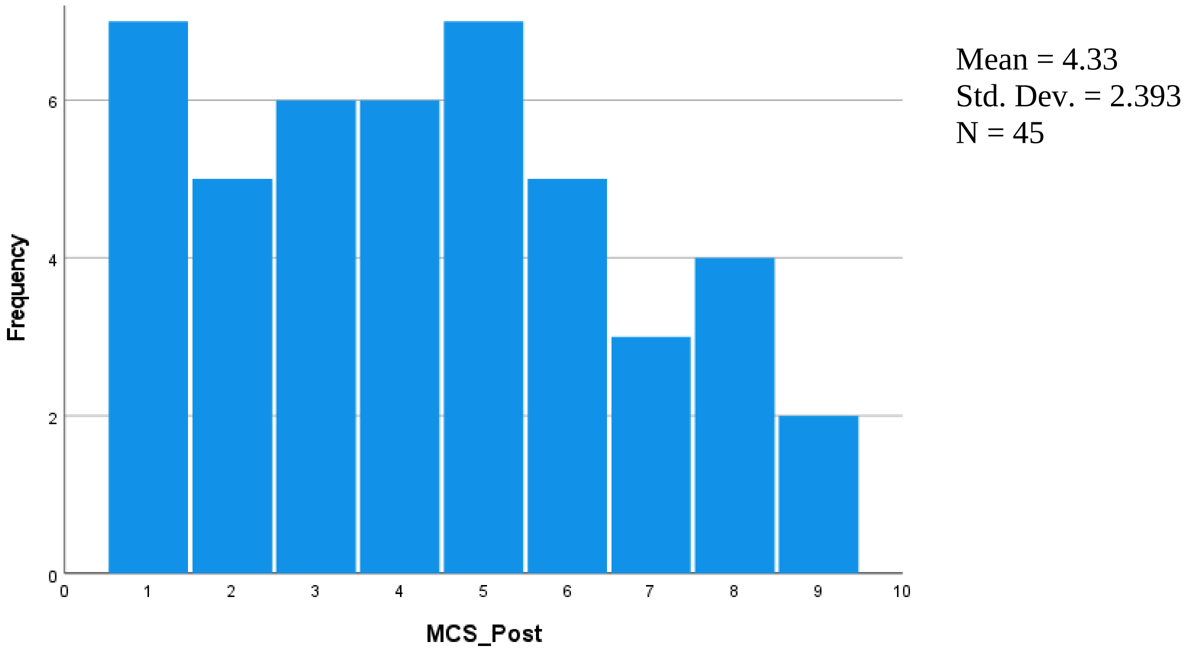


Figure 4.4: *Histogram of post-semester misconception scores*

The post-semester scores on the CAEQ are shown below in Figure 4.4. Skewness and kurtosis, the symmetry of the distribution of the scores and the shape of the distribution in terms of its peakedness respectively, of the CAEQ Scores (skewness = 0.098, kurtosis = -0.012) fall within the acceptable range of normality, which is ± 1 or ± 2 (Pallant, 2016). The Kolmogorov Smirnoff test, which tests for normality, indicated that the self-efficacy scores (statistic = 0.111, p = 0.200) is normally distributed.

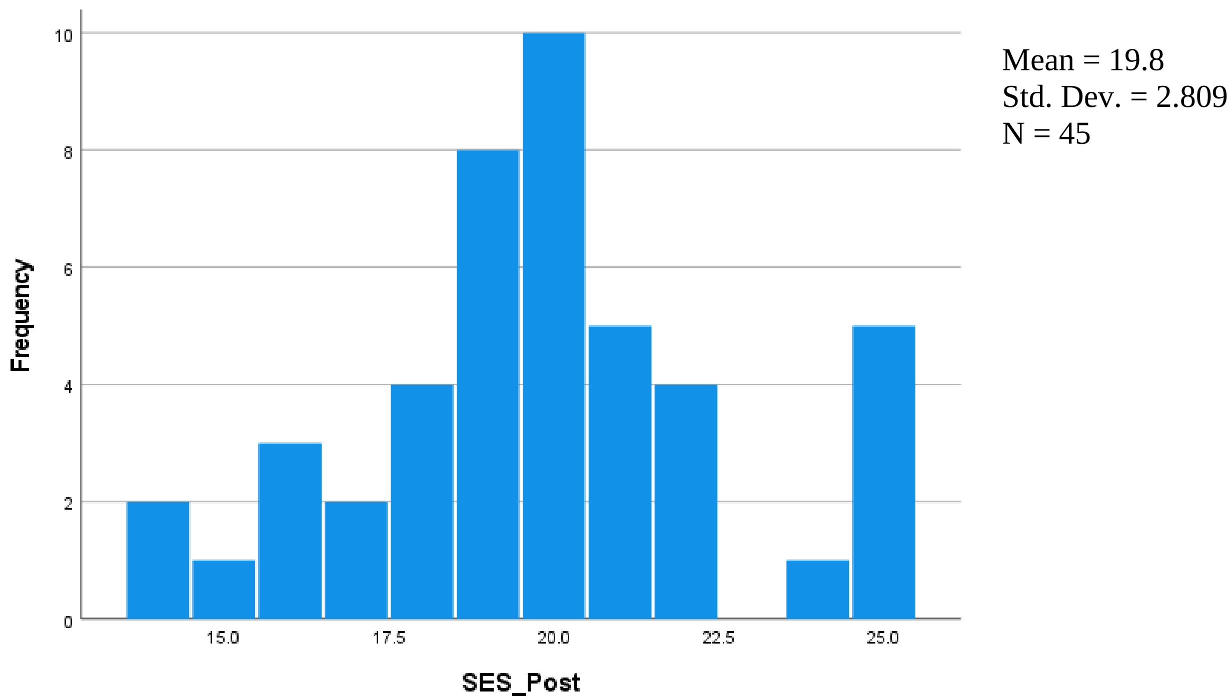


Figure 4.5: *Histogram of post-semester self-efficacy scores*

Data Analysis Description and Rationale

The current data set did not fully meet all the assumptions acceptable for parametric analysis. Thus, the data were analyzed using a non-parametric correlation statistical analysis: the Spearman's Rho correlation. A multiple regression analysis was also utilized in this study. Although not non-parametric, there are several underlying assumptions of parametric statistics (e.g., normality, large sample size, independence of observations, apparent linearity, and homoscedasticity) (Pallant, 2016). One additional assumption of this statistical test may be problematic: the regression analysis is designed for continuous variables. This study employed the CAEQ which is a Likert scale survey instrument. However, it is acceptable to utilize the score from the CAEQ as a continuous variable based on intervals (Norman, 2010).

When one or more questions were not completely answered, the survey was considered not complete. Using these incomplete results could introduce errors into the sample and would require multiple imputation (Manly & Wells, 2015). According to Manley and Wells (2015), multiple imputation aims to allow for the uncertainty about missing data by creating plausible imputed data sets (2015). An alternative to multiple imputation would be excluding those surveys that are not complete. Surveys that were fully complete were deemed acceptable for data analysis.

For all acceptable survey results, the MOSART HS PS items were calculated for the misconception score (misconceptions chosen total) based on the previous work of misconception DDMC assessments (Chen, Sonnert, Sadler, & Sunbury, 2020). Higher scores on the misconception score revealed high instances of misconceptions chosen in the DDMC assessment. The items from the CAEQ were coded for a five-point Likert scale. All statements are written positively in the CAEQ items, which allows for scoring as follows: 'strongly disagree' = 1 point and a 'strongly agree' = 5 points. Higher numbers on the CAEQ (4 or 5) indicated that students feel very confident about completing the given task, while lower numbers (1 or 2) indicated students were not so confident about completing the given task. Each participant had a misconception score as well as a chemistry self-efficacy score for pre-semester data collection. Along with these continuous variables, the three answers relating to demographic information were tabulated and dichotomized for SPSS analysis.

The demographic information was analyzed in the multiple regression analysis. Gender in the demographic items was treated as dichotomous: male or female. Underrepresented status was determined through four questions identifying ethnicity and first-generation status. Finally, experience in organic chemistry was identified through one question. Participants were asked if they had attempted organic chemistry before or not. Experience was dichotomized giving non-experienced status to participants taking organic chemistry for the first time. These data were entered into SPSS.

Correlation Among Variables

The relationship between two variables can be elucidated by computing the correlation coefficient (Urdan, 2017). The most appropriate statistic to use in this project is the Spearman's Rho correlation. The Spearman's Rho correlation aids in determining the strength and direction of a linear relationship between two continuous variables (Urdan, 2017). In this study, the CAEQ is an ordinal variable as it is based on the Likert scale. However, it has been acceptable to treat this summed score as a continuous variable based on, not necessarily equal, intervals (Norman, 2010).

To address the primary and secondary research questions regarding the existence and nature of a relationship between chemistry-oriented misconceptions held by university students and their organic chemistry self-efficacy in both pre- and post-semester times, Spearman Rho correlations were conducted on the data. Table 4.6 and 4.7 (below) present the correlation results between each measurement. The correlations that are significant at the $p > 0.01$ level are indicated. The characterization of the strength of the correlation is based on the guidelines described by Cohen (1988): $r = 0.1 – 0.29$ is a small correlation, $r = 0.3 – 0.49$ is a medium correlation, and $r = 0.5 – 1.0$ is large.

Table 4.5

Nonparametric Correlations Pre-semester

	Misconception Score	Self-efficacy Score	Gender	Representation Status	Experience
Misconception Score	-	-.399**	.068	.150	.331**
Self-Efficacy Score	-	-	-.198	-.152	-.076
Gender	-	-	-	-.010	.116
Representation Status	-	-	-	-	-.054
Experience	-	-	-	-	-

**Correlation is significant at the 0.01 level (2-tailed).

Table 4.6

Nonparametric Correlations Post-semester

	Misconception Score	Self-efficacy Score	Gender	Representation Status	Experience
Misconception Score	-	-.495**	.011	.036	.048
Self-Efficacy Score	-	-	-.206	-.099	.267
Gender	-	-	-	-.087	-.145
Representation Status	-	-	-	-	.138
Experience	-	-	-	-	-

**Correlation is significant at the 0.01 level (2-tailed).

These results indicate that misconception score was moderately, negatively correlated with self-efficacy (-0.399) in the pre-semester survey. The misconception score was strongly, negatively correlated with self-efficacy (-0.495) in the post-semester survey. Interestingly, the misconception score was also moderately correlated with experience (0.331) in the pre-semester survey. This was a finding outside the scope of the initial research questions in this study. This finding will be briefly discussed in the next Chapter.

Multiple Regression Analysis

Based on the strength of the correlation results, it was necessary to investigate the interactions between the variables to assess the primary research question: To what extent does a relationship exist between chemistry-oriented misconceptions held by university students and their organic chemistry self-efficacy? Multiple regression was used for pre-semester data to predict the value of a variable based on the value of two or more other variables (Urdan, 2017). In order to perform a regression analysis, multiple assumptions have to be met. The first two assumptions relate to study design: both the dependent and at least one of the independent variables must be continuous (Urdan, 2017). The dependent variable is the outcome or target variable, which needs to be a continuous variable. In this project, the dependent variable was organic chemistry self-efficacy scores. The variables that are being used to predict the dependent variable are called the independent variables. Independent variables can be continuous or categorical. For this project, chemistry-oriented misconception score (continuous), gender (categorical), underrepresented status (categorical), and experience (categorical) are the independent variables I explored. Multiple regression analysis examined the relationship among all of the scales and the predictive values.

Similar to the Spearman's Rho correlation, multiple regression makes assumptions about the data and the distribution of scores (Pallant, 2016). According to the sample size requirements outlined by Tabachnick and Fidell (2019), for four independent variables as proposed here, the sample size will need to be 82 (following $N > 50 + 8m$; where m is the number of independent variables). Only the pre-semester data were utilized for the regression analysis due to the fact that the post-semester data does not meet the participant sample size requirements.

Further, there are more assumptions in order to conduct a multiple regression analysis. These include independence of observations, the presence of a linear relationship, homoscedasticity of residuals, multicollinearity or singularity, the lack of significant outliers, and check that the residuals are approximately normally distributed (Laerd Statistics, n.d.; Pallant, 2016). Multiple regression does not work well when the independent variables are highly correlated or when one independent variable is a combination of another.

Many of these assumptions can be assessed in the model summary of the linear and multiple regression analyses. There was independence of residuals, as assessed by a Durbin-Watson statistic of 2.076 (linear) and 2.101 (multiple regression). Utilizing a scatterplot, a linear relationship between the two continuous variables was visually confirmed. There was homoscedasticity, as assessed by visual inspection of a plot of studentized residuals versus unstandardized predicted values. Multicollinearity occurs when there are two or more independent variables that are highly correlated with each other. This data set does not have any independent variables with correlations greater than a 0.7 correlation coefficient. Along with this, tolerance and VIF were also verified. The tolerance were all greater than 0.1 and the VIF values were all less than 10 which indicated that the data set does not have an issue with collinearity. Finally, a visual analysis of the histogram and P-P plots confirmed an approximately normal distribution.

As shown above, the data sets meet the assumptions of a regression analysis (Laerd Statistics, n.d.). The first regression analysis was conducted with misconception score and self-efficacy. This linear regression indicated a R^2 of 0.110 and the adjusted $R^2 = 0.101$ ($F(1,95) = 11.797$, ANOVA significance < 0.001). This finding (Table 4.8) indicated that misconception scores alone accounted for 11% of the variation in self-efficacy scores. Additionally, VIF values (the inverse of the tolerance values that indicate how much variability in the independent variables is not explained by other independent variables) and collinearity values indicate that the data meet the assumptions of multiple regression (Pallant, 2016). As the maximum Cook's distance (0.203) falls below one (Tabachnik & Fidell, 2013), outliers appear not to have a significant impact on the analysis.

Table 4.7

Regression Analysis among Self-efficacy Score and Misconception Score

Variable	Standard Beta coefficient	Partial correlation coefficient
Misconception Score	-.332**	-.332**

**Significant at the 0.01 level

Secondly, another regression was conducted with misconception score, demographics (gender, underrepresented status, and experience), and self-efficacy score. The multiple regression indicated a R^2 of 0.161 and the adjusted $R^2 = 0.125$ ($F(4,92) = 4.414$, ANOVA significance = 0.003). This finding indicated that these variables accounted for 16% of the variation in the Self-efficacy scores. Of that 16% variation, the Beta and partial coefficients listed in Table 4.9 below indicate that the misconception score accounts for the majority of the variability in the self-efficacy score. As the maximum Cook's distance (0.119) falls below one (Tabachnik & Fidell, 2013), outliers appear not to have a significant impact on the analysis.

Table 4.8

Regression Analysis among Self-efficacy Score and All Other Variables

Variable	Standard Beta coefficient	Partial correlation coefficient
Misconception Score	-.297**	-.290**
Gender	-.183	-.181
Representation Status	-.138	-.136
Experience	.005	.005

**Significant at the 0.05 level.

It is important to note that the only significant variable in this multiple regression model is the misconception score. Gender, underrepresented status, and experience were not significant variables. The meaning of this addressed in the next Chapter. Further investigation into the interactions between the variables was also conducted via a logistical regression analysis. There were no significant interactions between the variables.

Conclusions

This Chapter has presented results for studying the relationship between chemistry-oriented misconceptions held by university students and their organic chemistry self-efficacy. Results indicated there was a relationship between misconceptions and student self-efficacy in both the pre- and post-semester of organic chemistry. The next Chapter will discuss the implications of these results, limitations of this study, and the opportunities for future research.

Chapter 5: Discussion

This dissertation was an investigation into chemistry-oriented misconceptions held by university students and their organic chemistry self-efficacy. In this Chapter, I summarize the study and consider the implications of the results. I compare the results of this research to the literature discussed earlier, address the limitations of my research, and discuss possibilities for future research.

Summary of the Study

The purpose of this study was to investigate the relationship between chemistry-oriented misconceptions and university student organic chemistry self-efficacy. To address this desired goal, 97 students were surveyed regarding their misconceptions in foundational chemistry knowledge, their chemistry self-efficacy, and their basic demographic information. During the first two weeks of the fall semester, students completed a 30-item MOSART HS (Sadler et al., 2013) to assess their chemistry-oriented misconceptions. To assess chemistry self-efficacy, students completed a five-item CAEQ (Dalgety et al., 2003). Students also reported their demographic characteristics (e.g., gender, underrepresented status, and experience in organic chemistry).

Of the 97 survey respondents, 45 returned to repeat the survey at the end of the semester. I calculated the scores of the pre- and post-semester results for each instrument and used the Spearman's Rho correlation to explore the relationship between each variable. In addition, a linear and multiple regression analysis were employed to further investigate the relationships between the variables to predict and explain the variation in chemistry self-efficacy scores.

Summary of the Results

The mean score for the CAEQ was 18.70 (out of 25) at the beginning of the semester, which compares as high chemistry self-efficacy to previous research (Villafañe et al., 2014). The mean correct score for the MOSART HS at the beginning of the semester was 21.91 (out of 30), which appears as higher than middle school or high school student results (Chen, Sonnert, Sadler, & Sunbury, 2020; Sadler et al., 2013). The mean misconception score for the MOSART HS assessment at the beginning of the semester was 4.59 (out of 30).

At the end of the semester, the mean score for the CAEQ was 19.80 (out of 25) which again compares as high chemistry self-efficacy (Villafañe et al., 2014). The post-semester mean correct score for the MOSART HS was 22.56 (out of 30) and the post-semester mean misconception score for the MOSART HS was 4.33 (out of 30). There is difficulty in comparing the results of the MOSART HS assessment (for correctness or misconception strength) as this is the first time the assessment has been utilized in the higher education setting. The higher correct scores and lower misconception strength appears to be understandable due to the fact that participants in this project have all taken and passed general chemistry.

The misconception score was significantly and negatively correlated with student chemistry self-efficacy (r = -0.399) at the beginning of the semester as well as at the end of the semester (r = -0.495). Experience in organic chemistry showed a moderate, positive correlation to misconception strength as well (r = 0.331) at the beginning of the semester.

A linear regression analysis indicated that misconception scores accounted for 11% of the variance in self-efficacy scores. A multiple regression analysis indicated that the variables (misconceptions, gender, underrepresented status, and experience) accounted for 16% of the variance in self-efficacy scores for organic chemistry students, with the majority of that variance being misconception scores (29.7%). In both of these analyses, misconception score was the only significant variable. Gender, underrepresented status, and experience were not significant in explaining the the variance in the self-efficacy scores.

Implications

In this section, I analyze the results of this dissertation and compare them to the existing literature. I begin by exploring the results here that are similar to previous research in foundational knowledge in higher education chemistry courses, misconceptions in chemistry, and higher education chemistry self-efficacy. I conclude with a discussion on the importance of the relationship held between misconceptions and self-efficacy in organic chemistry courses.

Foundational Chemistry Knowledge

The most common misconception held by participants in this study focused on structure and properties of matter, specifically in the bonding category labeled PS1_A. The participants misconceptions focused on the spatial and bonding patterns of atoms and small molecules. Results here identified that the number of participants forming misconceptions in this topic increased at the end of the semester. Similar to previous research in chemistry education, O'Dwyer and Childs (2015) identified the greatest difficulties for novice learners related to the macroscopic to submicroscopic levels of chemistry. Their study focused on evidence-based teaching in a high school classroom and pedagogical reforms that could mitigate poor understanding.

Pedagogical reforms have also been studied in relation to the foundation topics of subatomic particles and bonding by King, et. al. (2019). In this study, King created a pre-organic chemistry preparatory course to review topics she identified as prerequisite content. This content included bonding, structure, and electron configuration which are covered in the NGSS standard

PS1_A. King et. al. (2019) found that students were lacking in the understanding of these topics and the prerequisite course became a refresher for them prior to tackling organic chemistry. From these studies, it is apparent that students may be entering organic chemistry with poor knowledge in previous topics in chemistry that are accepted as important by the scientific community (King, et. al., 2019). However, a misconception related to atomic structure and bonding may be a roadblock to their increasing self-efficacy and success in the course. Pedagogical reform and review courses may not be enough to mitigate the misconception as we have seen here with the increase in participants selecting misconceptions in this topic.

Misconceptions in Organic Chemistry

It has been well established that teacher knowledge and identification of student misconceptions in chemistry early on can more effectively challenge them (Taber, 2010; Zoller, 1990). A teacher who is both familiar with common misconceptions and able to anticipate where and when the distorted learning began, is more equipped to contest them. This dissertation appears to stand as one of the first in higher education chemistry to probe for multiple areas where misconceptions could exist. It was shown here that students entering organic chemistry have an average correct score of 73.0% (21.91 out of 30) and a misconception score of 15.3% (average misconception score of 4.59 out of 30). The end of semester (post) results were an average correct score of 75.2% (22.56 out of 30) and an average misconception score of 14.4% (4.33 out of 30). Although this specific assessment has not been utilized in higher education chemistry populations, comparative research has been completed regarding the physical science concepts in middle and high schools as well as other DDMC science concepts in post-secondary education settings.

Sadler, Sonnert, Coyle, Cook-Smith, and Miller (2013) utilized a DDMC assessment for understanding the relationship between teacher knowledge and student learning in middle school physical science classrooms. Middle school students correctly scored 37.7% on pretests and 44.8% on post-tests. Although very different than this research, it is understandable that college students would have higher correct scores. These results, however, show that correct scores typically increase on post assessments as educators using traditional methods may have knowledge of common misconceptions and present them during the semester.

Chen, Sonnert, Sadler, Sasselov, et al. (2020) identified in a similar DDMC survey on their Astronomy and Space Science Concept Inventory an average misconception score of 22% (2.64 out of 12). Participants in this study were registered for a Massive Online Open Course (MOOC) and retention based on misconception score was analyzed. Although a different setting and science concept, the average misconception score was similar to results here.

Organic Chemistry Self-efficacy

With an average CAEQ, chemistry self-efficacy, score of 18.70 (individual 3.74 out of 5), students in this study exhibited moderate chemistry self-efficacy at the beginning of the semester. This dissertation found an average self-efficacy score of 19.80 (individual 3.96 out of 5) at the end of the semester. Villafañe et al. (2014), utilizing the same 5-Likert scale assessment noted self-efficacy scores of 16.3 (individual 3.26 out of 5) average out of 25 during a college preparatory chemistry course. Score differences in this study were not found between male and females in general which are similar to this dissertation. Villafañe noted differences were only taken into account when separating race/ethnicity. Generally, self-efficacy scores increased over the course of the semester for most participants. Ferrell and Barbera (2014) utilized a different 8-Likert scale assessment for self-efficacy in a first semester general chemistry and found an average score of 3.29. Similar to this and previous research, self-efficacy increased over the course of the semester.

Cordova et. al. (2014) assessed student prior misconceptions and self-efficacy regarding their scientific understanding of seasonal change in higher education students before and after an educational intervention. Self-efficacy reported an average of 8.29 out of 11 (3.77 comparative to a 5-point Likert scale) which is similar to the results of this dissertation. Misconception score was calculated based on two independent raters with a possible range of 0 to 35. Results identified an average misconception score of 6.06 out of 35 (17.3%) on their pre assessment and an average misconception score of 4.69 out of 35 (13.4%) on the post assessment. Analogous to this dissertation, results indicated that misconceptions do relate to self-efficacy in scientific concepts. Cordova further concluded that conceptual change interventions, working to identify and mitigate misconceptions, may positively impact self-efficacy.

Kallia and Sentence (2019) identified in high school computer science courses that participants with misconceptions in programming had significantly lower self-efficacy than their peers without misconceptions ($t = 3.614$). They also reported that participants with misconceptions in computer science had lower self-efficacy as well ($z = 3.415$). This result compares to results here in this dissertation.

Experience in Organic Chemistry

Interestingly, the misconception score was also moderately correlated with experience (0.331) in the pre-semester survey. Although, this was a finding outside the scope of the initial research questions in this study, exploring the possible implications is important to future research. Retention has been investigated thoroughly in chemistry higher education settings based on pedagogical reforms (Dagley, M., Georgiopoulos, M., Reece, A., & Young, C., 2016;

King et. al., 2019). The number of misconceptions in a science topic has never been to my knowledge correlated to experience and retention in higher education.

Factors Related to Chemistry Self-efficacy

In this study, the strongest relationship among variables was the correlation between chemistry-oriented misconceptions and chemistry self-efficacy at the beginning (r = -0.399) as well as at the end (r = -0.495) of the semester. The pre-semester misconceptions account for 11% of the variance in self-efficacy. As previous research postulated there is a relationship between misconceptions and self-efficacy in science topics (Cordova et al., 2014; Kallia & Sentance, 2019). Understanding how misconceptions in organic chemistry affect student self-efficacy is imperative to address the growing challenges revolving around student success in organic chemistry. This research supports the case for further investigations into the long-term relationship of misconceptions and self-efficacy in organic chemistry.

Impact on Chemistry Educators

The fact that there are students entering into organic chemistry with misconceptions that may affect their self-efficacy should be more understood by instructors in higher education. This research identifies there is a relationship that may not be mitigated with traditional instruction. As we identified with the initial t-test, there was no significant difference in the participants pre- and post-semester misconceptions scores which indicated that the semester of instruction in organic chemistry did not affect nor improve their foundational knowledge in chemistry. The misconceptions students enter in with may be hindering them from success. If organic chemistry instructors aim to enhance student learning of chemistry, we must grapple with the misconceptions in order to effectively change them.

Limitations and Recommendations for Future Research

There are several limitations to this study that offer recommendations for future research prospects. The diverse nature of the participant population regarding the origins of their foundational knowledge was not considered. Also, this study only investigated four-year university students in Southern California. Future research should inquire as to general chemistry and high school chemistry scores within multiple higher education settings (e.g., private, public, and community colleges) where organic chemistry is offered. The various high school backgrounds of these populations may have influence on misconceptions as well as self-efficacy in chemistry. Probing to chemistry grades or GPA could allow for a more effective measure of experience during the regression analysis.

Another limitation to this research is regarding the pre and post analysis. Factors within the classroom, within the laboratory, and within study groups or individualized studying may have affected self-efficacy and misconceptions of participants. Although difficult to control all of these factors, future research could survey more than twice in a given semester. An interesting project would involve a longitudinal study tracking misconceptions and self-efficacy multiple times throughout the first two years of chemistry curriculum (both general and organic chemistry). Accounting for pedagogy (e.g., flipped style, peer-led, or traditional styles) would also be interesting to probe as instructors utilizing different modes of instruction may influence the results.

Additionally, participants may have guessed on the survey. The choice of utilizing a DDMC assessment for misconception analysis greatly reduces this, however, in that students have only a 20% chance of identifying the misconception. The CAEQ is only one instrument currently validated in the literature aimed at identifying self-efficacy in chemistry. The 5-point

Likert scale may be limiting as other studies presented utilized an 11-point Likert scale for self-efficacy. Also, the use of full existing instrument in self-efficacy would allow for broadening the understanding of how a student's laboratory self-efficacy can influence that of lecture in organic chemistry.

Finally, it is also interesting to investigate student enrollment in other courses and chosen major and how that affects the variables presented here as well as retention. This dissertation received 46.4% of participants returning for the post-semester data collection. The other 53.6% of participants could have forgotten to return for the post-semester survey collection dates or possibly dropped the course. The significant correlation involving more misconceptions found with experienced students may lead to future studies involving pedagogical reform as well as retention in other courses. Future post-analysis may include grade outcome for the semester or retention status. This information could enhance the view of success.

Conclusion

This dissertation explored relationships between chemistry-oriented misconceptions and chemistry self-efficacy in organic chemistry university students. A survey of 97 students completed at the beginning of the first semester organic chemistry course was conducted to probe for foundational topics in chemistry, chemistry self-efficacy, and demographic information.

The results of this study indicated that the more chemistry-oriented misconceptions a student holds the lower their self-efficacy in organic chemistry. The most prevalent misconception involved bonding and spatial recognition of atoms and molecules which is imperative early on in organic chemistry. The negative relationship between the number of misconceptions and self-efficacy strengthened throughout the semester.

These data, which are similar in nature to those in previous studies, have broader implications for chemistry educators. As science educators agree that organic chemistry is important for STEM students in higher education, any misconceptions that may hinder student self-efficacy and success is problematic. The comparison between the pre- and post-semester results here indicated that only a few misconceptions are actually resolved throughout the course. The results may mean that students are not retaining new, correct information, or they are resorting to memorization of new material. This indicates that the assimilation and accommodation process may not be successful which could pose challenges in the future for student success and retention.

Given that organic chemistry courses are undertaken by many students in a variety of fields, a clear understanding of foundational knowledge and misconceptions is imperative for producing successful scientists. By understanding what misconceptions are present each semester and creating curriculum and pedagogy to help mitigate these misconceptions, educators may effectively enhance student self-efficacy and retention in STEM higher education. It is essential that chemistry educators continue to explore how students learn and accept organic chemistry into their foundational knowledge in order to positively affect the success of students.

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Appendix A: Survey Instrument

Part 1

MOSART HS PS Misconception Assessment

Please answer the following questions. In some cases, there may be more than one correct answer. However, each question has only one best answer. Choose the single best answer from the five choices for each question. Mark your answer sheet by completely filling in the circle on the sheet that matches your choice. If you change an answer, be sure to thoroughly erase your original choice.

1. Which of the following would a scientist say is true?
   a. An atom in a mirror is shiny.
   b. An atom in a cherry is red.
   c. An atom in a fur coat is soft.
   d. All of the above.
   e. None of the above.

2. If the nucleus of an atom was left undisturbed for several years, which of the following would most likely happen?
   a. Electrons would collide with the protons in the nucleus.
   b. Protons would lose their charge.
   c. The neutrons would become electrically charged.
   d. Some protons and neutrons would merge together.
   e. Nothing.

3. The atoms in all materials are alike because they have:
   a. nuclei.
   b. electrons.
   c. mass.
   d. Only two of the above.
   e. All of the above.

4. The difference between carbon-14 and carbon-12 is the:
   a. number of protons.
   b. number of electrons.
   c. number of neutrons.
   d. hardness of shells.
   e. type of neutrons.

5. If you were to hammer some gold into a thin sheet, the atoms:
   a. would each flatten out.
   b. weigh less.
   c. are pushed closer together.
   d. are unchanged.
   e. None of the above.

6. A portion of the Periodic Table is shown below.

N	O
P	S

Of the elements shown, which has chemical properties most like those of element S?
   a. N.
   b. O.
   c. P.
   d. All of the other elements are equally like element S.
   e. None of the other elements is like element S.

7. The Periodic Table is arranged according to the:
   a. number of protons in each element's atoms.
   b. color of each element.
   c. melting point of each element.
   d. phase of the element at room temperature.
   e. order in which the elements were discovered.

8. Which of the following is an element on the periodic table?
   a. Water.
   b. Salt.
   c. Carbon.
   d. Air.
   e. Blood.

9. Which of the substances below is **not** an element?
   a. Gold.
   b. Salt.
   c. Neon.
   d. Iron.
   e. Copper.

10. Elements in the same group on the periodic table have the same number of:
   a. valence electrons.
   b. protons.
   c. neutrons.
   d. radioactive neutrons.
   e. physical states.

11. Elements are ordered in the periodic table according to their electron configuration and:
   a. number of protons.
   b. melting point.
   c. atomic mass.
   d. radioactive neutrons.
   e. date of discovery.

12. A sample of which of the following substances contains some kind of bond?
    a. Copper.
    b. Carbon monoxide.
    c. Neither.
    d. Both.
    e. It depends on the isotope ratio.

13. When two atoms of the same or similar electronegativity bond with equal sharing of electrons, the result will most likely be:
    a. a polar covalent bond.
    b. a hydrogen bond.
    c. an ionic bond.
    d. a non-polar covalent bond.
    e. a helium bond.

14. What kind of bond usually exists between sodium and chlorine?
    a. Metallic.
    b. Covalent.
    c. Ionic.
    d. Polar covalent.
    e. Dipole.

15. Most ionic compounds are soluble in water because:
    a. water's polarity enables it to surround and separate the ions.
    b. all ions dissolve in water.
    c. ions are repelled by water.
    d. water forms covalent bonds with ions.
    e. water can dissolve everything.

16. In chemical reactions energy is utilized to make and break chemical bonds, thus rearranging the atoms. If a reaction gives off heat energy it is referred to as:
    a. a synthesis reaction.
    b. a decomposition reaction.
    c. an endothermic reaction.
    d. an exothermic reaction.
    e. an isothermic reaction.

17. A chemical ice pack is an endothermic reaction. It feels cool to the touch because:
    a. the system takes in energy from its surroundings.
    b. the system gives off cold energy.
    c. the system releases energy into the surroundings.
    d. the system has a negative change in energy.
    e. the system is incapacitated.

18. One reason that food is preserved in a refrigerator is because when reactant molecules get cold these molecules:
    a. slow down.
    b. shrink.
    c. become heavier.
    d. absorb energy.
    e. lose electrons.

19. In oxidation/reduction reactions:
    a. atoms share electrons to create bonds.
    b. electrons change their charge.
    c. energy is always released.
    d. electrons are lost or gained.
    e. oxygen must be involved.

20. If a sample is said to have a high pH, what does that mean?
    a. It has no detectable H^+ or OH^- ions.
    b. It has equal concentrations of H^+ and OH^- ions.
    c. It has very high concentrations of OH^- ions.
    d. It has very high concentrations of H^+ ions.
    e. It is neutral.

21. Solid carbon dioxide (dry ice) goes directly from a solid to a gas at room temperature. The surroundings get colder as energy is absorbed by the molecules in the solid. This occurs because:
    a. all chemical reactions release energy.
    b. molecules of a solid must gain energy to change to a gas.
    c. molecules of a gas gain energy to form new compounds.
    d. molecules of a gas release energy to form new compounds.
    e. all solids will cool the area around them.

22. For all reactions in all circumstances, equilibrium is best defined as the circumstance when the:
    a. concentrations of reactants and products are constant.
    b. rates of the forward and reverse reactions are identical.
    c. concentration of at least one reactant is zero.
    d. concentrations of all reactants and products are equal.
    e. forward and reverse reactions are very fast.

23. Predict which of actions listed below would shift the equilibrium to the right in the following reaction: $C_2H_2(g) + H_2O(g) \rightleftharpoons CH_3CHO(g)$
    a. Removing $H_2O(g)$ from the system.
    b. Adding CH_3CHO (g) to the system.
    c. Removing C_2H_2 (g) from the system.
    d. Adding H_2O (g) to the system.
    e. Adding a catalyst to the system.

24. Chemical equations must have equal numbers of the same atoms on each side because of the law of:
    a. conservation of energy.
    b. conservation of numbers.
    c. conservation of mass.
    d. conservation of chemical bonds.
    e. conservation of molecules.

25. 2.0 grams of H_2 will react completely with:
    a. 2.0 grams of O_2.
    b. 4.0 grams of O_2.
    c. 10.0 grams of O_2.
    d. 16.0 grams of O_2.
    e. 20.0 grams O_2.

26. Scientists can use radioactive isotopes to date some rocks because:
    a. rocks do not change over time.
    b. only the non-radioactive parts of rocks change.
    c. the rocks are not as dangerous as they once were.
    d. radioactive materials in rocks decay at a predictable rate.
    e. only the radioactive parts of the rocks remain.

27. Nuclear chemistry is the study of:
    a. changes that can occur in the nuclear makeup of an atom.
    b. large uncontrolled explosions with mushroom clouds.
    c. the design, construction, and operation of nuclear power plants.
    d. the nuclear navy consisting of submarines and ballistic missiles.
    e. the structure and function of nucleic acids.

28. The $^{32}_{15}P$ nucleus contains 15 protons. This nucleus loses an electron in a process called beta decay. Select the correct product nucleus from the choices below.

$^{31}_{14}Si$	$^{32}_{14}Si$	$^{31}_{15}P$	$^{32}_{16}S$	$^{31}_{16}S$
A	B	C	D	E

29. The law of conservation of energy can be best explained by which statement below?
a. More energy efficient appliances are better for the environment.
b. When transforming from one type to another, some energy is always destroyed.
c. Energy can neither be created nor destroyed, only transformed.
d. Energy is created in chemical reactions by the breaking of chemical bonds.
e. Energy is destroyed in an endothermic reaction.

30. An exothermic chemical reaction can best be described as a reaction:
    a. in which the potential energy of the products is greater than the potential energy of the reactants.
    b. in which there is no change in the potential energy of the reactants or products.
    c. that releases energy in the form of heat only.
    d. in which the potential energy of the products is less than the potential energy of the reactants.
    e. reaction that has a very low energy of activation.

Part 2

Chemistry Self-efficacy (CSE) scale

CSE Item Number	CSE Statement[a]	Likert Scale Range		
		Low	To	High
1	Applying a set of chemistry rules to different elements of the Periodic Table	Strongly disagree	---	Strongly agree
2	Tutoring another student in a first-year chemistry course	Strongly disagree	---	Strongly agree
3	Explaining something that you learnt in this chemistry course to another person	Strongly disagree	---	Strongly agree
4	Choosing an appropriate formula to solve a chemistry problem	Strongly disagree	---	Strongly agree
5	Determining the appropriate units for a result determined using a formula	Strongly disagree	---	Strongly agree

[a]All statements are preceded with "Please indicate how much you agree with the statement. I feel confident in:”

Part 3

Demographic Survey

1. What is your gender?
   a. Female
   b. Male
   c. Non-binary
   d. Other (including prefer not to say)
   ____

2. What is your ethnicity?
   a. White
   b. Black or African American
   c. American Indian or Alaska Native
   d. Asian
   e. Native Hawaiian or Pacific Islander
   f. Other ____

3. The federal definition of underrepresented groups in STEM majors includes those who identify their heritage as American Indian/Alaska Native, Black/African American, Hispanic/Latina/o or Native Hawaiian/Other Pacific Islander.
   With respect to this definition, I identify myself as an underrepresented group in STEM.
   a. Yes
   b. No

4. The federal definition of underrepresented groups in STEM majors includes those who identify their heritage as American Indian/Alaska Native, Black/African American, Hispanic/Latina/o or Native Hawaiian/Other Pacific Islander.
   With respect to this definition, I identify myself as an underrepresented group in STEM.
   a. Yes
   b. No

5. The National Council on Educational Statistics defines first-generation college students as those who are first in their family to attend college.
   Based upon this definition do you consider yourself a first-generation college student?
   a. Yes
   b. No

6. The Pell Institute defines first-generation college students as those whose parent(s) or guardian(s) did not attain a bachelor's degree.
   Based upon this definition do you consider yourself a first-generation college student?
   a. Yes
   b. No

7. Are you eligible to receive financial aid of any type?
    a. Yes
    b. No

8. Are you eligible to receive a Pell Grant?
    a. Yes
    b. No

9. Is this your first time taking Organic Chemistry?
    a. Yes
    b. No

Appendix B: Consent Information

CU IRB: Adult Informed Consent – Rev. February 2022

ADULT INFORMED CONSENT TO PARTICIPATE IN RESEARCH

Title of Study: *Investigation into the relationship between chemistry-oriented misconceptions held by university students and their organic chemistry self-efficacy*

Members of the Research Team

Student Researcher: Lauren Dudley Cell: (714) 697-3892

Lead Researcher: Dr. Brian Alters

Key Information

You are being asked to take part in a research study. Research studies include only people who choose to take part. You should take your time deciding whether or not you want to participate. If you agree to participate in this study, this research will involve:

- Individuals who are 18 years or older and be enrolled in organic chemistry 1 this semester.
- Procedures will include completion of a survey during the beginning of the Fall 2022 semester and the end of the Fall 2022 semester.
- 2 visits that will take 45 minutes total
- Risks do not exceed what would typically be encountered in daily life

Invitation

You are invited to take part in this research study. The information in this form is meant to help you decide whether or not to participate. If you have any questions, please ask.

Why are you being asked to be in this research study?

You are being asked to be in this study not only because organic chemistry courses are widely accepted as being a critical component for so many undergraduate majors, but also because student success in organic chemistry is particularly lacking. As such, it is imperative to understand how previous knowledge is constructed and organized for students entering organic chemistry to fully understand how misconceptions could influence their future success.

What is the reason for doing this research study?

This research seeks to examine (a) whether there is a relationship between foundational chemistry misconceptions and student organic chemistry self-efficacy, (b) the nature of those relationships throughout the first semester of an organic chemistry course, and (c) identify the most prevalent misconceptions held by students in organic chemistry courses.

What will be done during this research study?

You will be asked to complete two surveys during the Fall 2022 semester, one at the beginning and one at the end. Each session will take 25 minutes in a scheduled meeting area on campus.

How will my data be used?

Your data will not be sent to researchers outside of Chapman University. Although your data will initially be collected with identifying information, all personal identifiers will be removed from the data before being shared with another investigator or used for future research studies.

What are the possible risks of being in this research study?

As with any study involving collection of data, there is the possibility of breach of confidentiality of data. Data will be deidentified after the second survey is completed and stored on a password protected laptop.

It is possible that other rare side effects could occur that are not described in this consent form. It is also possible that you could have a side effect that has not occurred before.

What are the possible benefits to you?

You are not expected to get any direct benefit from being in this study.

What are the possible benefits to other people?

The benefits to science or society may include a better understanding of the foundational knowledge and misconceptions in organic chemistry that may affect student self-efficacy. A better understanding of the difficulties in organic chemistry will benefit the scientific community. New curriculum and pedagogical outcomes could be enhanced with this research.

What are the alternatives to being in this research study?

Instead of being in this research study, you can choose not to participate.

What will participating in this research study cost you?

There is no cost to you to be in this research study.

Will you be compensated for being in this research study?

You will not be compensated for your participation in this research study.

What should you do if you have a problem during this research study?

Your welfare is the primary concern of every member of the research team. If you have a problem as a direct result of being in this study, you should immediately contact one of the people listed at the beginning of this consent form.

How will information about you be protected?

Reasonable steps will be taken to protect your privacy and the confidentiality of your study data.

The data will be stored electronically in the office of the student researcher and will only be seen by the research team during the study and for 1 years after the study is complete.

The only people who will have access to your research records are the research team members, the Institutional Review Board (IRB), and any other person, agency, or sponsor as required by law. Information from this study may be published in scientific journals or presented at scientific meetings, but the data will be reported as a group or summarized data, and your identity will be kept strictly confidential. We cannot guarantee total privacy.

What are your rights as a research participant?

You may ask any questions about this research and have those questions answered before agreeing to participate in the study or during the study.

For study-related questions, please contact the investigator(s) listed at the beginning of this form.

For questions concerning your rights or complaints about the research, contact the Institutional Review Board (IRB) at (714) 628-2833 or irb@chapman.edu.

What will happen if you decide not to be in this research study or decide to stop participating once you start?

You can decide not to be in this research study, or you can stop being in this research study (i.e., "withdraw") at any time before, during, or after the research begins for any reason. Deciding not to be in this research study or deciding to withdraw will not affect your relationship with the investigator or with Chapman University. You will not lose any benefits to which you are entitled.

Documentation of informed consent

You are voluntarily deciding whether or not to be in this research study. Signing this form means that (1) you have read and understood this consent form, (2) you have had the consent form explained to you, (3) you have had your questions answered, and (4) you have decided to be in the research study. You will be given a copy of this consent form to keep.

____

Printed Name of Participant or Legal Guardian

____________________________________ _______________

Signature of Participant or Legal Guardian **Date**

Appendix C: SPSS Analysis

Explore - Pre-semester

Notes

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Case Processing Summary

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SEScore	97	100.0%	0	0.0%	97	100.0%

Descriptives

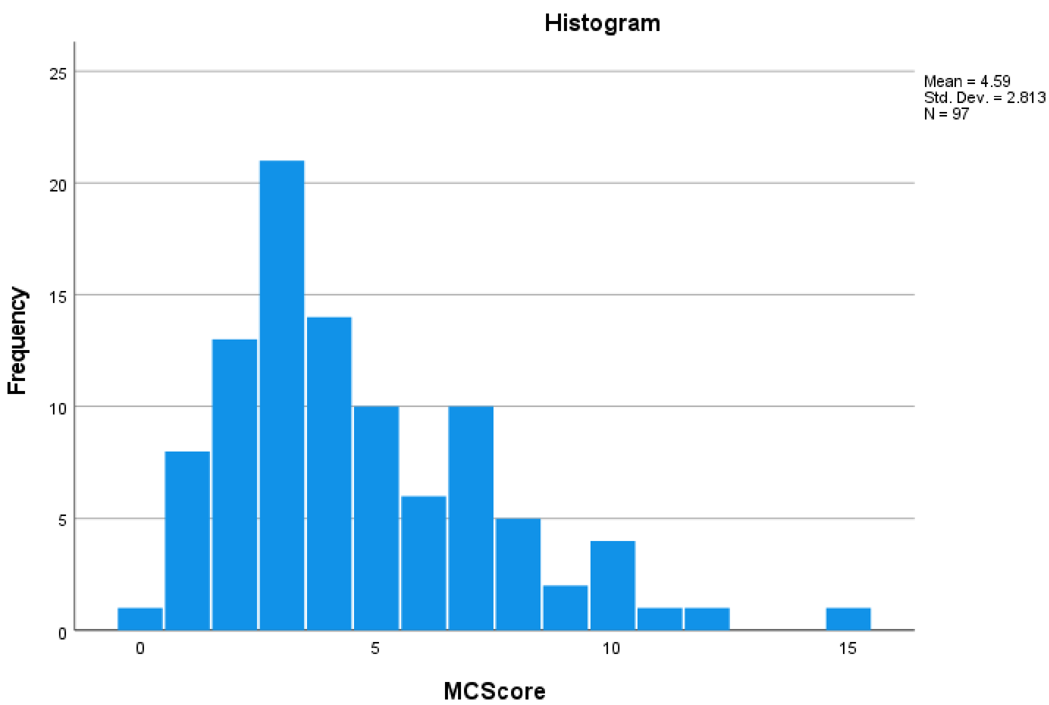
			Statistic	Std. Error
MCScore	Mean		4.59	.286
	95% Confidence Interval for Mean	Lower Bound	4.02	
		Upper Bound	5.15	
	5% Trimmed Mean		4.41	
	Median		4.00	
	Variance		7.912	
	Std. Deviation		2.813	
	Minimum		0	
	Maximum		15	
	Range		15	
	Interquartile Range		4	
	Skewness		1.044	.245
	Kurtosis		1.188	.485
SEScore	Mean		18.70	.390
	95% Confidence Interval for Mean	Lower Bound	17.93	
		Upper Bound	19.48	
	5% Trimmed Mean		18.90	
	Median		19.00	
	Variance		14.774	
	Std. Deviation		3.844	
	Minimum		8	
	Maximum		25	
	Range		17	
	Interquartile Range		6	
	Skewness		-.753	.245
	Kurtosis		.297	.485

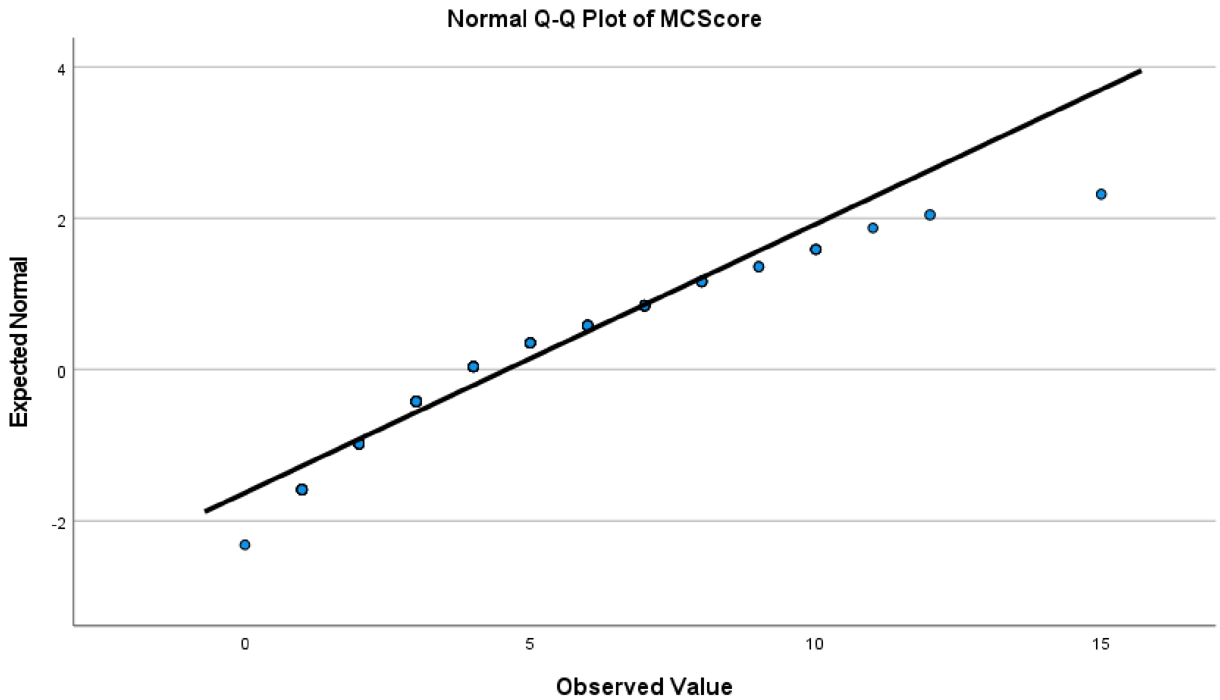
Tests of Normality

	Kolmogorov-Smirnov[a]			Shapiro-Wilk		
	Statistic	df	Sig.	Statistic	df	Sig.
MCScore	.170	97	<.001	.920	97	<.001
SEScore	.139	97	<.001	.947	97	<.001

a. Lilliefors Significance Correction

MCScore

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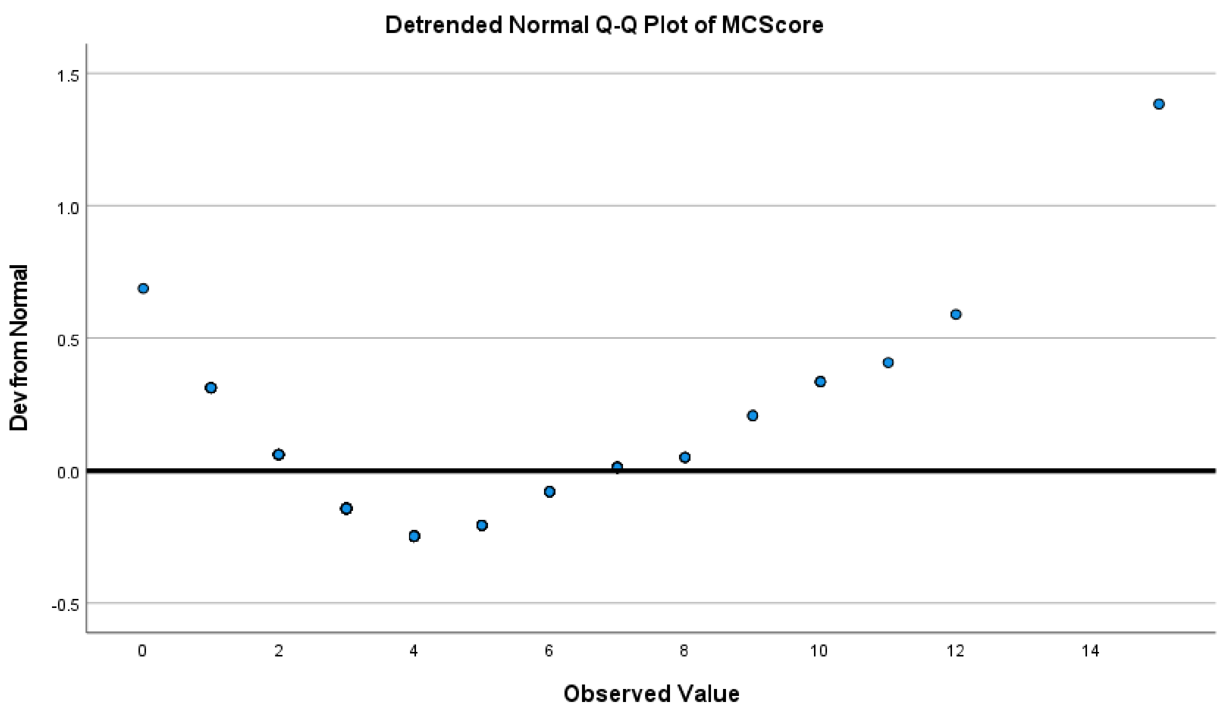
2
0
-2
0
5
10
15
Observed Value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Dev from Normal
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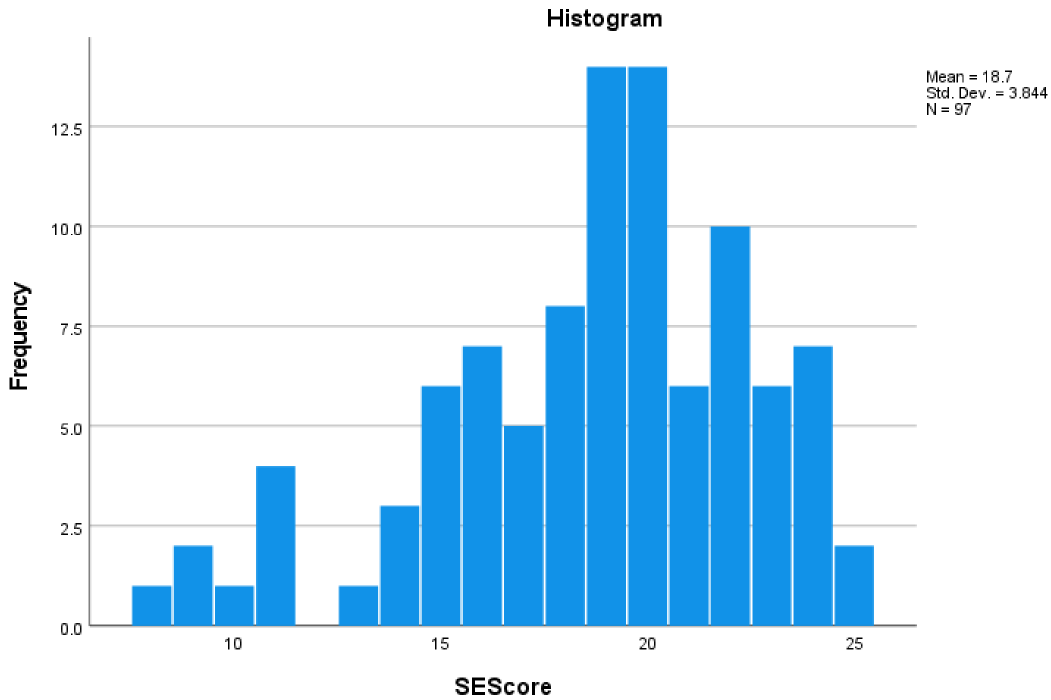
0
2
4
6
8
10
12
14
Observed Value

SEScore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7.5
5.0
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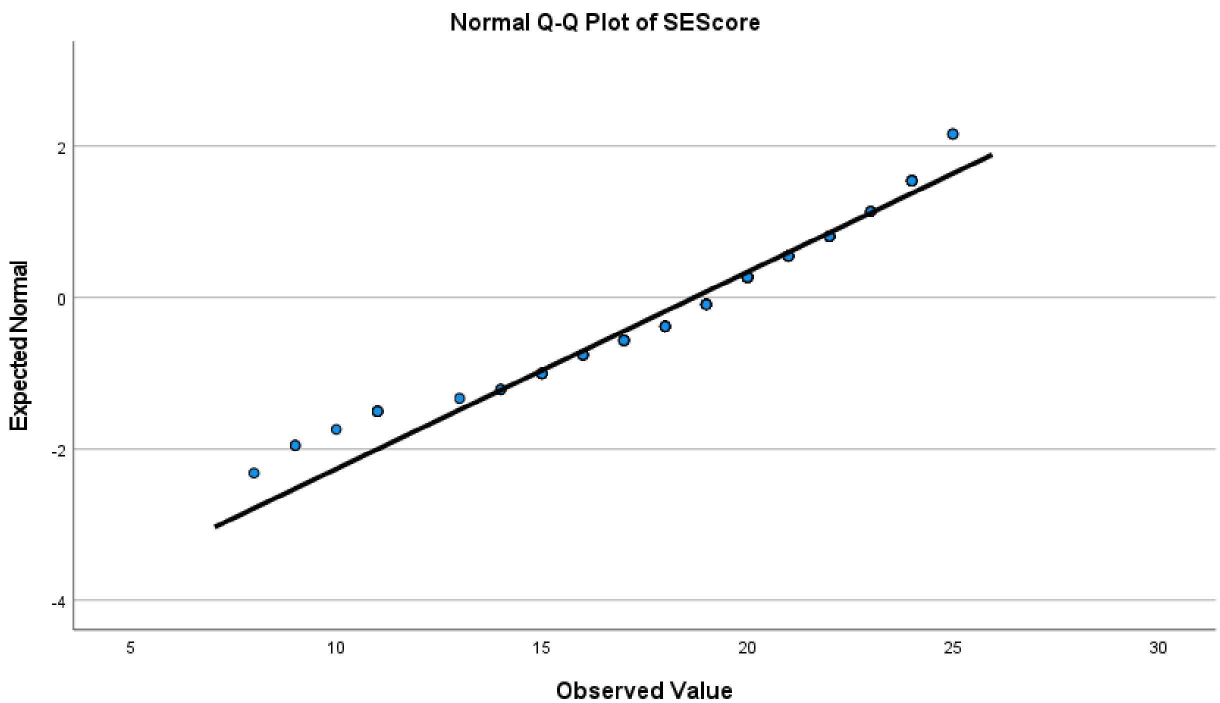
10
15
20
25
SEScore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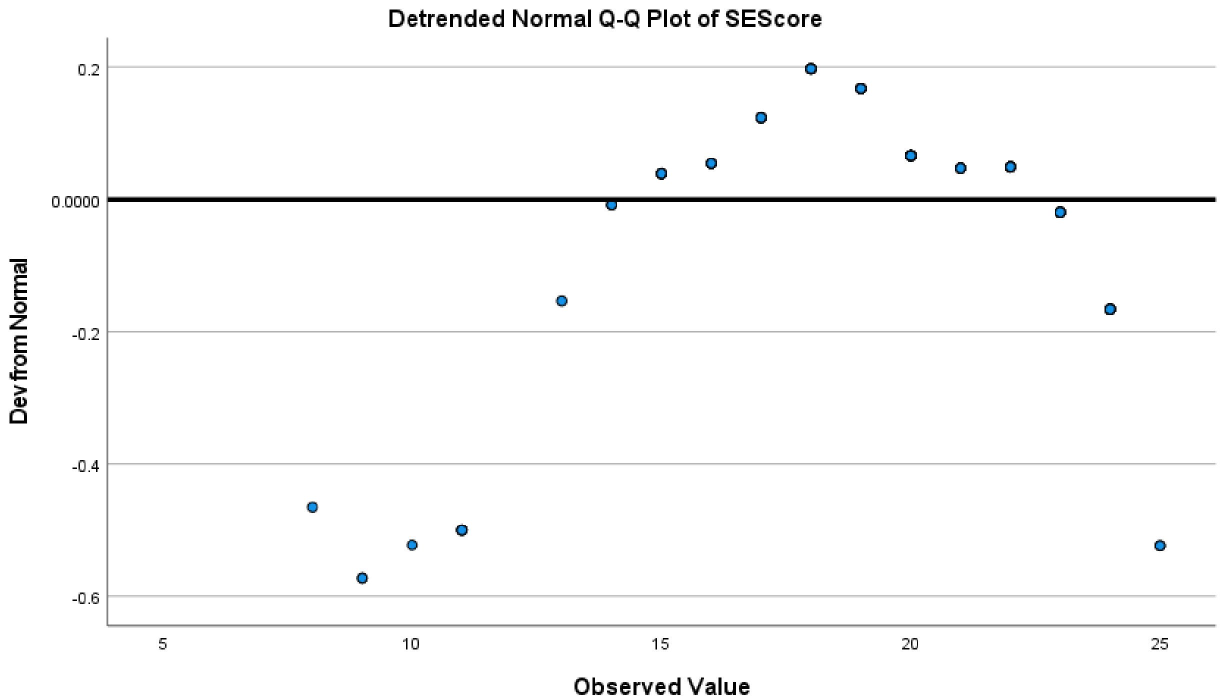
25
30
Observed Value



Explore - Post-semester

Notes

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MCS_Post	45	46.4%	52	53.6%	97	100.0%

Descriptives

			Statistic	Std. Error
SES_Post	Mean		19.80	.419
	95% Confidence Interval for Mean	Lower Bound	18.96	
		Upper Bound	20.64	
	5% Trimmed Mean		19.83	
	Median		20.00	
	Variance		7.891	
	Std. Deviation		2.809	
	Minimum		14	
	Maximum		25	
	Range		11	
	Interquartile Range		3	
	Skewness		.098	.354
	Kurtosis		-.012	.695

MCS_Post	Mean		4.33	.357
	95% Confidence Interval for Mean	Lower Bound	3.61	
		Upper Bound	5.05	
	5% Trimmed Mean		4.27	
	Median		4.00	
	Variance		5.727	
	Std. Deviation		2.393	
	Minimum		1	
	Maximum		9	
	Range		8	
	Interquartile Range		4	
	Skewness		.252	.354
	Kurtosis		-.917	.695

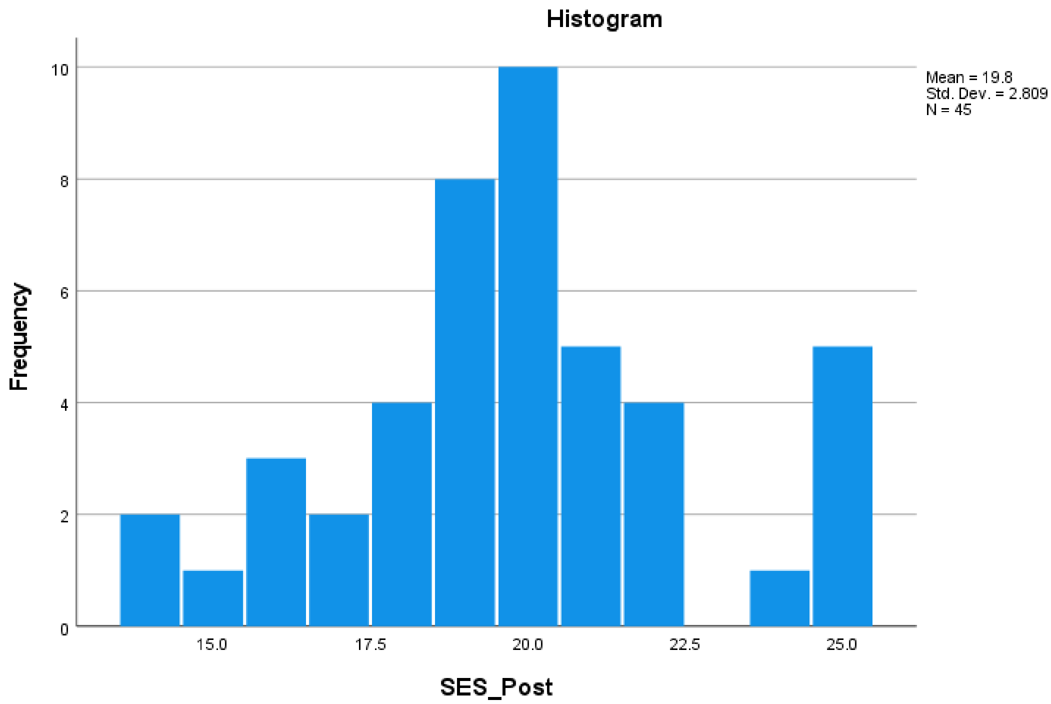
Tests of Normality

	Kolmogorov-Smirnov[a]			Shapiro-Wilk		
	Statistic	df	Sig.	Statistic	df	Sig.
SES_Post	.138	45	.031	.951	45	.053
MCS_Post	.111	45	.200*	.942	45	.025

*. This is a lower bound of the true significance.

a. Lilliefors Significance Correction

SES_Post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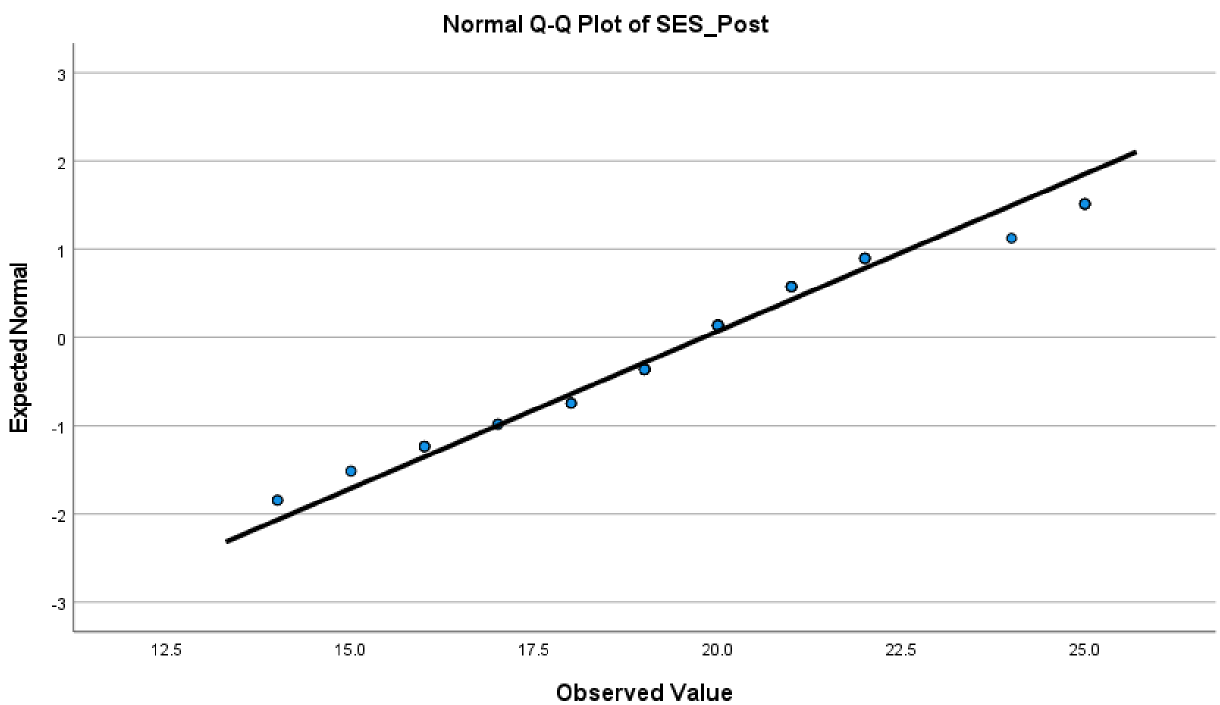
Std. Dev. = 2.809
N = 45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17.5
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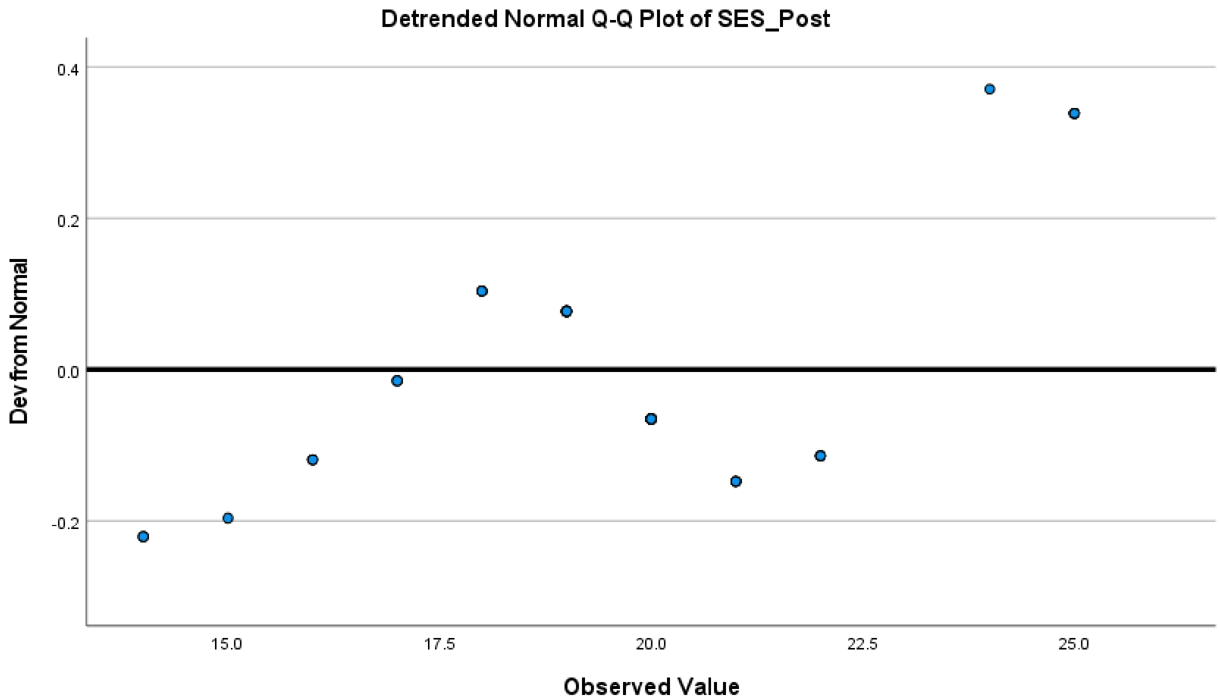
22.5
25.0
Observed Value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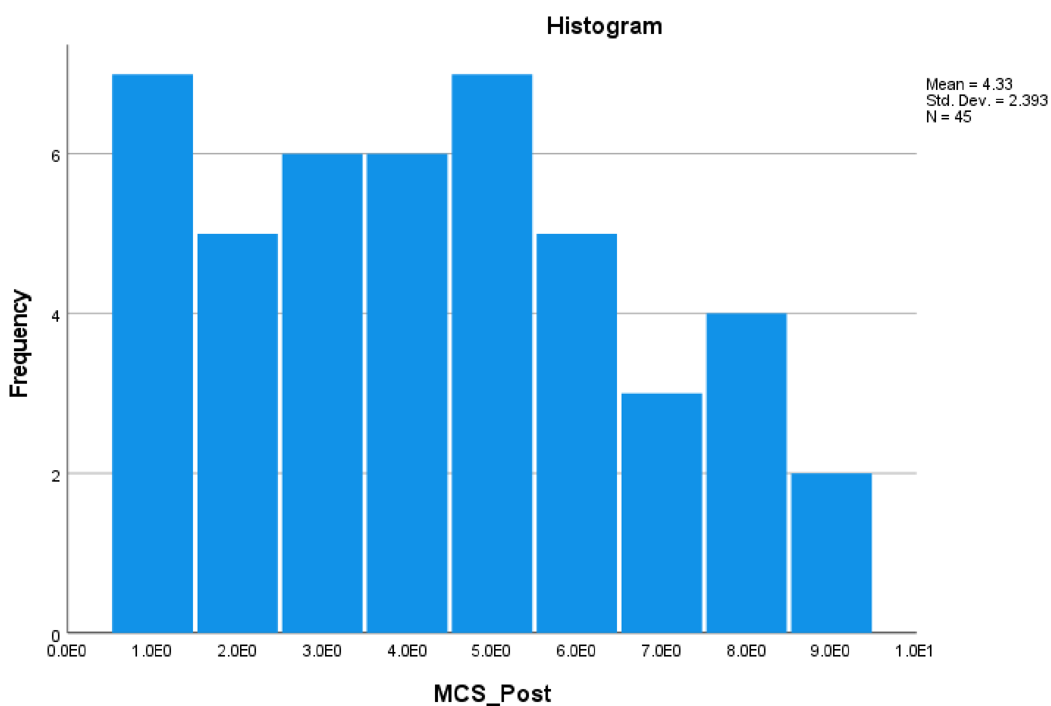
Observed Value

MCS_Post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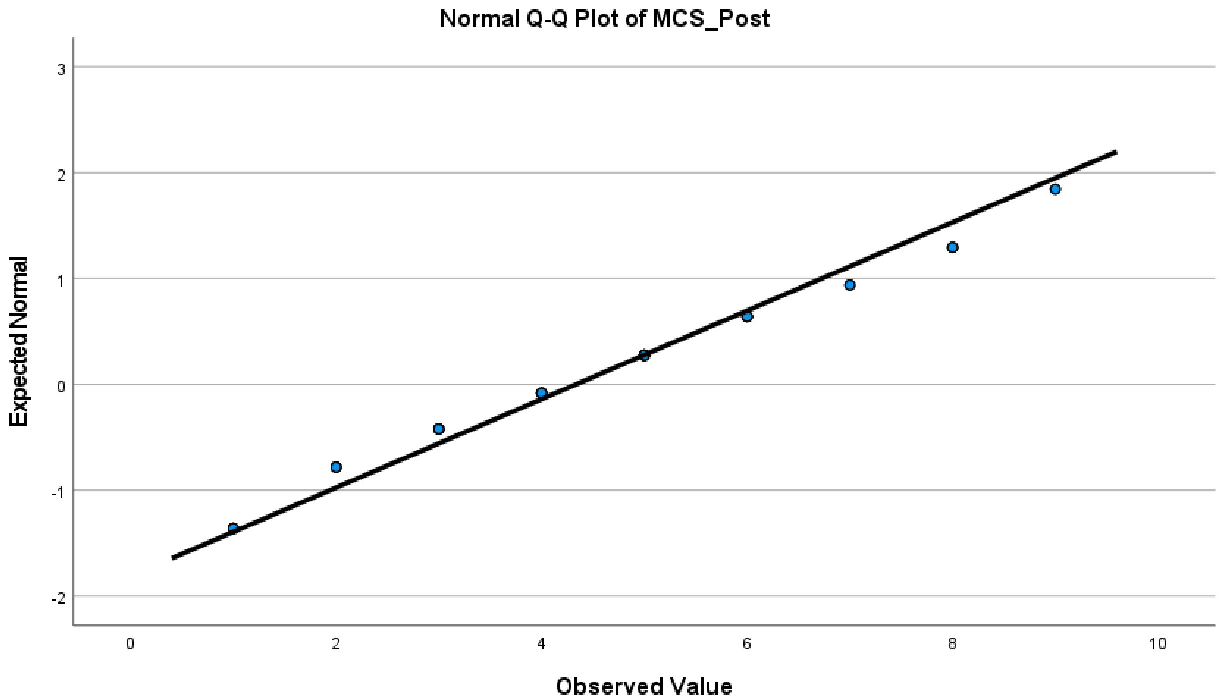
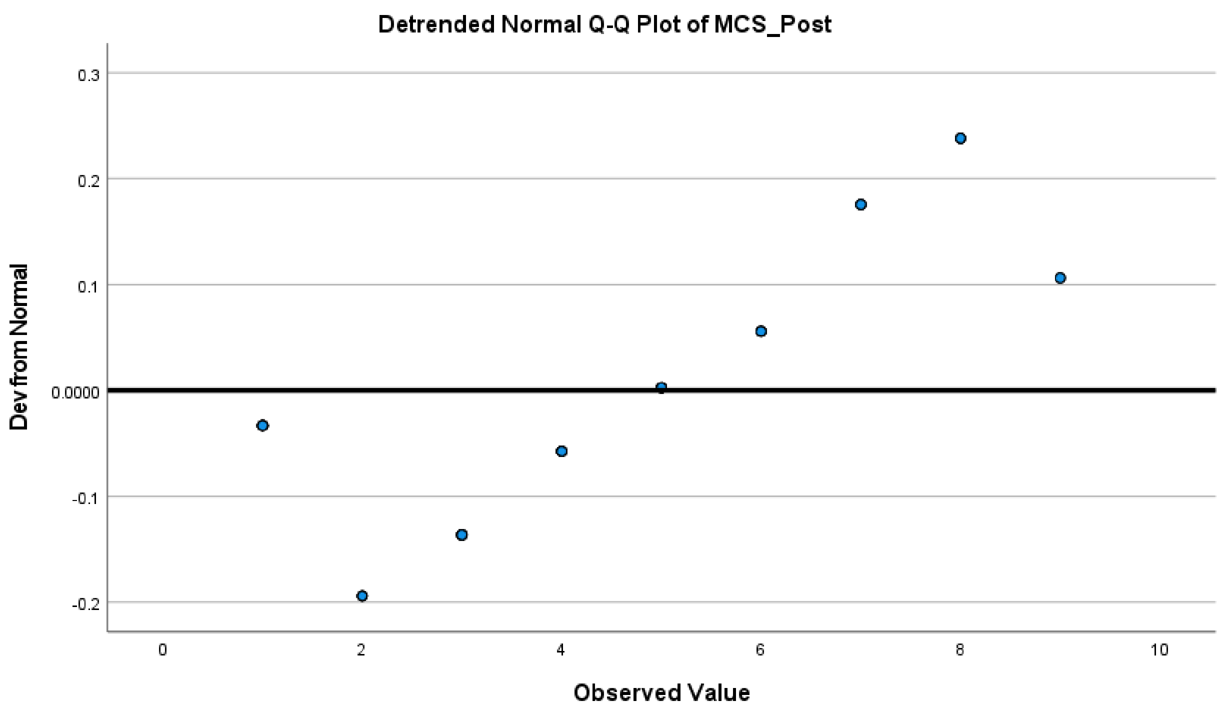
1.0E1
MCS_Post



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Variable: SES_Post          Type: Number   Width:   8   Dec: 0
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Descriptives - Pre-semester

Notes

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Descriptive Statistics

	N	Minimum	Maximum	Mean	Std. Deviation	Variance
MCScore	97	0	15	4.59	2.813	7.912
SEScore	97	8	25	18.70	3.844	14.774
Gender	97	0	1	.69	.465	.216
UnderrepresentedRace	97	0	1	.23	.421	.177

ExperienceOC	97	0	1	.12	.331	.110
Valid N (listwise)	97					

Nonparametric Correlations - Pre-Semester

Notes

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	Cases Used	Statistics for each pair of variables are based on all the cases with valid data for that pair.
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	Elapsed Time	00:00:00.00
	Number of Cases Allowed	393216 cases[a]

a. Based on availability of workspace memory

Correlations

			MCScore	SEScore	Gender
Spearman's rho	MCScore	Correlation Coefficient	1.000	-.399**	.068
		Sig. (2-tailed)	.	<.001	.506
		N	97	97	97
	SEScore	Correlation Coefficient	-.399**	1.000	-.198
		Sig. (2-tailed)	<.001	.	.052
		N	97	97	97
	Gender	Correlation Coefficient	.068	-.198	1.000
		Sig. (2-tailed)	.506	.052	.
		N	97	97	97
	UnderrepresentedRace	Correlation Coefficient	.150	-.152	-.010
		Sig. (2-tailed)	.143	.136	.919
		N	97	97	97
	ExperienceOC	Correlation Coefficient	.331**	-.076	.116
		Sig. (2-tailed)	<.001	.460	.258
		N	97	97	97

Correlations

			Underrepresented Race	ExperienceOC
Spearman's rho	MCScore	Correlation Coefficient	.150	.331**
		Sig. (2-tailed)	.143	<.001
		N	97	97
	SEScore	Correlation Coefficient	-.152	-.076
		Sig. (2-tailed)	.136	.460
		N	97	97
	Gender	Correlation Coefficient	-.010	.116
		Sig. (2-tailed)	.919	.258
		N	97	97
	UnderrepresentedRace	Correlation Coefficient	1.000	-.054
		Sig. (2-tailed)	.	.600

		N	97	97
	ExperienceOC	Correlation Coefficient	-.054	1.000
		Sig. (2-tailed)	.600	.
		N	97	97

**. Correlation is significant at the 0.01 level (2-tailed).

Descriptives - Post-semester

Notes

Output Created		09-MAR-2023 19:42:44
Comments		
Input	Data	C:\Users\ldudl\Desktop\Dudley DissertationData.sav
	Active Dataset	DataSet1
	Filter	<none>
	Weight	<none>
	Split File	<none>
	N of Rows in Working Data File	97
Missing Value Handling	Definition of Missing	User defined missing values are treated as missing.
	Cases Used	All non-missing data are used.
Syntax		DESCRIPTIVES VARIABLES=MCS_Post SES_Post /STATISTICS=MEAN STDDEV VARIANCE MIN MAX.
Resources	Processor Time	00:00:00.00
	Elapsed Time	00:00:00.00

```
[DataSet1] C:\Users\ldudl\Desktop\DudleyDissertationData.sav
```

Descriptive Statistics

	N	Minimum	Maximum	Mean	Std. Deviation	Variance
MCS_Post	45	1	9	4.33	2.393	5.727
SES_Post	45	14	25	19.80	2.809	7.891

Valid N (listwise)	45					

Nonparametric Correlations - Post-semester

Notes

Output Created		09-MAR-2023 19:44:43
Comments		
Input	Data	C:\Users\ldudl\Desktop\Dudley DissertationData.sav
	Active Dataset	DataSet1
	Filter	<none>
	Weight	<none>
	Split File	<none>
	N of Rows in Working Data File	97
Missing Value Handling	Definition of Missing	User-defined missing values are treated as missing.
	Cases Used	Statistics for each pair of variables are based on all the cases with valid data for that pair.
Syntax		NONPAR CORR /VARIABLES=MCS_Post SES_Post Underrepresented Gender Experience /PRINT=SPEARMAN TWOTAIL NOSIG FULL /MISSING=PAIRWISE.
Resources	Processor Time	00:00:00.00
	Elapsed Time	00:00:00.00
	Number of Cases Allowed	393216 cases[a]

a. Based on availability of workspace memory

Correlations

			MCS_Post	SES_Post	Underrepresented
Spearman's rho	MCS_Post	Correlation Coefficient	1.000	-.495**	.036
		Sig. (2-tailed)	.	<.001	.816

		N	45	45	45
	SES_Post	Correlation Coefficient	-.495**	1.000	-.099
		Sig. (2-tailed)	<.001	.	.517
		N	45	45	45
	Underrepresented	Correlation Coefficient	.036	-.099	1.000
		Sig. (2-tailed)	.816	.517	.
		N	45	45	97
	Gender	Correlation Coefficient	.011	-.206	-.010
		Sig. (2-tailed)	.941	.175	.919
		N	45	45	97
	Experience	Correlation Coefficient	.118	.058	-.054
		Sig. (2-tailed)	.439	.706	.600
		N	45	45	97

Correlations

			Gender	Experience
Spearman's rho	MCS_Post	Correlation Coefficient	.011	.118
		Sig. (2-tailed)	.941	.439
		N	45	45
	SES_Post	Correlation Coefficient	-.206	.058
		Sig. (2-tailed)	.175	.706
		N	45	45
	Underrepresented	Correlation Coefficient	-.010	-.054
		Sig. (2-tailed)	.919	.600
		N	97	97
	Gender	Correlation Coefficient	1.000	.116
		Sig. (2-tailed)	.	.258
		N	97	97
	Experience	Correlation Coefficient	.116	1.000
		Sig. (2-tailed)	.258	.
		N	97	97

**. Correlation is significant at the 0.01 level (2-tailed).

Regression 1 - multiple

Notes

Output Created		28-SEP-2022 20:20:08
Comments		
Input	Data	H:\My Drive\PhD\Dissertation\Dissertation Data_PreSemester.sav
	Active Dataset	DataSet4
	Filter	<none>
	Weight	<none>
	Split File	<none>
	N of Rows in Working Data File	97
Missing Value Handling	Definition of Missing	User-defined missing values are treated as missing.
	Cases Used	Statistics are based on cases with no missing values for any variable used.
Syntax		REGRESSION /DESCRIPTIVES MEAN STDDEV CORR SIG N /MISSING LISTWISE /STATISTICS COEFF OUTS CI(95) R ANOVA COLLIN TOL CHANGE ZPP /CRITERIA=PIN(.05) POUT(.10) /NOORIGIN /DEPENDENT SEScore /METHOD=ENTER MCScore Gender UnderrepresentedRace ExperienceOC /PARTIALPLOT ALL /RESIDUALS DURBIN HISTOGRAM(ZRESID) NORMPROB(ZRESID) /CASEWISE PLOT(ZRESID) OUTLIERS(3) /SAVE PRED COOK LEVER SRESID SDRESID.
Resources	Processor Time	00:00:00.69
	Elapsed Time	00:00:00.40
	Memory Required	4704 bytes

	Additional Memory Required for Residual Plots	2232 bytes
Variables Created or Modified	PRE_3	Unstandardized Predicted Value
	SRE_3	Studentized Residual
	SDR_3	Studentized Deleted Residual
	COO_3	Cook's Distance
	LEV_3	Centered Leverage Value

Descriptive Statistics

	Mean	Std. Deviation	N
SEScore	18.70	3.844	97
MCScore	4.59	2.813	97
Gender	.69	.465	97
UnderrepresentedRace	.23	.421	97
ExperienceOC	.12	.331	97

Correlations

		SEScore	MCScore	Gender	Underrepresented Race
Pearson Correlation	SEScore	1.000	-.332	-.216	-.170
	MCScore	-.332	1.000	.117	.115
	Gender	-.216	.117	1.000	-.010
	UnderrepresentedRace	-.170	.115	-.010	1.000
	ExperienceOC	-.102	.313	.116	-.054
Sig. (1-tailed)	SEScore	.	<.001	.017	.048
	MCScore	.000	.	.128	.131
	Gender	.017	.128	.	.460
	UnderrepresentedRace	.048	.131	.460	.
	ExperienceOC	.161	.001	.129	.300
N	SEScore	97	97	97	97
	MCScore	97	97	97	97
	Gender	97	97	97	97

	UnderrepresentedRace	97	97	97	97
	ExperienceOC	97	97	97	97

Correlations

		ExperienceOC
Pearson Correlation	SEScore	-.102
	MCScore	.313
	Gender	.116
	UnderrepresentedRace	-.054
	ExperienceOC	1.000
Sig. (1-tailed)	SEScore	.161
	MCScore	.001
	Gender	.129
	UnderrepresentedRace	.300
	ExperienceOC	.
N	SEScore	97
	MCScore	97
	Gender	97
	UnderrepresentedRace	97
	ExperienceOC	97

Variables Entered/Removed[a]

Model	Variables Entered	Variables Removed	Method
1	ExperienceOC, UnderrepresentedRace, Gender, MCScore[b]	.	Enter

a. Dependent Variable: SEScore

b. All requested variables entered.

Model Summary[b]

Model	R	R Square	Adjusted R Square	Change Statistics

				Std. Error of the Estimate	R Square Change	F Change	df1
1	.401[a]	.161	.125	3.596	.161	4.414	4

Model Summary[b]

	Change Statistics		
Model	df2	Sig. F Change	Durbin-Watson
1	92	.003	2.101

a. Predictors: (Constant), ExperienceOC, UnderrepresentedRace, Gender, MCScore

b. Dependent Variable: SEScore

ANOVA[a]

Model		Sum of Squares	df	Mean Square	F	Sig.
1	Regression	228.362	4	57.090	4.414	.003[b]
	Residual	1189.968	92	12.934		
	Total	1418.330	96			

a. Dependent Variable: SEScore

b. Predictors: (Constant), ExperienceOC, UnderrepresentedRace, Gender, MCScore

Coefficients[a]

		Unstandardized Coefficients		Standardized Coefficients		
Model		B	Std. Error	Beta	t	Sig.
1	(Constant)	21.885	.865		25.307	<.001
	MCScore	-.406	.139	-.297	-2.912	.005
	Gender	-1.514	.798	-.183	-1.897	.061
	UnderrepresentedRace	-1.257	.882	-.138	-1.425	.158
	ExperienceOC	.058	1.177	.005	.049	.961

Coefficients[a]

Model		95.0% Confidence Interval for B		Correlations		
		Lower Bound	Upper Bound	Zero-order	Partial	Part
1	(Constant)	20.168	23.603			
	MCScore	-.682	-.129	-.332	-.290	-.278
	Gender	-3.100	.071	-.216	-.194	-.181
	UnderrepresentedRace	-3.008	.495	-.170	-.147	-.136
	ExperienceOC	-2.280	2.395	-.102	.005	.005

Coefficients[a]

Model		Collinearity Statistics	
		Tolerance	VIF
1	(Constant)		
	MCScore	.878	1.139
	Gender	.979	1.021
	UnderrepresentedRace	.978	1.023
	ExperienceOC	.888	1.126

a. Dependent Variable: SEScore

Collinearity Diagnostics[a]

Model	Dimension	Eigenvalue	Condition Index	Variance Proportions			
				(Constant)	MCScore	Gender	Underrepresented Race
1	1	3.134	1.000	.02	.02	.02	.03
	2	.885	1.882	.00	.00	.00	.32
	3	.621	2.247	.02	.01	.07	.61

	4	.244	3.581	.02	.44	.62	.04
	5	.117	5.181	.95	.53	.29	.00

Collinearity Diagnostics[a]

Model	Dimension	Variance Proportions ExperienceOC
1	1	.02
	2	.55
	3	.33
	4	.05
	5	.05

a. Dependent Variable: SEScore

Casewise Diagnostics[a]

Case Number	Std. Residual	SEScore	Predicted Value	Residual
91	-3.049	9	19.97	-10.965

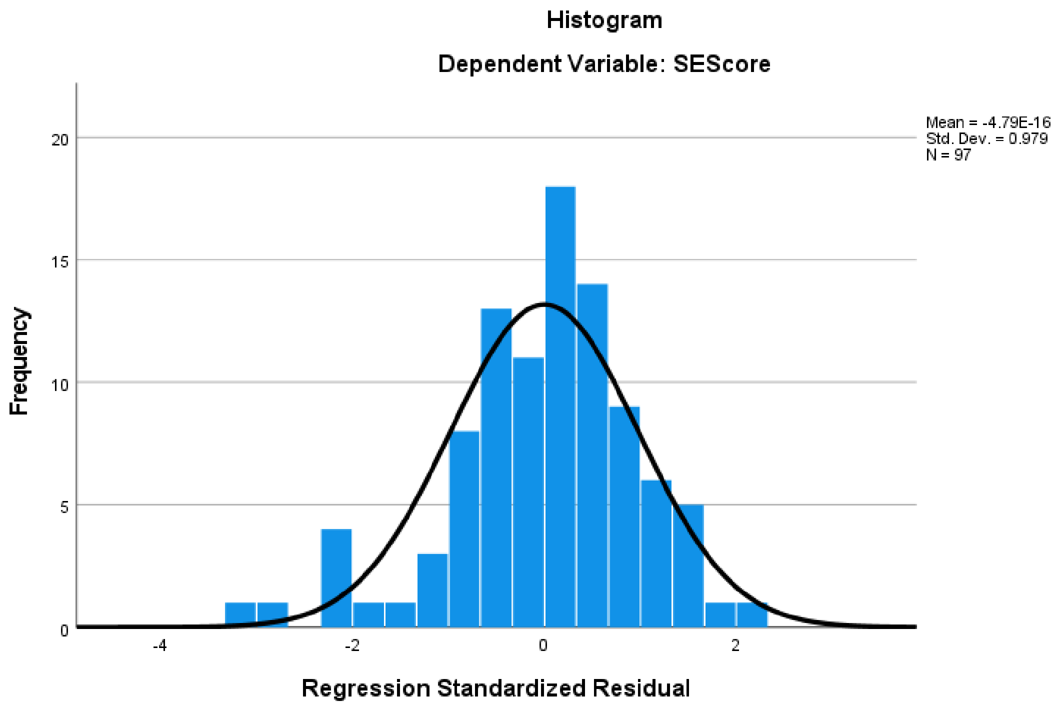
a. Dependent Variable: SEScore

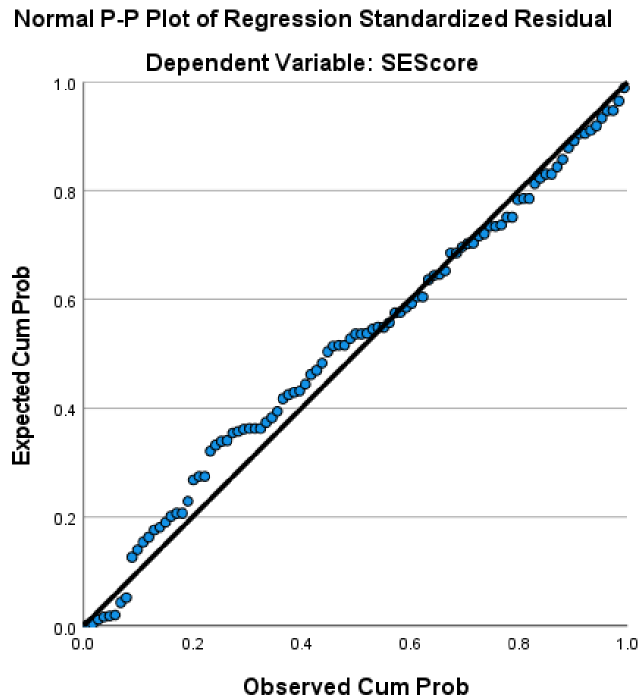
Residuals Statistics[a]

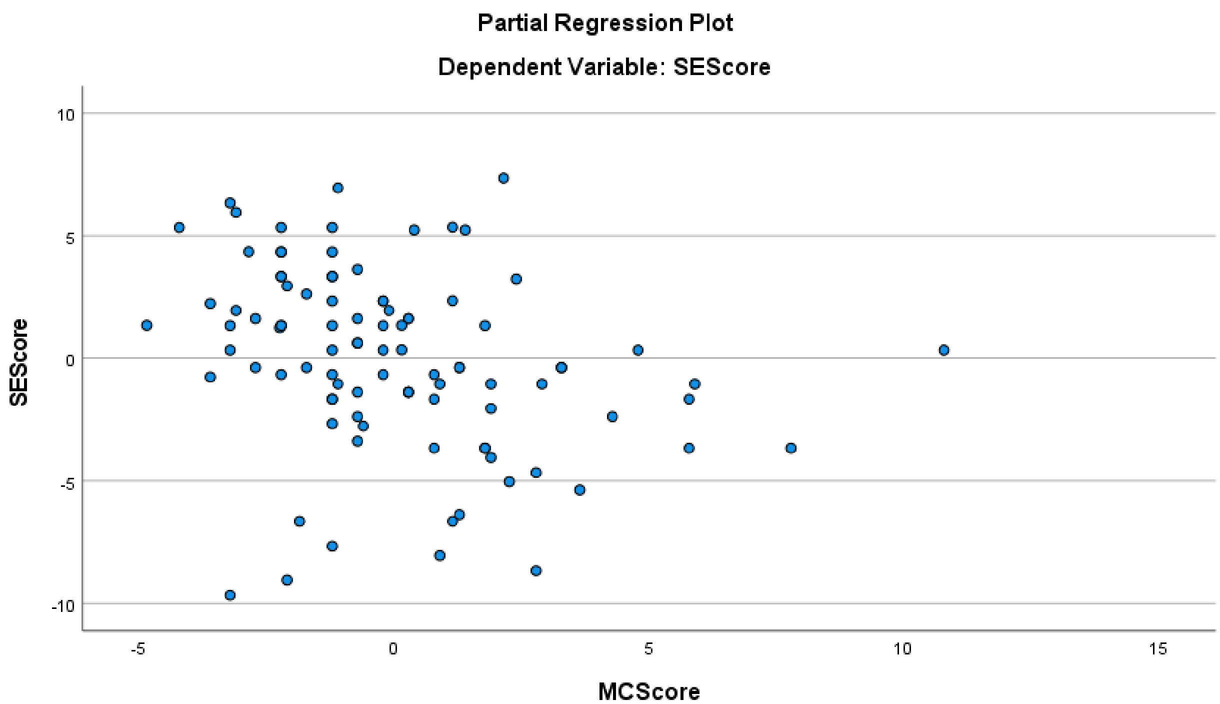
	Minimum	Maximum	Mean	Std. Deviation	N
Predicted Value	14.29	21.48	18.70	1.542	97
Std. Predicted Value	-2.861	1.802	.000	1.000	97
Standard Error of Predicted Value	.513	1.587	.782	.235	97
Adjusted Predicted Value	13.15	21.55	18.69	1.590	97
Residual	-10.965	8.221	.000	3.521	97
Std. Residual	-3.049	2.286	.000	.979	97
Stud. Residual	-3.105	2.401	.001	1.009	97
Deleted Residual	-11.372	9.066	.009	3.739	97
Stud. Deleted Residual	-3.264	2.466	-.002	1.025	97
Mahal. Distance	.966	17.706	3.959	3.191	97
Cook's Distance	.000	.119	.013	.024	97
Centered Leverage Value	.010	.184	.041	.033	97

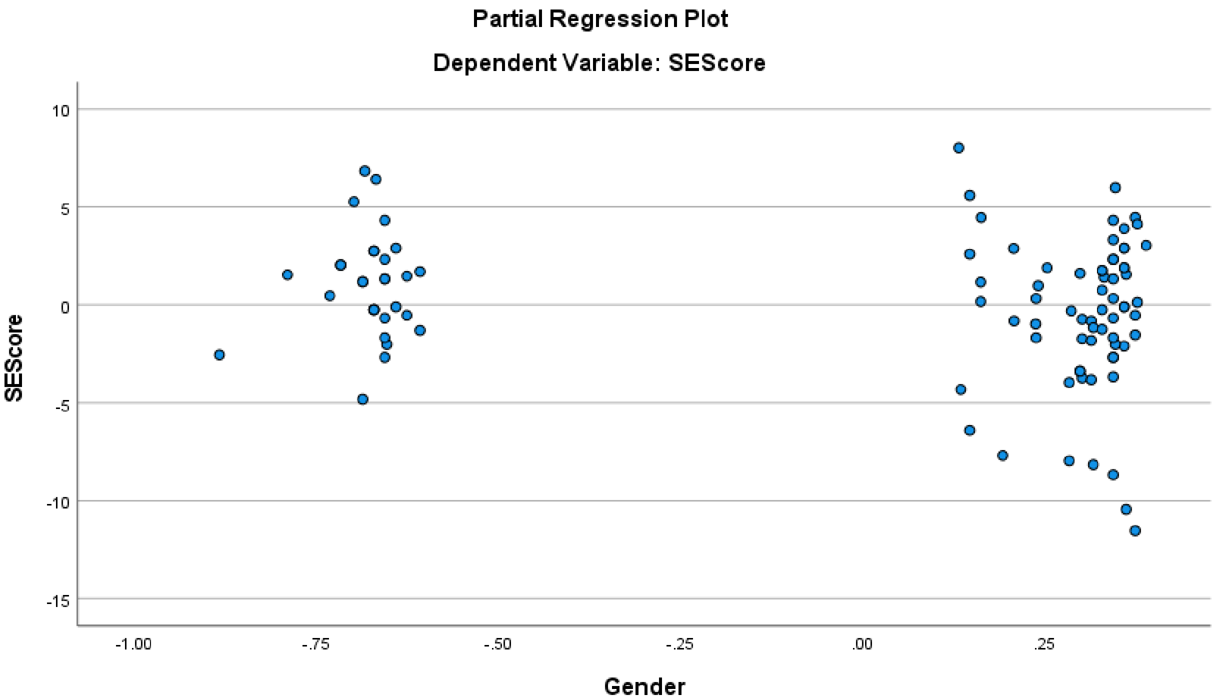
a. Dependent Variable: SEScore

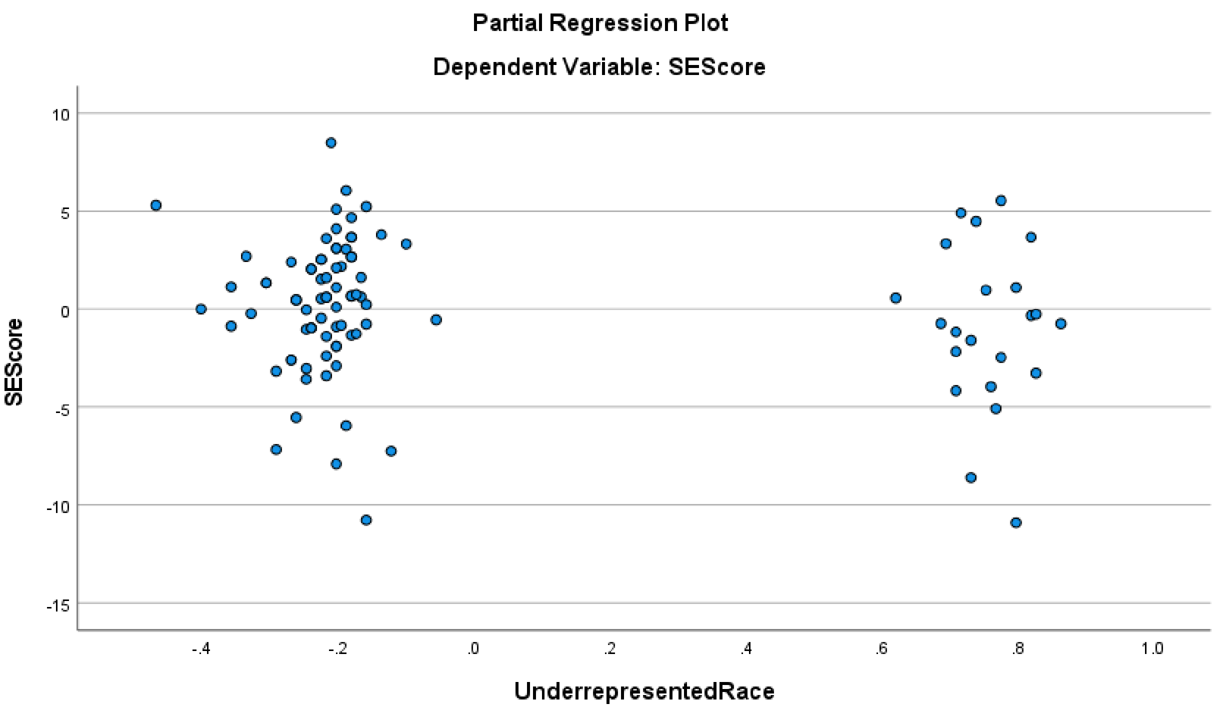
Charts

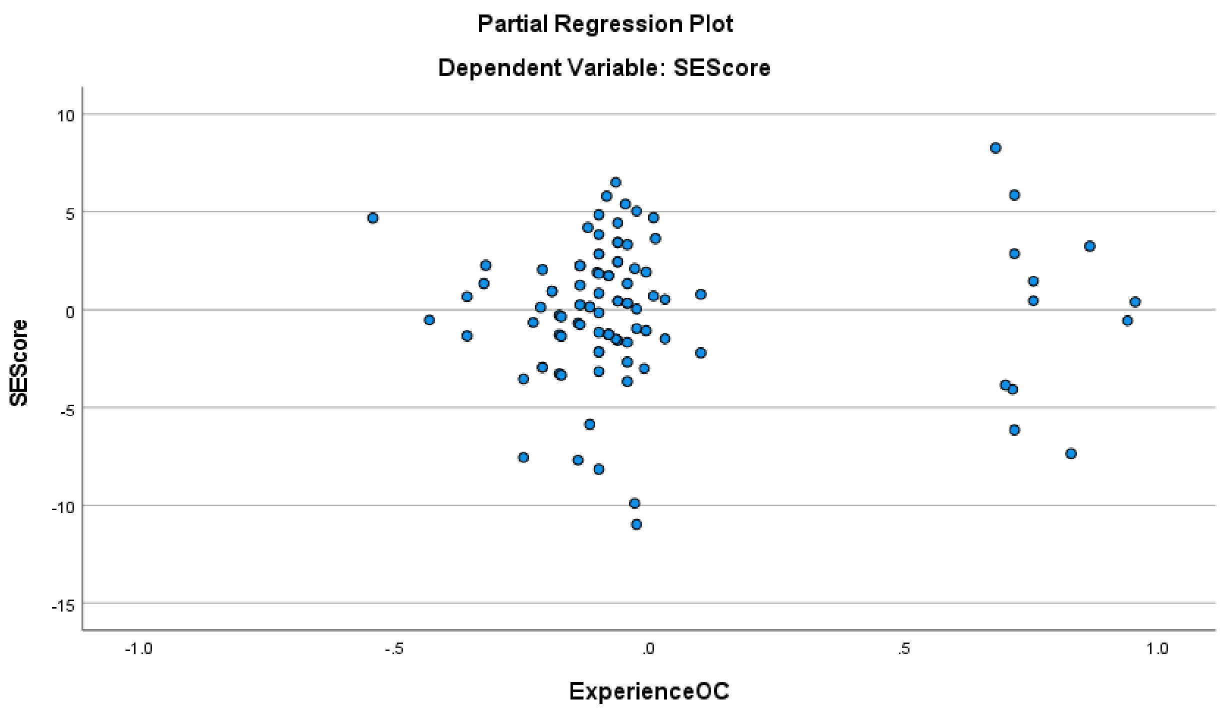

Histogram
Dependent Variable: SEScore
Mean = -4.79E-16
Std. Dev. = 0.979
N = 97
Frequency
0
5
10
15
20
-4
-2
0
2
Regression Standardized Residual


Normal P-P Plot of Regression Standardized Residual
Dependent Variable: SEScore
Expected Cum Prob
Observed Cum Prob
1.0
0.8
0.6
0.4
0.2
0.0
0.0
0.2
0.4
0.6
0.8
1.0


Partial Regression Plot
Dependent Variable: SEScore
SEScore
MCScore
10
5
0
-5
-10
-5
0
5
10
15


Partial Regression Plot
Dependent Variable: SEScore
SEScore
10
5
0
-5
-10
-15
-1.00
-.75
-.50
-.25
.00
.25
Gender


Partial Regression Plot
Dependent Variable: SEScore
SEScore
10
5
0
-5
-10
-15
-.4
-.2
.0
.2
.4
.6
.8
1.0
UnderrepresentedRace



Regression 2 - Linear

Notes

Output Created		28-SEP-2022 20:21:33
Comments		
Input	Data	H:\My Drive\PhD\Dissertation\Dissertation Data_PreSemester.sav
	Active Dataset	DataSet4
	Filter	<none>
	Weight	<none>
	Split File	<none>
	N of Rows in Working Data File	97
Missing Value Handling	Definition of Missing	User-defined missing values are treated as missing.
	Cases Used	Statistics are based on cases with no missing values for any variable used.
Syntax		REGRESSION /DESCRIPTIVES MEAN STDDEV CORR SIG N /MISSING LISTWISE /STATISTICS COEFF OUTS

		CI(95) R ANOVA COLLIN TOL CHANGE ZPP /CRITERIA=PIN(.05) POUT(.10) /NOORIGIN /DEPENDENT SEScore /METHOD=ENTER MCScore /PARTIALPLOT ALL /RESIDUALS DURBIN HISTOGRAM(ZRESID) NORMPROB(ZRESID) /CASEWISE PLOT(ZRESID) OUTLIERS(3) /SAVE PRED COOK LEVER SRESID SDRESID.
Resources	Processor Time	00:00:00.17
	Elapsed Time	00:00:00.13
	Memory Required	3328 bytes
	Additional Memory Required for Residual Plots	984 bytes
Variables Created or Modified	PRE_4	Unstandardized Predicted Value
	SRE_4	Studentized Residual
	SDR_4	Studentized Deleted Residual
	COO_4	Cook's Distance
	LEV_4	Centered Leverage Value

Descriptive Statistics

	Mean	Std. Deviation	N
SEScore	18.70	3.844	97
MCScore	4.59	2.813	97

Correlations

		SEScore	MCScore
Pearson Correlation	SEScore	1.000	-.332
	MCScore	-.332	1.000
Sig. (1-tailed)	SEScore	.	<.001
	MCScore	.000	.
N	SEScore	97	97
	MCScore	97	97

Variables Entered/Removed[a]

Model	Variables Entered	Variables Removed	Method
1	MCScore[b]	.	Enter

a. Dependent Variable: SEScore

b. All requested variables entered.

Model Summary[b]

Model	R	R Square	Adjusted R Square	Std. Error of the Estimate	Change Statistics: R Square Change	F Change	df1
1	.332[a]	.110	.101	3.644	.110	11.797	1

Model Summary[b]

Model	Change Statistics: df2	Sig. F Change	Durbin-Watson
1	95	<.001	2.076

a. Predictors: (Constant), MCScore

b. Dependent Variable: SEScore

ANOVA[a]

Model		Sum of Squares	df	Mean Square	F	Sig.
1	Regression	156.676	1	156.676	11.797	<.001[b]
	Residual	1261.653	95	13.281		
	Total	1418.330	96			

a. Dependent Variable: SEScore

b. Predictors: (Constant), MCScore

Coefficients[a]

Model		Unstandardized Coefficients: B	Std. Error	Standardized Coefficients: Beta	t	Sig.
1	(Constant)	20.785	.711		29.250	<.001
	MCScore	-.454	.132	-.332	-3.435	<.001

Coefficients[a]

Model	95.0% Confidence Interval for B: Lower Bound	Upper Bound	Correlations: Zero-order	Partial	Part	Collinearity Statistics: Tolerance

1	(Constant)	19.374	22.195				
	MCScore	-.717	-.192	-.332	-.332	-.332	1.000

Coefficients[a]

Model		Collinearity Statistics VIF
1	(Constant)	
	MCScore	1.000

a. Dependent Variable: SEScore

Collinearity Diagnostics[a]

Model	Dimension	Eigenvalue	Condition Index	Variance Proportions (Constant)	MCScore
1	1	1.854	1.000	.07	.07
	2	.146	3.560	.93	.93

a. Dependent Variable: SEScore

Casewise Diagnostics[a]

Case Number	Std. Residual	SEScore	Predicted Value	Residual
48	-3.134	8	19.42	-11.422
91	-3.109	9	20.33	-11.330

a. Dependent Variable: SEScore

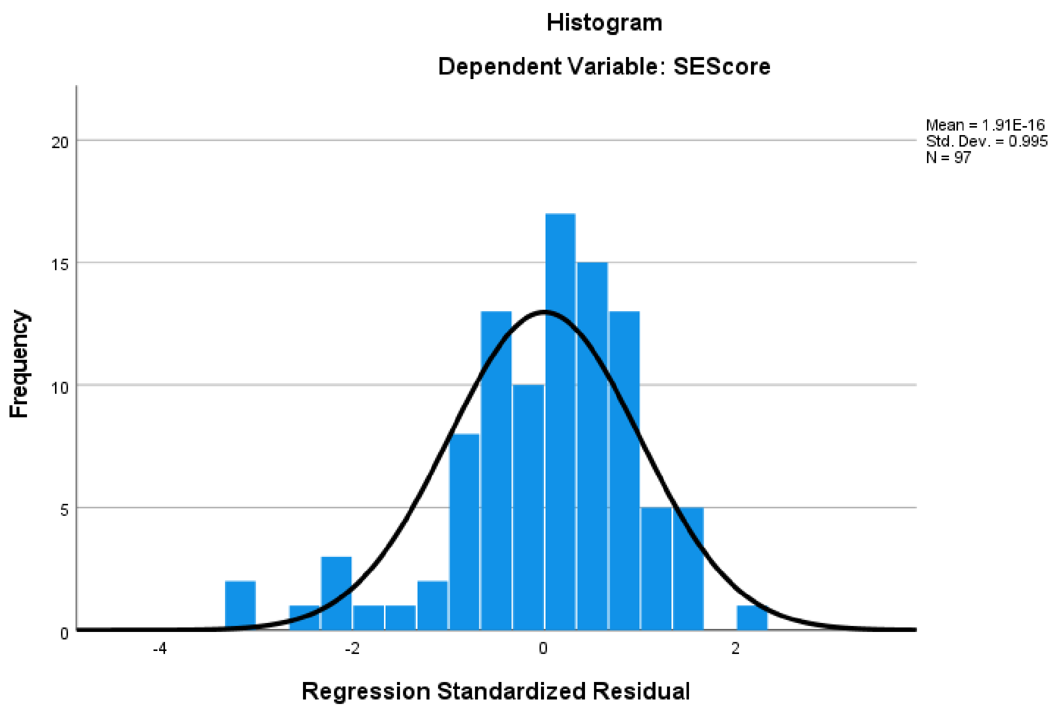
Residuals Statistics[a]

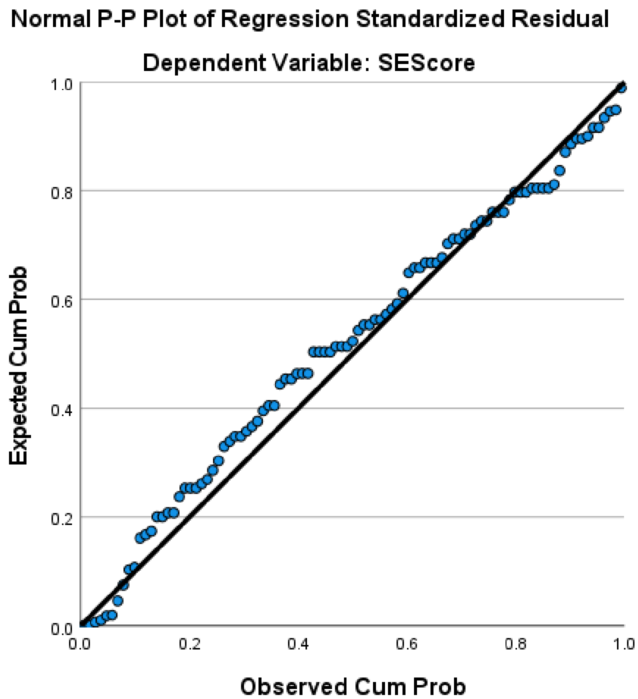
	Minimum	Maximum	Mean	Std. Deviation	N
Predicted Value	13.97	20.78	18.70	1.278	97
Std. Predicted Value	-3.702	1.631	.000	1.000	97
Standard Error of Predicted Value	.374	1.426	.498	.161	97
Adjusted Predicted Value	13.06	20.66	18.69	1.312	97
Residual	-11.422	8.303	.000	3.625	97
Std. Residual	-3.134	2.278	.000	.995	97
Stud. Residual	-3.156	2.320	.001	1.006	97
Deleted Residual	-11.648	8.613	.008	3.708	97

Stud. Deleted Residual	-3.318	2.377	-.004	1.024	97
Mahal. Distance	.021	13.704	.990	1.742	97
Cook's Distance	.000	.203	.012	.028	97
Centered Leverage Value	.000	.143	.010	.018	97

a. Dependent Variable: SEScore

Charts




Normal P-P Plot of Regression Standardized Residual
Dependent Variable: SEScore
Expected Cum Prob
Observed Cum Prob
0.0
0.2
0.4
0.6
0.8
1.0