Laboratory learning’s role on chemistry self-concept: A mixed methods approach

by

Derek John Base

B.S., Pittsburg State University, 2013
M.S., Fort Hays State University, 2019

AN ABSTRACT OF A DISSERTATION

submitted in partial fulfillment of the requirements for the degree

DOCTOR OF EDUCATION

Department of Curriculum & Instruction
College of Education

KANSAS STATE UNIVERSITY
Manhattan, Kansas

2024

Abstract

This study examines the impact of hands-on chemistry laboratories in shaping secondary students’ chemistry self-concepts. Utilizing a mixed methods approach, the research sought to address how students’ chemistry self-concept varied during the first semester of an introductory chemistry course and give voice to students’ understanding of the role that laboratories play in their chemistry self-concept development. Data collection involved qualitative and quantitative methods, including surveys, open-ended responses, and semi-structured student interviews. Findings revealed that students formed a stable chemistry self-concept quickly during their introductory course, with some groups experiencing no variation during the first semester. Additionally, the findings highlight that students enrolled in a laboratory-intensive chemistry course highly valued the influence of hands-on laboratory experiments in shaping their chemistry self-concept, particularly those with lower chemistry self-concepts. Conclusions underscore the importance for educators and curriculum developers to recognize the role of chemical experiments in shaping students’ chemistry self-concept development. Recommendations for future research encourage the investigation of teachers' understanding of students’ development of their chemistry self-concept, a call to investigate students outside of honors chemistry, and further investigation into students' perception of inquiry and non-inquiry laboratories.

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Approved by:

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Michael Lawson, Ph.D.

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Chapter 1 - Introduction

Over the next ten years, the U.S. Department of Labor Statistics projects jobs in STEM fields will grow at a rate of 10.8%, while jobs in non-STEM fields are projected to grow at only 4.9% (Krutsch & Roderick, 2022). With increased demand in STEM fields, universities must graduate STEM majors at a rate matching the job demand. When considering what impacts students' decisions to pursue STEM majors and enter STEM fields, Wang (2013) found that 12th-grade math achievement, exposure to science and math courses, and math self-efficacy beliefs most impact students' sentiments toward STEM employment and the STEM field at large. Further, these factors position the importance of secondary science and math courses as a determining factor in students' college majors. To provide a better STEM experience in K-12, encourage more STEM majors, and consequently help meet the future demand for STEM jobs, we must study students' secondary STEM education experiences.

Chemistry is a primary example of a STEM course that needs investigating. In a survey of 554 chemistry majors, George and colleagues (1985) examined why students selected chemistry as a major. The study found that the two most significant factors for students choosing chemistry were having a high aptitude for science and that students were "turned on" to chemistry through laboratory work (George et al., 1985). Given that secondary chemistry courses strongly rely on a laboratory component, it is essential to understand and support student experiences during these labs.

During postsecondary coursework, the importance of hands-on learning in chemistry can be seen in the adherence to laboratory coursework as a significant component of chemistry curricula despite its substantial cost (Reid & Shah, 2007). Academic institutions across the United States devote space and time to ensure that students engage in laboratory learning during chemistry courses, where most have a laboratory component associated with them. Thus, students do not just experience general chemistry lectures in college; they often concurrently engage in a two-hour lab credit that goes along with the three-hour lecture credit. Laboratory components continue throughout the undergraduate experiences. The American Chemical Society requires a minimum of 350 hours of laboratory time to be completed to obtain an American Chemical Society certified bachelor's degree (ACS, 2023). Further, institutions and instructors view this duality of lecture and lab work as a necessary and vital aspect of learning chemistry (Reid & Shah, 2007). However, even though participating in laboratory learning is considered essential and part of postsecondary coursework, literature has shown that the goals and purpose of laboratory learning have been unfocused (Hofstein & Lunetta, 1982; 2004).

One goal of laboratory learning, as presented by Bretz (2001), lies in the unique ability of laboratory learning to access student learning across three learning domains: cognitive, affective, and psychomotor. Using Novak's Theory of Education, Human Constructivism, Bretz (2001) outlines that learning is most meaningful when all three domains are activated and that laboratory learning allows students to activate all three domains simultaneously. Additionally, Hofstein and Lunetta (2004) suggest that isolating and defining goals for which laboratory learning offers a unique and significant contribution to science education is vital. By focusing on how laboratory learning interacts with cognitive, affective, and psychomotor learning domains, we can provide a more focused goal for incorporating laboratory learning and its role in chemical education.

The Uniqueness of Chemistry Lab Work in Secondary Education

Chemistry, possibly more than any other science, is one subject that can be best learned experientially. These experiences are best captured in laboratory work, and the critical role laboratory learning plays in chemistry has been evident since the 1800's. A lab component has almost always been included from the beginning of chemistry's inclusion into secondary education (Rudolph, 2007). This laboratory component augmented students' classroom knowledge by completing corresponding laboratory experiments and enhancing their understanding of chemistry. As Griffin (1892) stated, "The laboratory has won its place in school; its introduction has proved successful. It is designed to revolutionize education. Pupils will go out from our laboratories able to see and do" (as cited by Hofstein & Lunetta, 1982, p.202)

This revolution of laboratory work during chemistry learning is essential as it can make the complex nature of chemistry more approachable. For instance, one such famous story of students learning through chemical experiments is that of Ira Remsen, whose story of his exploration of declaration that nitric acid "acts upon" copper is retold by Getman (1940) :

> I was getting tired of reading such absurd stuff and I determined to see what this meant…A great colored cloud arose. This was disagreeable and suffocating- how should I stop this? I tried to get rid of the objectionable mess by picking it up and throwing it out the window… I learned another fact—nitric acid not only acts upon copper but it acts upon fingers. The pain lead to another unpremeditated experiment. I drew my fingers across my trousers and another fact was discovered. Nitric acid also acts upon trousers… It was a revelation to me… Plainly, the only way to learn about it was to see its results, to experiment, to work in the laboratory. (p. 9-10)

Remsen's experience highlights how the concepts in chemistry can often be abstract and difficult for learners to see and conceptualize. Combining this with the introduction of a new language and symbols that are unique to chemistry, many students often find the subject to be intimidating to learners, and laboratory work can frequently alleviate this tension.

The importance of lab learning in chemistry can also be seen through curriculum shifts and redesigns throughout the 20th and 21st centuries. From Dewey (1938), who advocated learning by doing, to today's curriculum, which emphasizes project-based learning (NGSS 2013), the role that labs play in learning chemistry is thought to be central to the subject itself (Hofstein & Lunetta, 2004). Chemistry has been seen as a process to be done, not just to learn.

Even given its importance, a primary concern with laboratory learning is that chemistry education is not standardized, and many teachers revert to rote memorization of facts and procedures with very little hands-on experimental learning (Lederman, 1992). The Next Generation Science Standards (NGSS) aim to combat this by emphasizing that science is best learned through doing (NGSS 2013). While NGSS does not specify a specific number of labs to complete, College Board's Advance Placement Chemistry (2022) course does, requiring that "25 percent of the instructional time engages students in lab investigation" (p.5). Assuming a 180-day school year, this would include 45 days or about five monthly laboratory activities for a nine-month school schedule. However, Boesdorfer and Livermore (2018) found that 25% of teachers in their study completed labs on a much lower frequency, with teachers reporting that they complete zero to one lab per month. Without laboratory learning in chemistry, students are given an incomplete view of chemistry based on abstraction and not experience.

Personal Experience

During my short tenure as a teacher, I noticed an interesting trend when telling people about my occupation. I have continued to be shocked that most conversations I have with others about my teaching career follow a very similar script. The conversation typically follows these lines: “What subject do you teach?” “I teach high school chemistry.” “Oh, wow. You must be really smart. I could never teach chemistry. I hated chemistry in high school.” This script is not unique to me. My colleagues have all reported having had similar conversations with many different people. With such a large percentage of people responding in the above way, I began to wonder what experiences elicited such strong associations and responses with the subject of chemistry. While reflecting on these conversations with people, I have found that they have a very different view and experience of chemistry than I do. When discussing people’s view of chemistry further, I often find that when they took the course, there was very little in the way of laboratory learning. From this incomplete view of chemistry, people might be left with a poor chemistry self-concept, only seeing chemistry as an abstract concept while never experiencing the very real nature of chemistry through lab work.

Self-Concept

Self-concept is defined as a person’s perceptions of their abilities formed from their experiences and interpretation of their environment (Shavelson et al., 1976). Students form self-concepts based on their past experiences and performance (Marsh & Martin, 2011). Additionally, a student’s self-concept has been shown to be a highly important and influential factor in their motivation, performance, happiness, and various other emotional and cognitive outcomes (Marsh & Martin, 2011; Nielsen & Yzierski, 2015; Franks & Capraro, 2019). Researchers have shown that students with poor self-concept in specific subjects are less motivated in those areas, tend to become less engaged, and may struggle to put forth the effort needed to complete tasks (Justicia-Galiano et al., 2017).

Given the critical role that self-concept plays in a student’s perception of their ability in a subject, it is paramount to understand what factors affect a student’s development of self-concept. Since chemistry shares many similarities with other fields in mathematics and science, it is essential to look at chemistry's uniqueness to determine the role that laboratory work plays in forming a student's self-concept in chemistry.

Research Problem

The topic of self-concept has received considerable attention for decades. Even so, there remains very little research in the field of chemistry self-concept (Flaherty, 2020; Rüschenpöhler & Markic, 2020). The studies that have been conducted tend to concentrate on students' self-concept and experiences in undergraduate chemistry, whereas studies with secondary students remain a much-needed area of investigation (Rüschenpöhler & Markic, 2020). While reviewing affective chemistry education research from 2000 to 2019, Flaherty (2020) found that of the 91 studies reviewed, only 13 focused on chemistry self-concept. Of these 13 studies, quantitative research shows a dominance of 12 studies, with many developing and validating self-concept scales and the only remaining study being mixed methods (Flaherty, 2020). (Flaherty, 2020).

Flaherty (2020) also stated that the review found no considerable qualitative research on chemistry students' self-concept. While quantitative research is critical, qualitative research is just as vital. Without a qualitative look into the development of students' chemistry self-concept, much remains to be learned before a complete picture of the complexity of students' chemistry self-concept can begin to be pieced together, particularly in secondary education.

Pilot Study

A pilot study was conducted during the spring of 2023 to situate chemistry teachers' understanding of the influences on students' development of chemistry self-concept, specifically emphasizing the role of laboratory experiments. The pilot was a qualitative study interviewing four high school chemistry teachers. It used a semi-structured interview to gain insight into their experiences of students' development over their chemistry self-concept. Qualitative methods were chosen to provide rich descriptions of phenomena and allow the participants to provide an understanding and context of events (Sofaer, 1999). By situating the pilot study as a qualitative study, I sought to give voice to teachers to explain why they continue to use experiments in their classrooms.

The interviews were analyzed through two coding cycles, using in vivo first and then pattern coding to capture the essence of the teacher's understanding of how students developed their chemistry self-concept (Saldaña, 2013). From the coding analysis, three themes emerged that explained how teachers understood the students' self-concept development: success, student-teacher relationship, and participation in hands-on laboratory work.

Key from these findings is that teachers thought that it was critical for students to experience chemistry by "doing." They described work in the laboratory as an essential component of their class and students' development of their chemistry self-concept. The teachers also spoke of chemistry being unique from other science courses because of its reliance on laboratory learning for students to develop a complete picture of the nature of chemistry. The pilot study strengthened my understanding of the importance of laboratory learning in chemistry from a chemistry teacher's perspective. It inspired an investigation of the student's perspective on the importance of laboratory learning.

Purpose of the Current Study

With the importance and uniqueness of the laboratory component of chemistry established, both in literature and through a preliminary pilot study, this study aims to investigate the relationship between students' development of their chemistry self-concept and their participation in hands-on laboratory learning. As the need for STEM majors increases, it is essential to understand how students build their chemistry self-concept. Hofstein and Lunetta (2004) observed that the lack of literature on students' attitudes toward chemistry has missed an opportunity to benefit educational experiences. This study will look to investigate the relationship between students' experience and exposure to laboratory learning and the development of their chemistry self-concept.

Research Questions

Motivated by the concerns above, this study will aim to accomplish the following goals-determine if there is a relationship between secondary students' participation in high school chemistry labs and their development of chemistry self-concept and how students conceptualize their self-concept in relationship to lab work.

Quantitative:

1. Over the course of 15 weeks in a laboratory experiment-heavy chemistry class, to what extent is the variation in students' chemistry self-concept explained by their pre-chemistry self-concept, mid-point chemistry self-concept, course grade, and gender?

2. Do students with different initial chemistry self-concepts (low, mid-low, mid-high, high) experience different variations in their chemistry self-concepts over 15 weeks in a laboratory chemistry class?

Qualitative:

1. What do students describe as impacting their confidence level when doing experiments in a laboratory setting?

2. How do groups of students with low, mid-low, mid-high, and high chemistry self-concept scores experience and perceive the role of hands-on laboratory work in developing their chemistry self-concept?

Methodology Overview

The study used an explanatory sequential mixed-method design to answer the research questions. The study first collected and analyzed quantitative data and then used qualitative interviewing to help unpack and explain the results of the quantitative analysis. During the study's first phase, I used the Chemistry Self-Concept Inventory (CSCI) (Bauer, 2005) to collect data from students enrolled in honors chemistry from a suburban high school in the Midwest. This data was used to test if chemistry self-concept is a fixed or mobile construct during the students' first semester of an introduction to chemistry course. The CSCI survey was administered the day following a lab while students completed the post-lab analysis. The survey was administered at three different points during the first semester of the year, during the first two weeks of school, after the first eight weeks of school, and the final administration occurred after 15 weeks of school had been completed. The quantitative data assessed if the variance in students' chemistry self-concept was explained by their pre-chemistry self-concept, mid-point chemistry self-concept, course grade, and gender. The second qualitative phase was conducted following the quantitative results to help determine how students understand the development of their chemistry self-concept.

Implications

There are three implications for the current study. First, the current body of literature clarifies that the development of students' self-concept should be a priority in education. With students' chemistry self-concept being a strong indicator of multiple areas of academic success and a strong determiner of career choice, developing a positive chemistry self-concept must be taken seriously as an outcome of chemistry education. The research into chemistry self-concept is still relatively new within the chemical education community; while seeing a rise in prominence in the last 20 years, there is still much to be learned about developing students' self-concept. A current blind spot in academic research is reliance on quantitative studies (Flaherty, 2020). While important to the generalization of trends and overall view of students' chemistry self-concept, quantitative studies fail to highlight the underlying interactions that occur during a student's development of their self-concept. To fully understand how students develop their chemistry self-concept, qualitative approaches must be utilized to gain a richer understanding of the construct.

Second, the intersection between hands-on laboratory work and students' chemistry self-concept development has not been investigated. Research has shown that laboratory work is a critical component of chemistry education and plays a significant role in students' attitudes toward the subject (Hofstein & Mamlok-Naaman 2021). With students' development of their self-concept dependent on their interaction with the subject matter and laboratories being a critical component of the curriculum, this study showed that students' experience with chemistry experiments plays a role in the development of their self-concept. When looking to increase positive aspects of students' chemistry self-concept, it becomes imperative to understand what role laboratory learning plays in its development. As such, this research helped fill the gap presented in literature through a mixed method approach to investigate how students' experience in the chemistry laboratory intersects with the development of their chemistry self-concept.

Finally, this study discovers practical implications for classroom teachers and curriculum developers. This study shows the importance that students place on hands-on laboratory work for their understanding of chemistry. The findings of this study show that classroom teachers can implement laboratory learning to assist in developing a positive chemistry self-concept. Curriculum developers can assist teachers in implementing laboratory learning to establish a positive chemistry self-concept by designing curriculums that emphasize the development of a positive chemistry self-concept.

Terms and Definitions

Self-Concept is described as an individual's general perception of the self in a given field (Shavelson et al., 1976)

Academic Self-Concept refers to individuals' knowledge and perceptions about themselves in achievement or learning situations (Bong & Skaalvik, 2003)

Chemistry Self-Concept refers to individuals' knowledge and perceptions about themselves with regard to concepts in chemistry (Bauer, 2005).

Laboratory Learning is hands-on learning in which students interact with chemicals and/or laboratory equipment to conduct a chemical experiment.

Limitations

The current study has three potential limitations. First, this mixed methods research design is grounded in case study (Creswell, 2021). By examining multiple students from one teacher's classes, the study will be grounded by its context and not necessarily generalizable. Although generalizability is a goal for quantitative studies, qualitative research looks at the complexity of the human experience instead of prioritizing dependability and transferability. Nevertheless, this study draws upon both design approaches to address these trustworthiness strategies. However, by gaining a rich data foundation, I gained insight into the development of students' chemistry self-concepts.

Second, a modified version of Bauer's (2005) CSCI was used to measure students' chemistry self-concept scores. The sample size of 71 students may limit the ability to determine the validity and reliability of the instrument. Additionally, the sample of students is homogenous and not representative of the diversity needed to ensure the instrument and results are generalizable to a larger population.

Finally, I (the researcher) am a teacher at the school where this study took place, and students might feel a need to give "correct" answers to me due to my status. To mediate this potential limitation, I selected students with which I do not evaluate academically and who are from the classrooms of another teacher. In addition, students were assured that their responses to this study would remain confidential and had no impact on their chemistry grades. I ensured students were aware that their answers were only seen by me, the researcher, and had anonymity through pseudonyms in any sharing of direct quotes.

Delimitations

The study has been limited to students in a singular Midwestern school district. This district was selected due to the researcher's access to the students and the relationship between the district and the researcher. This selection will limit the generalizability of the study's outcome to similar school districts and student populations.

The participants recruited for the study were only students who were enrolled in an honor's introductory chemistry course. Students taking their second year of chemistry will be omitted from the study. This delimitation was imposed as I sought to determine how a student's chemistry self-concept develops during their first semester of chemistry. While a student's chemistry self-concept could continue to develop as the student is exposed to more courses, this study will not investigate this phenomenon. This delimitation will not allow me to see if students' chemistry self-concept continues to change beyond their first semester of chemistry coursework.

Chapter Summary and Organization of Dissertation

In this chapter, I describe the purpose of the current study and the subsequent research questions. I also briefly described the literature grounding this study and the mixed methodology research design I will use. In Chapter 2, I will situate the study within constructivism, outline the importance of the inclusion of laboratory learning within chemistry education, and give an overview of the importance of student academic self-concept literature. In Chapter 3, I provide more details about the methodology described here, specifically the study context, participant selection, data sources, collection procedures, and data analysis procedures. In Chapter 4, I continue with the insights gained through the data analysis. Finally, I discuss the key findings, implications of the study, and recommendations for future research in Chapter 5.

Chapter 2 - Literature Review and Theoretical Framework

The purpose of this study is to investigate the impact of laboratory learning on the development of secondary students' chemistry self-concept and to investigate how students conceptualize the role of lab work on their self-concept. In this chapter, I first offer an epistemological perspective I bring to the study and then follow with a review of the literature. The literature review offers an examination and analysis of the current body of research to provide context for the study and situate the study within the current academic field. This review is organized around three key themes. The first theme in the literature is that chemistry laboratories play a unique and historic role in chemical education. The second theme is that subject-specific academic self-concept is a robust predictive measurement of student success. Finally, the third theme reviews what is currently known about the development of students' chemistry self-concept. The final component of the literature review will be the rationale for this research and a discussion of the interrelationship between students' experiences in the laboratory and the development of their chemistry self-concept.

Constructivism and Student Learning

Constructivist traditions can be traced back to the work of Piaget. Piaget viewed children as "little scientists" who built their knowledge through interactions and information extracted from their immediate environment. Knowledge then is built as "a function of experience: either by immediate contact (perception), or by successive liaisons as a function of time and of objective repetitions" (Piaget, 1973, p. 100). Piaget stressed that knowledge is constructed on the basis of reflection and elaboration on one's experiences.

Building on Piaget's view of knowledge construction through experience, reflection, and elaboration, Hoover (1996) expressed that constructing knowledge was not a passive activity;

instead, learning is an active process in which experiences build upon current knowledge. As learners' experiences grow, their knowledge adapts to incorporate new experiences. This act of adapting to new and current experiences forces learners to be active in the process of knowledge building. Christie (2005) presented that knowledge is constructed from experiences and then is modified through different experiences.

Constructivism is an epistemology that tries to understand and describe the process of which persons develop their knowledge about the world around them (Merriam & Caffarella, 1999). It is important to establish an epistemological stance when investigating how students process classroom activities and make since of the learning that takes place through those activities. To this end, I approach this study from a constructivist viewpoint.

Constructivists understand learning as the process of constructing meaning, which is built through peoples' experiences and interactions with the world (Merriam & Caffarella, 1999). As the learner gains more experiences they develop an internal illustration of knowledge and interpretation of the experiences (Amineh & Asl, 2015). As a result, these experiences culminate in the construction of knowledge possessed by the individual.

Using constructivism, Novak's (1993) Theory of Human Constructivism argues that education must consist of experiences that empower students to construct knowledge. When new knowledge is created, meaningful learning takes place. Meaningful learning happens during the integration of thinking, feeling, and acting (Novak, 1993). Bretz (2001) places the integration of thinking, feeling, and acting into cognitive, affective, or psychomotor domains. When students experience cross through all three domains, only then will meaningful learning take place. One such activity that incorporates all three domains is that of laboratory experiments.

Laboratory Education

History of Laboratory Learning

During the early 1800s, science education was considered a dispensary of knowledge. Students saw teachers as the keepers of scientific knowledge, and the discipline was viewed as a set of facts and figures to be memorized. This view of science changed during the 1880s. During this time, colleges noticed that students were coming to them unprepared for the demands of college-level science courses (Rudolph, 2007). The answer to the lack of practical laboratory skills was found by looking overseas into the German science education model. Unlike the current American view of science education, the German model, pioneered by Justis von Liedig, contained a sizeable practical laboratory component (Rudolph, 2007). Students learning through the laboratory method augmented their classroom knowledge by completing corresponding laboratory experiments. Seeing this model as an answer to the current problem with science education, Edwin Hall, a physics professor at Harvard, created a textbook based on 40 physics experiments that high school students should complete to be prepared for education in sciences at Harvard (Rudolph, 2007). This shift in science education created the answer for college preparatory for students and created the inclusion of laboratory work as now a critical component of science education.

During the significant curriculum reforms of the 20th century, laboratory experience remained an integral part of the science curriculum (Hofstein, 2004). As science education underwent substantial changes in the 1960s, educators emphasized providing students with hands-on opportunities to engage with science in the laboratory (Hofstein, 2004). One notable effort to reshape chemistry education was the Chemical Education Materials Study (CHEM Study), funded by a $2.8 million grant from the National Science Foundation (Ridgway &

Pimentel, 1970). This initiative firmly established laboratory learning as a critical component of chemistry pedagogy. George Pimentel, the editor of CHEM Study, argued that laboratory experiences were essential for deepening students' understanding of chemical systems, linking their practical work to the concepts taught in class and read about in textbooks (Hofstein, 2004). The curriculum reform of the ‘60s anchored laboratory learning at the center of science teaching. Laboratories allowed students to interact with the nature of science, which was viewed as the emphasis on inquiry and science process skills (e.g. observing, hypothesizing, inferring, interpreting data, and designing experiments) by focusing on students' experience in the labs and leading students through the discovery of natural phenomena (Abd-El-Khalick & Lederman, 2000; Hofstein and Mamlok-Naaman, 2021). Reflecting on the historical significance of laboratory learning in science education, Tobin (1990) went as far as to say that educators have viewed laboratory work as an “almost sacred” component of science education (p. 403). The revolution of laboratory work that had started in physics had also made its way to the chemistry classroom.

In chemistry, laboratory learning offers a more genuine learning environment by including a hands-on dimension to chemistry pedagogy. During a well-constructed laboratory activity, students construct their knowledge, work on logical reasoning, explore inquiry-based skills, work collaboratively with their peers, and develop their problem-solving abilities (Hofstein, 2004; Tobin, 1990). In addition, laboratories can assist in developing students’ psychomotor skills (Hofstein, 2004; Lewis et al., 2009). This intersection of so many different domains places laboratory learning in a distinct position compared to traditional classroom learning in chemistry. Hofstein and Mamlok-Naaman (2021) suggest that it is a widely held belief that the laboratory provides the only place in school for certain kinds of skills, abilities, and understanding to be developed (e.g., analytical methods, model testing, technical record-keeping, sample preparation, scientific measuring, etc.). Beyond fostering cognitive and technical skills, laboratory experiences are instrumental in shaping students' affective responses to chemistry.

Laboratories and Affective Measures

Laboratory experiences are vital to students' engagement and enjoyment in chemistry courses. These experiences have been reported as the most important method to increase student engagement and interest in chemistry studies (Ben-Zvi et al., 1976; Hofstein, 2004). Students stated that hands-on work in the laboratory was the greatest method to increase their engagement in the chemistry classroom (Ben-Zvi et al., 1976). More recently, van Vorst (2018) reported that students view conducting experiments positively, whether or not they had a positive or negative view of the chemistry course in general. Notably, students reported a lack of or infrequent engagement in hands-on laboratory work as a negative. Students cited lessons that did not include laboratory work as boring and struggled to engage in the content.

The inclusion of increased laboratory work from the chemical education reform of the mid-20th century provided students not only the opportunity to learn chemistry through a hands-on method but also increased student engagement and enjoyment in chemical learning. As more students engaged with chemical experiments, educational research saw that laboratory learning provided superior content learning along with increased emotional perceptions of chemistry.

Self-Concept

Researchers also postulated that students' emotions and perceptions of themselves might be the most important variable in education (e.g., Bloom, 1976; Brookover et al., 1964).

Emotions play a critical role in education affecting the ability that students have to learn, as a person's thoughts and attitudes are deeply tied to their emotions (Damasio et al., 1990; Goleman, 1995; Oatley, 1991). Damasio and colleagues (1990) have shown that the union between emotion and cognition happens at a physiological level. During their study, the researchers found that individuals who had damaged their frontal cortex were no longer able to activate affective states linked to punishment and reward, despite having no impairment to their knowledge or knowledge access.

Bloom (1976) believed that students who continually received negative feedback throughout their schooling would develop major mental problems later in life. For instance, after thirteen years of schooling students who only heard of their failures, could start to see themselves as failures or rejects (Bloom, 1976). Understanding the link between emotions and cognition is critical in understanding how students' emotions hinder or facilitate learning in the classroom particularly when students undergo challenging intellectual tasks or subjects (Flaherty, 2020).

Educational psychologists have examined self-constructs and perceptions that students create and have shown that students with strong, positive self-constructs and perceptions perform at higher levels in the academic setting (Bong & Skaalvik, 2003; Marsh & Martin, 2011). Students with positive self-constructs are shown to persist longer on a difficult task, feel less anxious, set more challenging academic goals, and have higher levels of academic achievement (Rüschenpöhler & Markic, 2019). Students develop their self-constructs through their past achievements and experiences. As a student has continued experiences in school, their beliefs about their academic ability become deeply rooted. With the critical role that emotions and self-constructs have shown to play in the educational setting, it is paramount to investigate these constructs at a deeper level.

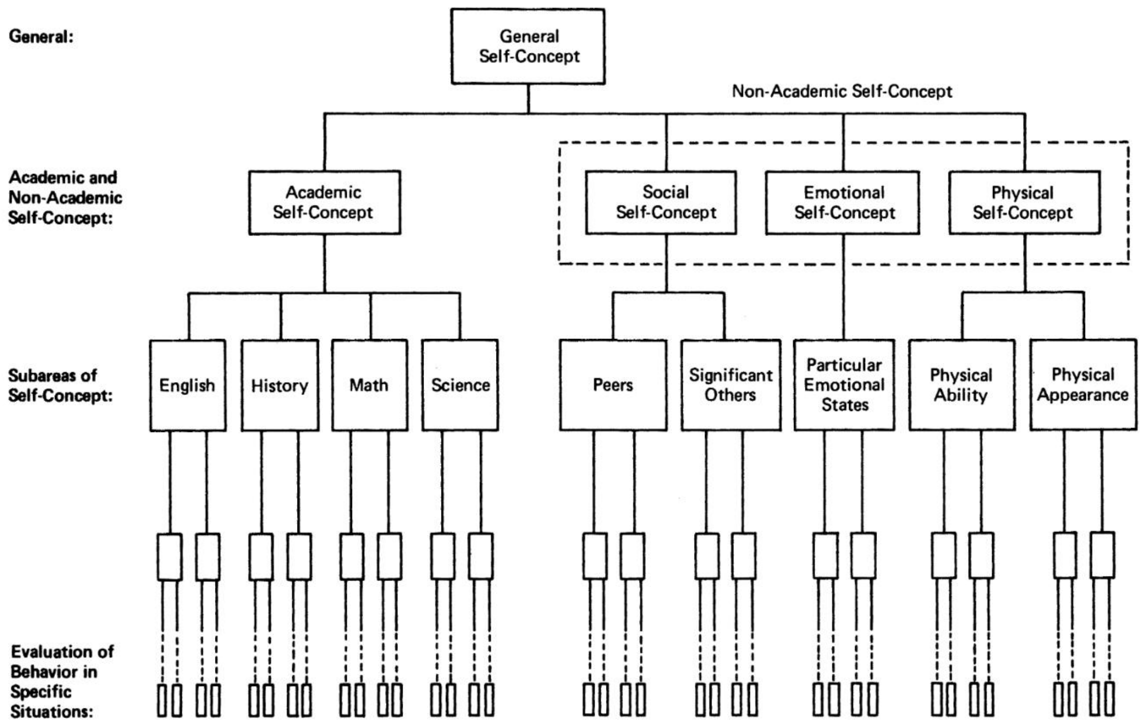
One such psychological construct is self-concept. Self-concept is defined as the "person's perception of themselves. These perceptions are formed through experience with and interpretations of one's environment. They are influenced by evaluations by significant others, reinforcements, and attributions from one's own behavior" (Marsh & Shavelson, 1985, p. 107). A seminal review of self-concept research by Shavelson and colleagues (1976) marked the beginning of self-concept research, as it made the work made several empirically testable assumptions about the structure of self-concept (Arens et al., 2021). Notably, Shavelson and colleagues (1976) defined seven identifying and testable characteristics of self-concept: organized or structured, multifaceted, hierarchically arrange, stable at the apex of the model, developmental, evaluative, and differentiable from other constructs.

Self-concept is organized or structured based on the experiences of an individual. Individuals have diverse set of experiences and all of these experiences produce the data that a person uses to base their perceptions about themselves. In order to reduce the complexity of experiences, a person organizes and structures experiences into simpler forms to indicate the focal area of one's experience (e.g., family, school, and friend experiences). The categories one creates represent way to organize experiences and create overall meaning. Shavelson and colleagues (1976) proposed that self-concept continues to divide into academic and non-academic realms. This study will focus on academic self-concept, which refers to one's abilities within school or academic settings in relationship to one's academic progress (Brunner et al., 2010). Further, academic self-concept has also shown to be multifaceted. Students from subject specific self-concepts by subdividing overall academic self-concept into individual subjects, such as English, math, science, and even subdividing within these subjects (e.g., chemistry self-concept).

A third feature of outlined by Shavelson and colleagues (1976) is that self-concept is hierarchical (Figure 2.1). At the top of the apex of the hierarchy is one's general self-concept and as one moves down to the base, the individual experiences that make up each facet of the subcategories are formed by the individual experiences of each multidimensional aspect. For example, to get to one's chemistry self-concept, a person's general self-concept can be split into academic and non-academic. Then, one's academic self-concept can be subdivided into science, English, mathematics, etc. Subsequently, the science self-concept can be further broken down into areas such as physics, biology and chemistry, leading to one's chemistry self-concept. Moving back up the hierarchy, the individual experiences that create one's self-concept at the subject-specific level (ex. chemistry, physics, biology) then build to create a general science self-concept. The subdivided self-concepts combine together with math, English, history form one's academic self-concept. The final culmination of academic self-concept with non-academic self-concept forms one's general self-concept.

The bottom of the hierarchy is based upon more specific and limited experiences (e.g., a student takes a semester-long class in biology) and is in turn less stable than the apex, overarching general self-concept. To change the general self-concept of a person there must be many situation-specific interactions that are inconsistent with the previous general self-concept. The hierarchical structure of self-concept is shown in Figure 2.1. Shavelson and colleagues (1976) concluded that the multidimensional aspect of self-concept leads to the stability of one's general self-concept.

Figure 2.1. Shavelson et al. (1976) hierarchically construction of self-concept.



As a person engages in more experiences during their lifetime they continue to add more facets to their general and subdivided self-concepts. This creates a developmental component to self-concept (Shavelson et al., 1976). Young children begin with a very global undifferentiated sense of self-concept. As children begin to age and mature, they develop the ability to categorize and differentiate their experiences. This maturing process allows for different aspects of self and the world to be examined. As one encounters more experiences new categories of self-concepts can be created. For example, a baby would not have developed a chemistry self-concept, but a sophomore in an introductory to chemistry course will have the experiences that develop their chemistry self-concept. Individual's self-concepts become increasingly subdivided and specific as they have more experiences and the ability to differentiate parts of their lives.

Shavelson and colleagues (1976) also hypothesized that a sixth feature of self-concept is that is its evaluative character. One does not only describe themselves in a particular situation but also makes an evaluation of themselves. The evaluation could be made against an ideal standard, class grade, or can be made against relative standards such as classmates. Evaluations can also be formed from an outside perceived evaluation of significant others, such as teachers, peers, or parents. The amount of weight that one puts on the evaluation depends on the individual's past experience and the particular situation they are experiencing (Shavelson et al., 1976. A perceived evaluation from a teacher might carry more weight on a student's academic self-concept than that of a peer. Finally, Shavelson and colleagues (1976) proposed that self-concept as a differentiable from other theoretically related psychological and behavioral constructs, such as self-esteem and self-efficacy.

Shavelson and colleagues' (1976) influential work provided a springboard for the next generation of self-concept research (e.g., Arens et al., 2021; Marsh et al., 2018; Marsh & Seaton, 2015). Their development of a constructive approach in defining self-concept and proposing the structural model of self-concept has profoundly shaped subsequent studies in the field (Marsh & Seaton, 2015). This multidimensional approach laid the groundwork for examining self-concept in specific domains, one of the most prominent being academic self-concept.

Academic Self-Concept

Shavelson and colleagues' (1976) work in self-concept provided the building blocks needed for the emerging field of study to gain traction. From their initial work in self-concept the field of academic self-concept (ASC) emerged. Academic self-concept is defined as the mental representation of one's academic abilities in general and in different academic domains (Brunner et al., 2010). With most of the academic self-concept research being conducted within schools, ASC commonly refers to only the school context (Marsh & Craven, 2006). From Shavelson and colleagues' initial representation of ACS as a high order factor model, academic self-concept research has continued to build models to further explain the construct.

At the current time of this paper there are four other major models outside of Shavelson and colleagues' higher-order factor model, including the Marsh/Shavelson Model, Nested marsh/Shavelson Model, Bifactor-ESEM Representation, and the First-Order Factor Model (Arens et al., 2021). The models differ in how they understand the hierarchal formation of ASC. Whereas the Shavelson model saw a global ASC at the peak of the hierarchy, the Marsh/Shavelson Model proposed that there is not a single global ASC but instead higher order math ASC and verbal ASC (Arens et al., 2021). All five models of ASC reviewed by Arens and colleagues continue to capture the multidimensionality of ASC proposed by Shavelson and colleagues (1976) and assert that domain-specific ASCs are better able to explain and predict domain specific achievement than a general ASC (Arens et al., 2021; Swann et al., 2007). Marsh and Craven (2006) assert that self-concept cannot be understood if its multidimensionality is not considered, emphasizing that researchers should focus on domain specific self-concepts rather than a global component that might or might not appear at the apex of the hierarchy. To understand the domain-specific self-concepts it is important to understand how self-concepts are developed.

Development of Academic Self-Concept

The academic self-concept that a student forms in high school continues to predict their long-term educational attainment long after high school graduation (Marsh and O'Mara, 2008). These effects of ACS were beyond that of school grades, standardized achievement test, IQ and even socioeconomic status. With the predictive power that ACS has it is critical to understand how students develop their self-concept.

Individuals' perceptions and beliefs about themselves are developed and formed from their past achievements. As an individual interacts with a domain, their views and perceptions about the domain begin to form. Positive interaction and high achievement in a domain will positively influence a person's self-concept of said domain (e.g., I did well in my math class, therefore I must be good at math). As these positive interactions with the domain increase, increased interest and pursuit of the domain develop in a reciprocal relationship between achievement and self-concept (Guay et al., 2003.; Marsh et al., 2018).

Shavelson and colleagues (1976) understood individuals do not form their perceptions and beliefs in a vacuum, instead through multiple frames of references. Frames of reference provide markers to which they evaluate their accomplishments and in turn, form their self-concepts. These frames of reference include an absolute idea (e.g., scoring above a 30 on the act); a personal internal standard (e.g., comparing against your personal best); the expectations of significant others (e.g., the feedback from teachers); or a relative standard based on comparisons with peers (e.g., receiving a higher grade in a class than the class average). Shavelson and colleagues initial proposed frames of references have given birth to three main theoretical models and understanding of the formation of ASC (Marsh et al., 2018) . They are the following:

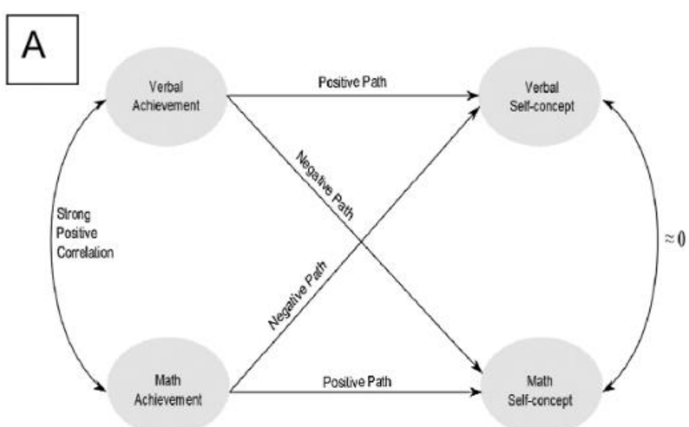
- the internal/external frame of reference (I/E) model;
- the big-fish-little-pond effect (BFLPE); and
- the reciprocal effects model (REM).

Internal/External Model (I/E)

The I/E model was developed by Marsh (1986) to provide a rationale for why students' math and verbal self-concepts were so distinct from each other. Their research showed that students with strong math skills often tend to also have strong verbal skills. This is contrary to most people's perception of themselves as either "math" or "language/verbal" person. Individuals' perceptions have carried over into their self-concepts with math and verbal self-concepts being uncorrelated or even negatively correlated with each other (Marsh & Craven, 2006). According to the I/E model self-concepts are formed in relationships to both an internal and external frame of reference:

- External frame of reference: is a social comparison in which students compare their self-concepts and abilities to peers within their frame of reference (e.g., students who go to the same school will compare their abilities with their fellow classmates).
- Internal frame of reference: is a comparison within a student's own self-perceived ability. Students will compare their own self-perceived abilities in math with their verbal abilities and use this comparison to arrive at their self-concept in each area.

Figure 2.2. Internal/External Frame of Refence (I/E) Model relating verbal and math achievement to math and verbal self-concept (Marsh & Craven, 2006).



Skaalvik and Skaalvik (2002) found that internal frames of reference include: comparisons of achievement in different subjects at a given time, comparisons of achievement of the same subject over some time, and comparisons of achievement vs effort in given school subjects. Comparisons of achievement in different subjects at a given time constitute when students compare their perceived ability in math to their perceived ability in history at a specific time frame (e.g. during their sophomore year). Comparisons of achievement of the same subject over time are when students compare their math ability in the 10th grade to their perceived math ability from the 8th and 9th grades. A comparison of achievement versus effort in a given subject can be seen when students succeed without much effort, forming the perception that they succeed because of high ability rather than hard work.

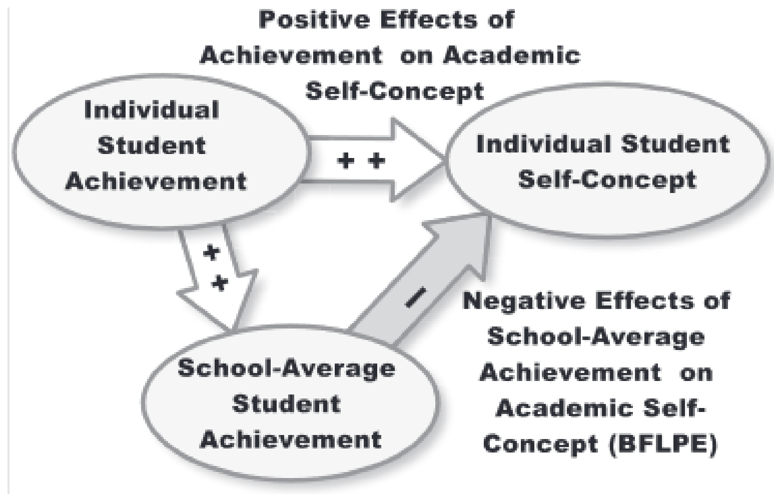
The external frames of reference include school average ability, class average ability, selected students in class, and selected students outside of class. School average ability is when students compare themselves to other students in the school. Class average ability is when a student compares their ability only to those within the particular class, such as honors students comparing their abilities to only other honors students. Finally, selected students outside of class include comparisons to siblings or close friends outside of their class. These comparisons are different in that they are not chosen due to their level of achievement or proximity but due to the relationship to the student making the comparison.

The development of students' academic self-concepts comes through the synthesis of all of the individual frames of reference. As students experience more academic settings they also increase the frames in which they interact with. These experiences continue to shape students' academic self-concept development.

Big-Fish-Little-Pond Effect (BFLPE)

A specific external frame of reference that has gained much research is that of the big-fish-little-pond effect (BFLPE) (Marsh & Seaton, 2015). The BFLPE model of ASC development emphasizes the external frame of reference of relative performance of classmates. The BFLPE proposes that students strongly compare their own academic achievement with that of their classmates (Marsh et al., 2018). According to BFLPE students who attend high-ability schools tend to have lower ASCs than students who attend mixed or lower-ability schools (Figure 2.3).

Figure 2.3. The big-fish-little-pond-effect (Marsh et al., 2018).



The BFLPE has shown to be one of psychology's most universal phenomena. Data collected from three successive Programme for International Students Assessment showed that the effect of school-average achievement on ASC to be negative in all but one of the 123 samples and significantly so in 114 samples (Marsh & Hau, 2003; Nagengast & Marsh, 2012). The strong correlation of BFLPE on student ASC highlights the importance that students place on external frames of reference while developing their own self-concepts.

Reciprocal Effects Model (REM)

With academic achievement so closely tied to ASC researchers proposed that there must be a causal link between the two. The question is whether academic self-concept causes academic achievement or academic achievement causes academic self-concept. To better understand the relationship between self-concept and academic achievement three models were presented: the self-enhancement model (Calsyn & Kenny, 1977), the skills development model (Calsyn & Kenny, 1977) and the reciprocal effects model (REM) (Marsh, 1990). The self-enhancement model proposed that academic self-concept is a primary determinant of academic achievement, whereas the skills development model suggest that academic achievement is the driving force behind the development of academic self-concept. Marsh and colleagues criticized both the self-enhancement model and skills development model as too simplistic, methodologically unsound, and inconsistent with academic self-concept theory (Marsh, 1990; Marsh & Yeung, 1999; Marsh & Craven, 2006). Instead of a unidirectional causal understanding Marsh (1990) proposed an integration of these two models into the reciprocal effects model (REM).

Marsh and Craven (2006) argue that a student's previous academic success plays a role in the development of ASC and that prior ASC affects subsequent achievement. Valentine et al. (2004) found clear support for REM model in their meta-analysis work. Marsh and O'Mara (2008) completed a longitudinally study on reciprocal effects among academic self-concept, self-esteem, academic achievement, and post-secondary education attainment using five waves of data from the Youth in Transition database. They found positive reciprocal effects between academic self-concept and academic achievement. Interestingly they found the relationships between self-esteem and academic achievement to be weak and inconsistent. This further supported the belief that global measures such as self-esteem are not as strong predictors as domain-specific measures, as found in self-concept research (Marsh et al., 2005). The work focusing on the REM model led Marsh and Martin (2011) to suggest:

> If a teacher enhances students' academic self-concept without improving achievement, the gains in self-concept are likely to be short-lived. However, if teachers improve students' academic achievement without also fostering students' self-beliefs in their academic capabilities, then the achievement gains are also unlikely to be long lasting. If teachers focus on either one of these constructs to exclusion of the other, then both are likely to suffer. Hence, according to the reciprocal effects model, teachers should strive to improve simultaneously both academic self-concept and achievement.
> (p. 72)

The REM model helps illustrate that academic self-concept is a multifaceted and complex construct that produces a reciprocal and mutually reinforcing system among students' academic self-concept and academic achievement. This supports Shavelson and colleagues' (1976) proposal that self-concept is both an important outcome of education and a mediating variable that helps explain other academic outcomes or, as Marsh and colleagues (1999) demonstrated academic self-concept is both a cause-and-effect of academic achievement. With the importance of academic self-concept well established in the literature, educational researchers recognized the need to explore domain-specific self-concepts in greater detail.

Chemistry Self-Concept

The domain of science self-concept can be further broken down into different scientific fields such as biology, physics, and chemistry. These field-specific self-concepts have shown to be distinct and distinguishable constructs (Brunner et al., 2010). In a 2005 article, Bauer created the first chemistry-specific Inventory (CSCI) to measure chemistry self-concept. Bauer argued that previous attempts to measure chemistry self-concept were not robust enough to investigate the construct thoroughly, and as such, crafted a 40-question inventory that allowed researchers to measure the domain specific construct. The newly validated CSCI provided researchers with the tools needed to measure chemistry self-concept and showed that it is a distinct construct within the scientific fields.

The CSCI measures students' perceptions of their capacity to learn, understand, and use chemistry knowledge and mathematic knowledge, their overall academic ability, their enjoyment of learning as well as their general creativity self-concept (Bauer, 2005). The CSCI has been a widely used instrument in chemical education research. Flaherty's 2020 meta-analysis found that seven of the thirteen studies on chemistry self-concept from 2000 to 2019 used the CSCI to measure students' chemistry self-concept. While initially designed to be used among undergraduate chemistry students the CSCI has also been validated for use by high school chemistry students (Werner et al., 2021). A modified version of Bauer's CSCI will used in this study to measure students chemistry self-concept.

Chemistry Self-Concept and Student Success

Academic achievement has been a frequently examined outcome of academic self-concept (Arens et al., 2021; Marsh & Craven, 2006; Valentine et al., 2004). Academic achievement is often measured through school grades or standardized test scores. Studies have shown that school grades are more strongly correlated to ASC than standardized testing (Arens et al. 2017; Marsh et al., 2005). Therefore Marsh and colleagues (2018) propose that school grades are a particularly salient source of feedback for students and have important implications for academic careers, giving them a stronger correlation to ASC than standardized testing.

Chemistry self-concept is a strong predictor of multiple academic outcomes in chemistry. Chan and Bauer (2014) were able to use the CSCI and five other affective characteristics, self-efficacy, test anxiety, emotional satisfaction, intellectual accessibility, and math self-concept, to identify academically at-risk students in their first semester of general chemistry. Their data clustered three groups of students into low, mid, and high effective groups. The grouping of students showed to be strongly correlated with the student's exam performance, with the majority of the students in the highly effective group performing significantly higher on both summative and formative exams (Chan & Bauer, 2014). The clustering of students stayed consistent even when accounting for students' Math SAT scores, with only 5% of students switching clusters, further indicating that affective profiles of students' have the ability to predict academic success.

Academic success can be measured outside of test scores. Rüschenpöhler and Markic (2019) found that students with higher chemistry self-concepts than their peers possessed multiple positive learning outcomes such as: persisting at difficult tasks for longer, enjoying learning new skills, and were not set back by failures in laboratory or classwork, but instead saw these setbacks as opportunities to continue to develop their skills. Students with higher chemistry self-concepts had stronger learning goal orientation mindsets and expressed stronger science aspirations than students with lower chemistry self-concepts. In line with other literature students with higher chemistry self-concept showed higher levels of enjoyment from taking chemistry, had lower levels of laboratory anxiety, were more likely to take higher level chemistry courses and developed more meaningful understandings of chemistry concepts (Flaherty, 2020; Kang et al., 2021; Kurbanoglu & Akim, 2010; Lewis et al., 2009; Rüschenpöhler & Markic, 2019). Strong evidence from literature indicates positive chemistry self-concept is a powerful predictor of many outcomes in a chemistry course, further suggesting that developing a positive chemistry self-concept must be an integral part of science education.

Research in Development of Chemistry Self-Concept

Further, self-concept is constructed through personal experiences and history with a given domain. For a student to develop their chemistry self-concept, they must interact with the subject of chemistry. With many students, first exposure to chemistry at the high school level, students' chemistry self-concept begins forming well before they enter general chemistry at college. When looking at secondary chemistry students' self-concepts Nielsen and Yezierski (2015) found that students' chemistry self-concept stabilizes early in their chemistry course showing little variance after the mid-point of the semester. Students' greatest change in chemistry self-concept scores came between the first (mid-October) and second administration (mid-December) of the questionnaire (Nielsen & Yezierski, 2015). Students in Honors and AP chemistry were found to score higher on the CSCI than those in general chemistry, with students in AP chemistry showing to have the highest level of chemistry self-concept (Nielsen & Yezierski, 2015). The results from Nielsen and Yezierski's (2015) work conform previous research that students with higher chemistry self-concepts are more likely to take more chemistry courses.

The role that gender plays in the development of chemistry self-concept has seen mixed findings. While some research has shown results that fall in line with many other STEM fields, being that male students have higher chemistry self-concept than female students (Chan & Bauer, 2015), other studies have not seen the same results (Rüschenpöhler & Markic, 2019). In Rüschenpöhler and Markic's (2019) study female students of Turkish background were found to have higher chemistry self-concept scores than their corresponding male peers. This has led researchers to speculate that in addition to gender, cultural backgrounds play an important role in students' development of their chemistry self-concept.

The composition of the chemistry courses is an important factor in students' development of their chemistry self-concept. Students form their chemistry self-concept early into their course, the composition of the course and interactions the students have with chemistry early in the class play an important role in forming students' chemistry self-concept. Courses in which students have more inquiry activities have been shown to have a positive effect on students' development of their chemistry self-concept (Jansen et al., 2019; Lewis et al., 2009; Vorst, 2018). Research indicates that teachers' presentation of the material and students' interaction with the curriculum plays an important role in student's development of their chemistry self-concept (Jansen et al., 2019; Lewis et al., 2009; Vorst, 2018). The use of laboratories provides students with opportunities to interact with chemistry in a hands-on method that is not available in traditional teaching methods. Agwu and Nmadu's (2023) study showed that students who participated in cooperative learning experiences, such as laboratories, showed increased chemistry self-concept over those who did not.

More recent work in chemistry self-concept literature has investigated the role of the use of digital lab materials on chemistry self-concept development. Hensen and Barbera (2019) investigated how the use of a digital Beer's Law lab compared to that of a traditional lab. They found that students who completed the virtual lab had on average lower affective scores than students who completed the lab in person. Where virtual labs have seen some positive results is in the use as pre-lab activities (Gungor et al., 2022). Gungor and colleagues (2022) found that students in organic chemistry showed an increase in their measured chemistry self-concept when completing a virtual reality component as a pre-lab assignment for their organic chemistry course. This result along with other research has shown that hands-on laboratory continues to play an important role in students' development of their chemistry self-concept (Chaytor et al., 2017; Kapici et al., 2020; Makransky et al., 2020).

Summary

The inclusion of laboratory learning in chemistry has long been see as an essential aspect of chemical education (Hofstein & Mamlok-Naaman 2021). The process of students completing hands-on laboratory learning allows interactions with chemistry in an unique way that is not replicated in other academic disciplines. The literature has shown there is currently a blind spot when addressing the role that laboratory learning plays in the development of student affective measures. One such affective measure is that of academic self-concept.

Academic self-concept is reported to be multidimensionality construct that produces domain-specific ASC (Arens et al., 2021). Domain-specific ASC has strong correlations to student achievement, motivation, and other success measures (Arens et al. 2017; Chan & Bauer, 2015; Marsh et al., 2005). With the importance that domain-specific ASCs play in student domain achievement, it is important to understand how to develop positive academic self-concept in students. The current body of work relies heavily on quantitative methods to measure students' ASC. The has been a neglect of the potential of mixed methods research design to gain a better understanding of how students perceive the formation of their chemistry self-concept and the relationship that it has with the participation in laboratory learning.

Chapter 3 - Methodology

The purpose of this study is to explore how high school chemistry students develop their chemistry self-concept during an introductory chemistry course. The development of a positive academic self-concept has been shown to correlate to many positive academic outcomes; including higher test scores, stronger student engagement, increased interest in the given field and a higher likelihood of students taking more classes in that content (Flaherty, 2020; Kang et al., 2021; Kurbanoglu & Akim, 2010; Lewis et al., 2009; Rüschenpöhler & Markic, 2019). With the ever-increasing demand for STEM careers, it is critical that educators move to develop positive self-concepts in the STEM fields (Flaherty, 2020). However, for teachers to promote the development of positive chemistry self-concept, it is critical to understand what factors play a role in a student's development of their chemistry self-concept. As such, this study aims to identify associations between a student's experiences in an introductory chemistry course and the development of their chemistry self-concept using an explanatory sequential mixed methods research design.

Research Questions

The following research questions guided this study:

Quantitative:

1. Over the course of 15 weeks in a laboratory experiment-heavy chemistry class, to what extent is the variation in students' chemistry self-concept explained by their pre-chemistry self-concept, mid-point chemistry self-concept, course grade, and gender?

2. Do students with different initial chemistry self-concept (low, mid-low, mid-high, high) experience different variations in their chemistry self-concepts over 15 weeks in a laboratory chemistry class?

Qualitative:

1.What do students describe as impacting their level of confidence when doing experiments in a laboratory setting?

2. How do groups of students with low, mid-low, mid-high and high chemistry self-concept scores experience and perceive the role of hands-on laboratory work in developing their chemistry self-concept?

Research Design

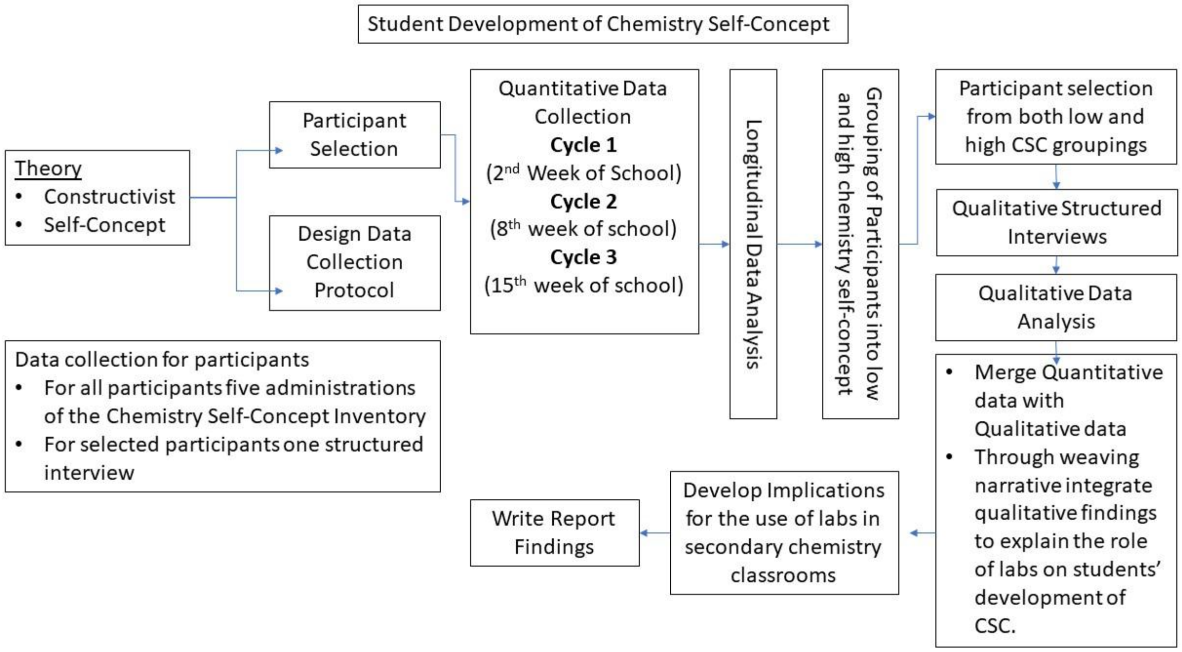
This study will address the formation of secondary high school students' chemistry self-concept with the use of an explanatory sequential mixed method design. The study was conducted by collecting quantitative survey data first and then explaining the results of the quantitative analysis using qualitative interview data (Creswell, 2021). By collecting and analyzing both quantitative and qualitative data, the study was able to build the data sets onto one another.

The choice to collect and analyze both quantitative and qualitative methods allowed for a richer description of the students' perception of the development of their self-concept, while quantitative methods allowed for the determination of whether a students' chemistry self-concept is a fix or variable construct and qualitative data allowed for a more nuanced student perspective of the role that laboratory learned played in the development of their chemistry self-concept. The use of quantitative data and statistical analysis provided a general understanding of students' chemistry self-concept, while qualitative data helped explain those statistical results by exploring participants' views more in-depth (Ivankova et al., 2006). Overall, a mixed methods approach was able to produce a more complete viewpoint of how students develop their chemistry self-concept (Johnson & Onwuegbuzie, 2004).

The strength of the mixed method approach is not merely the collection of both qualitative and quantitative data, instead is founded in the integration of the two data sets (Creswell, 2013). This study does not aim to stand as two separate studies, one qualitative and one quantitative, but rather an integration of the two provided richer insights than either data set could provide on its own.

Further, the choice to use a sequential explanatory model allowed for students' chemistry self-concept to be measured and students to be placed into quartiles of low, mid-low, mid-high and high chemistry self-concept. The placement of students in quartile groups allowed for the study to determine if students with different initial chemistry self-concepts showed different variations throughout the 15-week-long study. The quartile groups were analyzed together to capture how students' chemistry self-concept moved as they engaged in the chemistry course and subsequent laboratory work. From these quartile groups, a sample of 17 students was selected to participate in semi-structured interviews to better understand the experiences they describe concerning their chemistry self-concept. The sequential nature of this study provided a purposeful examination of students' chemistry self-concept and a fuller picture of the construct, as students in different chemistry self-concept groups developed their self-concepts in different ways.

Figure 3.1. Study design**.**



Study Context and Participants

This study was carried out at a high school in a mid-west, suburban school district. The building enrollment sits at around 1000 students per year. Of those students 89% are non-economic disadvantaged with 11% qualifying as economically disadvantaged. The student demographic of the school shows that 78% of the students are white, 7.3% are Hispanic, 6.3% are Asian, 5.1% are multiracial, and 2.6% are listed as other. Ninety-nine percent of the students are not English language learners, with only 10.8% of the student body qualifying as students with disabilities.

The study participants were enrolled in honors chemistry. The students enrolled in honors chemistry are typically sophomores and their demographic breakdown follows that of the whole student body, with the exception of students qualifying with disabilities. Students in honors chemistry who qualify for Special Education services have typically been identified as gifted. Additionally, all student participants were taken from a single teacher's classroom. The classroom teacher has been in education for the past 22 years and has been teaching chemistry for the past 18 years. For the 2023-2024 school year, this teacher taught six sections of honors chemistry, which included all of the student participants of the study.

Participant Recruitment

The recruitment process for the participants in the study was approved by Kansas State University's IRB before data collection. During the recruitment process, I made the initial contact with students in person. The cooperating teacher allowed me to come into his class for the first five minutes of class to explain the purpose of my study. During the students' initial contact, they were given assent/consent forms to take home to their guardians. The prospective participants and their guardians were provided with a follow-up email with the details of the survey and interviews. All participation in the study was voluntary and participation or nonparticipation had no impact on the students' grades. Students were informed during the initial contact and all subsequent contacts that their participation in the study was voluntary and had no impact on their grades. Students and guardians were given my contact information to discuss any questions or to learn about the findings after the study was completed. No parent or student contacted me with concerns about the study.

Students were asked to return the signed guardian assent forms within one week of the initial contact. The cooperative teacher collected student and guardian assent and consent forms during the next week. Two days after the initial recruitment contact with students, I went back into the cooperative teacher's classroom at the beginning of the class to ask students if they had any questions about the survey or if they had any forms signed.

At the end of the one-week recruitment period, 73 students selected to participate in the study. There were 118 students across all six sections of the cooperative teacher's classes. During the course of the study, no new participants joined. During the course of the study, 2 students elected to drop out of the study. This left 71 students who completed the entirety of the study.

This study takes place in a mid-west state that recently passed a new law governing educational surveys and data collection on students. The Bill states that all questionnaires pertaining to student personal and private attitudes, values, or beliefs must be approved by guardians before the administration of such questionnaires. The guardian approval must occur no earlier than 4 months before the administration of the survey, where a no response given by the parents considered an optout. The student continues to have the right to opt-out of the survey at the time of administration. In addition to parent assent, the bill requires all survey questions to be uploaded onto a district database. To comply with the district protocols the chemistry self-concept inventory and semi-structured interview questions were uploaded onto the district database in which parents were able to access the questions before the survey and interviews were given to students.

The site of the research was selected due to the relationship I have with the district. I am currently employed by the district as a chemistry teacher and have a professional working relationship with the selected teacher. The district administration was brought into the conversation of student data collection early to provide guidance on the district's process of data collection of students for non-district use. District leadership was supportive of the research project and gave consent before any contact was made to participants.

Phase 1: Qualitative

Instruments of Data Collection

To measure students' chemistry self-concept, the Chemistry Self-Concept Inventory (CSCI) was utilized (Bauer, 2005). The CSCI was developed and validated to specifically measure students' self-concept in chemistry. Bauer's (2005) CSCI is derived from Marsh's Self-Description Questionnaire III (SDQ) and breaks students' scores in to five different self-concept subscales: mathematics, chemistry, academic, academic enjoyment, and creativity. Since first being used at the university level the CSCI has shown to be valid for use among secondary students (Nielsen & Yezierski, 2015; Werner et al., 2021).

With an aim of this study to only investigate students' chemistry self-concept the entire CSCI was not used. The survey was shorted to include only the chemistry self-concept subset questions. This choice was made to help reduce survey fatigue among participants and reduce the burden on the cooperating teacher. In total, Bauer's CSCI consists of 40 questions, of which 10 have been shown to factor onto the chemistry self-concept subset. The reduction of the instrument from 40 items to 10 items helped make the administration of the survey more manageable and reduce survey fatigue among students.

Werner and colleagues (2021) examined the psychometric properties and overall reliability and validity of the CSCI among 1140 high school students and outlined some improvements to be made the initial CSCI for higher validity among high school students. The five self-concept subscales determined in Werner and colleagues (2021) findings matched those found by Bauer (2005), further validating the 10 chemistry specific questions map onto students' chemistry self-concept. A second major finding was that high school students struggled with cross-loaded or negatively stated items. The presence of these items on the inventory lead to respondent confusion and may cause inaccurate measurements (Werner et al., 2021). Following the advice of Werner, the items that presented cross-loaded or negatively stated items have been re-written to promote better internal validity within the instrument (Table 3.1). The full survey can be found in Appendix D. Both Bauer (2005) and Werner and colleagues (2021) proposed that future research could implement a shorted version of the CSCI, hypothesizing that the measurement of the chemistry subscale would not be affected by the elimination of the other subscale measurements.

Table 3.1. Original and restated CSCI prompts.

Chemistry Self-Concept Subset	
Negatively Stated Item	Restated Item
I have never been excited about chemistry.	I have been excited about chemistry.
I would hesitate to enroll in courses that involve chemistry.	I would look forward to enrolling in courses that involve chemistry.
Chemistry intimidates me.	Chemistry does not intimidate me.
I have always had difficulty understanding arguments that require chemical knowledge.	I am able to understand arguments that require chemical knowledge
I have trouble understanding anything based on chemistry.	I understand topics based on chemistry.

Instrument Administration

The CSCI was administered at three intervals during the semester to determine if students' chemistry self-concept changed during first fifteen weeks of their introductory to chemistry course. The first administration was given during the second week of school. By administrating the first survey before students had much interaction with their introductory chemistry course, it showed what attitudes students bring into the chemistry classroom with them and provide a base-line understanding of their chemistry self-concept. The second administration was given after the first eight week of school. At this time students had completed eight different laboratory experiments. The third and final administration of the CSCI was administered after the students had completed fifteen weeks of school. At the final administration of the CSCI the students had completed sixteen different laboratory experiments.

All administrations of the CSCI were conducted on paper. The first administration of the CSCI was given to students at the beginning of a class period. The first administration of the survey did not include the final open-ended question included in the second and third administration. The second and third administration were given to students as a portion of their post-lab write ups to complete (Appendix D). Students completed these administrations during the first five minutes of class following a laboratory experiment the day before. The decision to use paper administration of the CSCI was made after consulting with cooperating teacher. The teacher completes all lab assignments on paper, the use of a paper survey streamlined the workload of the cooperating teacher. The paper survives were collected and scanned to create a digital copy. The data from the survives was imported onto Microsoft Excel and stored on a locked computer.

To better determine if the act of learning in the laboratory had an impact on the students' chemistry self-concept the second, and third cycle of the CSCI were administered one day after the students completed a laboratory experiment as a portion of their post laboratory analysis. This helped ensure that the students had a recent interaction with a chemical lab when they were filling out the CSCI. The first administration occurred before students had completed a lab experiment and gave an initial measurement of the students' chemistry self-concept.

Data Analysis

Following each administration of the CSCI, student responses were imported from Excel into Stata BE, Version 17, for statistical analysis. Each student received a single chemistry self-concept score. This score was calculated as the average of all 10 responses on the CSCI. The score was representative of the student's overall chemistry self-concept. For each administration of the CSCI descriptive statistics were calculated using the students' average chemistry self-concept score.

To answer the study's first research question and determine to what extent is the variation in students' chemistry self-concept explained by their pre-chemistry self-concept, mid-point chemistry self-concept, course grade, and gender, a regression analysis was conducted. Regression analysis is a statistical tool that is used to investigate the relationships between variables (Sykes, 2000). The study will use the following null and alternative hypothesis:

H.O. Students' chemistry self-concept variance cannot be correlated to their pre-chemistry self-concept, mid-point chemistry self-concept, course grade, and gender.

H.A. Students' chemistry self-concept variance shows a correlation to their pre-chemistry self-concept, mid-point chemistry self-concept, course grade, and gender.

To further understand if laboratory participation had a correlation to students' chemistry self-concept, students will be split into four different groups or clusters. Students were grouped based on their chemistry self-concept score: low, middle-low, middle-high or high. The groups were determined by quartiles. The low chemistry self-concept group consisted of students who's CSCI score was in the 25th percentile. Students with a CSCI score that lies between the 25th and 50th percentile were placed in middle-low self-concept group. Students scoring between the 50th and 75th percentile were placed in the middle-high group. Students scoring above the 75th percentile were placed in the high self-concept group. All groupings are specific to this study and population of students.

Quartile groups remained set for the entirety of the study based on the placement from the initial CSCI administration. Responses to the CSCI were stored on a locked computer, in a password-protected folder. I was the only person with access to the computer and the contents contained on the computer.

Phase 2: Qualitative

Following a sequential explanatory mixed method design, the qualitative data collection phase took place following the initial quantitative phase (Creswell, 2021). In this study, the qualitative data sought to gain deeper insights on students' perspectives of how they form their chemistry self-concept specifically looking at the relationship that completing hands-on laboratory work has on their chemistry self-concept. In the following section, the participants and the data collection procedures for the qualitative phase are outlined.

Participants Recruitment

To ensure that a deep portrait of how secondary chemistry students form their chemistry self-concept, participants for the qualitative phase of the study were selected using stratified sampling (Palinkas et al., 2015). The placement in each group was determined by the quartile groupings of the final administration of the CSCI. In addition to students with low, mid-low, mid-high and high chemistry self-concepts, this study interviewed students that showed high mobility between the first administration of the CSCI and the final administration. Two highly mobile groups were formed after the administration of the final CSCI, these groupings included students who moved from the 1st quartile in the first administration to the 3rd or 4th quartile and students who moved from the 4th quartile in the first administration to the 1st quartile in the final administration.

Interviewing students who had varying levels of chemistry self-concepts allowed me to gain deeper insights and student perceptions while simultaneously providing multiple perspectives from different groups of students. By interviewing students of multiple levels of chemistry self-concepts the study aimed to reach saturation by providing as much detail as possible to ensure all aspects of the students' understanding of their chemistry self-concept development.

The study selected three students from each subset (low, middle-low, middle-high, high) and two students from the high mobility group to participate in a single semi-structured interview. The placement in the low, middle-low, middle-high, or high subgroup was based on the final administration of the CSCI. During the interview process one student asked if he could also be included in the interviews. This student, Jackson, was not initially selected to participate in the interviews. Jackson was added to the interviews and created a fourth participant for the high CSC quartile group. High-mobility students were chosen based on the difference between their first administration of the CSCI and the final administration of the CSCI. This selection produced a sample size of 17.

Qualitative Data Collection

The qualitative data was collected in two phases during the study. The first piece of qualitative data was collected during the second and third administrations of the CSCI. During the second and third administrations of the Chemistry Self-Concept Inventory students were asked the following open-ended question:

How confident did you feel while completing the lab yesterday? What do you think impacted your feeling this way?

Students' responses to this question were collected and copied into an Excel spreadsheet. The student answers were split into their most resent quartile grouping from the CSCI. Four sheets were created in Excel, each contained student responses to the open-ended question for each quartile grouping of students.

The second phase of qualitative data was collected through student interviews. The data was obtained by a single in-person interview with the seventeen students selected for interviews. The interviews followed a semi-structured format, outlined in the interview protocol (Appendix E). All interviews were audio recorded and transcribed on a Google Pixel 7. The audio recording software on the Pixel 7 included a transcription feature. Following the initial transcription by the Pixel 7, the transcripts were uploaded to Google Docs and reviewed for accuracy. During the interviews, I took notes on student responses and nonverbal communication cues. I looked specifically for paralinguistic cues (i.e., fluctuation of pitch, excitement, rate of speech, pauses, etc.) to gauge students' confidence while responding to interview questions (Scherer et al., 1973). I looked to see if students' responses and attitudes changed when describing different aspects of their chemistry class. Nonverbal and paralinguistic responses helped triangulate students' responses.

The interviews were administered one week after the final administration of the CSCI. All interviews were conducted during a single school day. To conduct the interviews students were pulled from their chemistry class for an average of ten minutes. The decision to conduct interviews during class was made to avoid conflicts in setting up interview times. The timeframe of the study required that the interviews be completed during the last two weeks of the fall semester. All interviews took place during a single day. The students selected for the interviews were spread evenly between the six honors chemistry courses of the cooperative teacher. During the interview students missed around ten minutes of review for their finals.

The interview protocol focused on how the students' experiences in class, specifically laboratories have shaped their chemistry self-concept. The protocol asked students to differentiate between aspects of their course including general course work and laboratory work. The audio recordings of each interview were stored on a locked phone for me to revisit during the coding process.

Data Analysis

Each phase of the qualitative data was analyzed independently. First, the student responses to the open-ended survey question were examined through a series of coding cycles. Saldaña (2013) describes coding as a key method for analyzing qualitative data, defining codes as symbolic labels that "assign a summative, salient, essence-capturing, and/or evocative attribute for a portion of language-based or visual data" (p. 5). By coding the survey response data, I captured the essence of students' perceptions of the factors that influenced their confidence in the laboratory setting.

In the first coding cycle, I applied in vivo coding to highlight the factors students identified as important in shaping their confidence in the lab. The in vivo codes were written on color-coded sticky notes, with each quartile group of students assigned a specific color. The sticky notes were then placed on different whiteboards, one for each quartile, to visually organize the codes. Using sticky notes allowed flexibility in moving and categorizing the codes as themes emerged.

The categorization of each quartile's codes was completed in separate sessions, which helped me focus on the specific codes from each quartile group and understand how students with varying levels of chemistry self-concept might experience laboratories differently. Finally, I combined the in vivo codes from all quartile groups onto a single whiteboard, organized under seven emergent themes. The use of color-coded sticky notes provided a visual map of the differences between the quartile groups.

The second phase of qualitative data analysis took place after I drafted the initial report of the themes from the first phase. In this phase, I conducted additional coding cycles to analyze the interview data, capturing the students' understanding of how they developed their chemistry self-concept and how this development interacted with their participation in labs during this phase each interview was coded.

To begin the coding process, I listened to each interview in full at least twice at normal playback speed. After the initial listen, I replayed the interviews at half-speed to check the accuracy of the transcription. Following these steps, I documented each student's profile and my initial perspectives in an Excel file. Once the interview had been thoroughly reviewed and the transcript verified for accuracy, I began the first cycle of coding.

In the first cycle, I used in vivo coding to capture how students understood their chemistry self-concept and the factors that contributed to its development. In vivo coding allowed me to focus on students' own words to identify what aspects of the lab and class they found important and relevant to the research questions of this study. Using in vivo coding in both initial phases kept me grounded in "the participant's voice" (Saldaña, 2021, p.100).

This approach also helped me bracket myself, as I did not want to influence the students' interviews with my perspective as a chemistry teacher. In vivo coding ensured that the students' voices were accurately represented (Saldaña, 2021). Additionally, Charmaz (2006, as cited in Saldaña, 2013) notes that in vivo coding "can provide a crucial check on whether you have grasped what is significant" to the participant (p. 57). By using in vivo coding, I maintained the authentic perspective of adolescent students, a group that is often marginalized, by capturing their thoughts in their own words (Saldaña, 2013).

To further ensure that I remained grounded in the students' voices, I conducted the first coding cycle line by line. Saldaña (2013) refers to this method as "splitting" and explains that it "encourages careful scrutiny of social action represented in the data" (p. 24). In contrast, "lumping," which involves coding large passages with a single code, may capture the essence of the phenomenon but risks superficial analysis (Saldaña, 2013, p. 24). By coding line by line, I was able to capture the students' perspectives in greater detail. To conduct the line by line coding I printed the transcripts and listened to the interviews again at half-speed while coding. I used highlighters to identify the initial in vivo codes. Once the initial codes were highlighted they were then placed into an Excel document. Typing the codes allowed me to engage with the interview data once more, prompting me to begin identifying potential emergent themes. These emergent themes were noted in my analytical memos for later review during the coding process.

Following my first coding cycle, additional coding cycles were carried out. Saldaña (2013) reminds us that coding is a cyclical act and is rarely complete after the first attempt of coding. Second-cycle coding and additional recording, further "manages, filters, highlights, and focuses the salient features of the qualitative data" (Saldaña, 2013, p. 8). The second coding cycle aimed to develop a sense of "categorical, thematic, conceptual, and/or theoretical organization" from my first cycle of codes (Saldaña, 2013, p. 205). The first cycle of codes produced a large number of codes, it was important to restructure and reassemble the data before looking for themes and categories.

My second cycle of coding utilized Focused Coding. Saldaña (2013) states that focused coding is appropriate for developing major categories or themes from the data. Data and codes from the first round of coding were clustered together and reviewed to create initial or tentative codes and categories. Saldaña (2013) notes that categories are constructed emergently during the restructuring process making sure that data is not forced to fit into pre-conceived categories. During my second cycle of coding, I looked at the interview data from each quartile group separately. Each interview underwent a second cycle of focused coding. After each quartile group underwent focus coding the data across all interviews was compared using the newly constructed codes. By comparing data across all participants, I looked to assess comparability and transferability of the codes created during the focused coding cycle (Saldaña, 2013).

The codes developed during the second coding cycle aimed to crystallize participants' experiences in the chemistry laboratory and their understanding of the role that lab work plays in shaping their chemistry self-concept. The codes from this cycle were inputted into Excel, where they were combined with those from the first cycle to create major categories, themes, concepts, and theories, contributing to a deeper understanding of the phenomena explored in this study (Saldaña, 2013).

To facilitate the transition from codes to themes, I employed several organizational methods to extract meaning from the data. First, I used Code Landscaping to visually represent the frequency of the codes (Saldaña, 2013). This Code Landscape was developed by color-coding the codes in Excel, enabling me to identify the most frequently used codes and begin the process of forming overarching categories or themes. From this initial post-coding step, I created preliminary themes and began organizing the codes within each theme in Excel. Initially, I identified 10 themes, but through constant comparative analysis (Glaser, 1965), I began merging them. As I drafted my initial findings, I continued refining these themes, ultimately combining several until I arrived at five final themes.

Throughout the coding cycles, I also used analytic memos to document decisions, thoughts, and insights that emerged during the process (Saldaña, 2013). These memos allowed me to reflect on and engage with the coding process, providing space for reflexivity and enabling me to challenge my own assumptions.

Ethical Considerations

Conducting ethical research is important for a number of factors: first there has been a history in both social science and medical fields of the unethical treatment of research subjects, this unethical treatment has led people to be weary of research, second only through conducting research can we continue to expand our body of knowledge (Shamoo & Resnik, 2009). Only through conducting ethical research will we be able to gain the trust of the participants and the public (Shamoo & Resnik, 2009). The completed study interacted with minor students, it was critical to ensure that all research practices are conducted to ensure the safety, confidentially, and anonymity of the students involved in the study.

The study underwent Kansas State University's IRB approval and district level approval. Both IRB and district approval was obtained before any participants were recruited to join the study. Participation in the study was strictly voluntary. Involvement in the study had no effect on students' grades or outcomes in their intro to chemistry course. Student participation in the study was obtained through a consent formed filled out by the student's guardian. After consent forms are on file students were given an assent form for their agreement to participate in the study. Both consent and assent forms are attached in the appendices of the study.

The district required that a copy of all survey questions be given to the guardians with a copy of the consent form. The survey was loaded onto the district's survey portal. The 10 question CSCI was included with the consent form for guardians to pre-screen all questions that were asked of the students. The consent form also included a section for guardians' consent for students to participate in structured interviews. Interview protocols were available for any guardian who wanted to inspect the questions asked of the students during the interviews.

All survey data was collected and stored on a password-protected computer or cell phone. Students were given an identifying number and that number was only known by myself. This was to compare student data across all surveys and interviews. All 71 final participants in the study were given pseudonyms. To ensure there were no repeated pseudonyms I selected the pseudonyms for all participants. The interviews were audio recorded on a Google Pixel 7. The phone remained password protected at all times. The interviews were titled with student's pseudonyms and identification numbers.

Issues of Trustworthiness

The qualitative phase of this explanatory sequential mixed methods study does not aim to produce generalizable data. Concepts that produce generalizability such as reliability and validity ground themselves in quantitative work. To address issues of quality and trustworthiness of the qualitative phase of this mixed method study, Lincoln and Guba's (1985) conceptualization of trustworthiness was used. Lincoln and Guba (1985) understand the trustworthiness of qualitative work to be established through the use of four criteria: credibility, transferability, dependability, and confirmability.

Credibility

Lincoln and Guba (1985) define credibility as the degree in which the study has recorded and analyzed the data and phenomenon in question. In order to insure credibility of this study I relied on the following strategies: member checking, and triangulation. Member checking occured during the student interviews. Lincoln and Guba (1985) proposed that member checking as a means to ensure accurate descriptions or interpretations of the phenomena of study. Member checking was used to ensure that the student's voice was coming through and that I am not imparting my own bias onto their responses.

Triangulation is understood as the use of multiple methods or data collection sources to enhance the understanding of the phenomenon ((Birt et al., 2016). As a mixed method study, the combination of the quantitative and qualitative data helped triangulate the data. In addition, the use of analytic memos served as another data source to enhance credibility.

Transferability

Transferability does not seek to promote generalizability but instead looks to understand the study and its context so that judgments about the use of the results might be made by others who are looking to apply the findings elsewhere (Schwandt et al., 2007). To allow for transferability the study must supply contextual information and a rich and thick description data (Schwandt et al., 2007). By providing study context and a rich description of student interviews in chapter 4 this study provides the transparency needed for transferring this study's findings to future research.

Dependability and Confirmability

In order to produce a study that is both dependable and confirmable an audit trail must be used (Lincoln and Guba, 1985). An audit trail shows how the researcher arrived at decisions and conclusions made during the data collection portion of the study. In order to produce an audit trail, I used analytic memos (Saldaña, 2013). Analytic memos serve as a researcher journal entry and allow the researcher to write their thoughts, and can be viewed as a conversation between the researcher and data (Saldaña, 2013). The use of analytic memos produced a timeline and framework of the process and decisions I made during the study. This trail will allow an outsider to check the data against the results of the study to determine if the connection between the two exist, providing a method to determine the dependability and confirmability of the current study.

Chapter Overview

In this chapter, I described the study design was used to investigate if there is a relationship between students' chemistry self-concept and their experiences in laboratory learning. A sequential explanatory mixed method study was performed. During the first quantitative phase of this study, students took a survey three times, during the initial mid-point and final weeks of the semester to measure if their chemistry self-concept had changed. After the administration of the quantitative survey students were split into six groups (low, mid-low, mid-high, high, and high mobility) three students from each quartile group, and two students from each high mobility group were selected to participate in interviews.

Student interviews were coded to identify themes related to how they understand the development of their chemistry self-concept. After coding the interviews, I synthesized the qualitative and quantitative data to explore the implications of using labs as a means to enhance chemistry self-concept. The findings are presented in Chapter 4, while Chapter 5 contains the discussion of these results and their broader implications.

Chapter 4 - RESULTS

Introduction

The purpose of this chapter is to discuss the findings of the study by revisiting and addressing the research questions. This mixed methods study was designed to determine if there is a relationship between secondary students' participation in high school chemistry labs and their development of chemistry self-concept, and how students conceptualize their self-concept in relationship to lab work. Chemistry self-concept has shown to be a powerful predictor of how students will perform in chemistry courses, and their desire to enroll in chemistry courses and pursue chemistry-oriented careers. To answer questions, an explanatory sequential mixed methods research study was completed.

The following research questions were posed:

Research Question 1: Over the course of 15 weeks in a laboratory experiment heavy chemistry class, to what extent is the variation in students' post chemistry self-concept explained by their pre-chemistry self-concept, mid-point chemistry self-concept, course grade and gender?

Research Question 2: Do students with different initial chemistry self-concept (low, mid-low, mid-high, high) experience different variation in their chemistry self-concepts over the course of 15 weeks in a laboratory chemistry class?

Research Question 3: What do students describe as impacting their level of confidence when doing experiments in a laboratory setting?

Research Question 4: How do groups of students with changes or no-changes in their chemistry self-concept experience and perceive the role of hands-on laboratory work in developing their chemistry self-concept?

The quantitative and qualitative data results will be presented in the following sections to address these questions.

Quantitative Results

Chemistry Self-Concept Inventory

The quantitative phase of this study sought to determine if the variance in students' chemistry self-concept can be seen during the first 15 weeks of an introductory chemistry course. If any variance was measured, to what extent could this variance be described by students' pre-chemistry self-concept, mid-point chemistry self-concept, course grade, and gender? A modified version of Bauer's (2005) Chemistry Self-Concept Inventory was employed to measure student chemistry self-concept.

The original Chemistry Self-Concept Inventory was shortened to only the chemistry self-concept subscale items to minimize admission time and survey fatigue. Bauer (2005) suggested that one could shorten the inventory to only the chemistry subset to shorten administration time. The second modification of the Chemistry Self-Concept Inventory included rewording negatively stated items within the Chemistry Self-Concept Inventory. Werner and colleagues (2021) found that negatively stated items should not be used with high school students, showing that the wording easily confused students. To test for the reliability and validity of the modified instrument, Cronbach's α and Rasch analysis were completed.

Cronbach's α (Table 4.1) was calculated to be (0.8938) in line with the literature.

Table 4.1. Cronbach's α.

Subscale	Cronbach's α	Number of Items
Chemistry Self-Concept	0.8938	10

Table 4.2 presents interitem correlations and Cronbach's α if any item was deleted. The data shows that each question on the instrument increases the overall Cronbach's α. The removal of any of the ten items presented on the survey would produce a decrease in Cronbach's α.

Table 4.2. Item fit statistics.

Question	Average Interitem Correlation	Cronbach's Alpha if Item is Deleted
1	0.4569	0.8834
2	0.4697	0.8885
3	0.4817	0.8932
4	0.4405	0.8763
5	0.4612	0.8851
6	0.490	0.8800
7	0.4640	0.8863
8	0.4582	0.8839
9	0.4429	0.8774
10	0.4464	0.8789

Rasch measurement was used to calculate the mean square (MNSQ) fit measures for each item on the instrument. Infit and outfit statistics were calculated to provide evidence about the goodness-of-fit for each item on the instrument. Linacre and Wright (1994) suggest that mean-square ranges for infit and outfit to be between 0.6-1.4 for surveys. Table 4.3 shows Infit and Outfit measurements for each item. All but one item falls within the above guidelines. Question 7 Infit (1.546) and outfit (1.594) suggest an underfit of the model. An underfit of the model suggests that there is more variance present than the model was able to predict item 7. The results from the Rasch analysis and Cronbach's α indicate that the shortened Chemistry Self-Concept Inventory to be a valid instrument for this subgroup of students.

Table 4.3. Item Fit Statistics from Rasch Analysis.

Question	MNSQ Infit	MNSQ Outfit
1	0.826	0.847
2	1.067	1.101
3	1.154	1.191
4	0.602	0.602
5	0.933	1.057
6	0.745	0.715
7	1.546	1.594
8	0.851	0.864
9	0.681	0.726
10	0.738	0.727
Average	0.9143	0.9424
Standard Deviation	0.265	0.298

Descriptive Statistics of CSCI

The summary of the group results obtained from the three admissions of the Chemistry Self-Concept Inventory is given in Table 4.4. The summary includes averages of each question and the average of all final CSCI scores, which is calculated based on each individual's response to the CSCI. Students were most likely to endorse item 3 (I find chemistry concepts interesting and challenging) and item 10 (I understand topics based on chemistry). Students were least likely to endorse item 9 (I have always done better in courses that involve chemistry than in most courses).

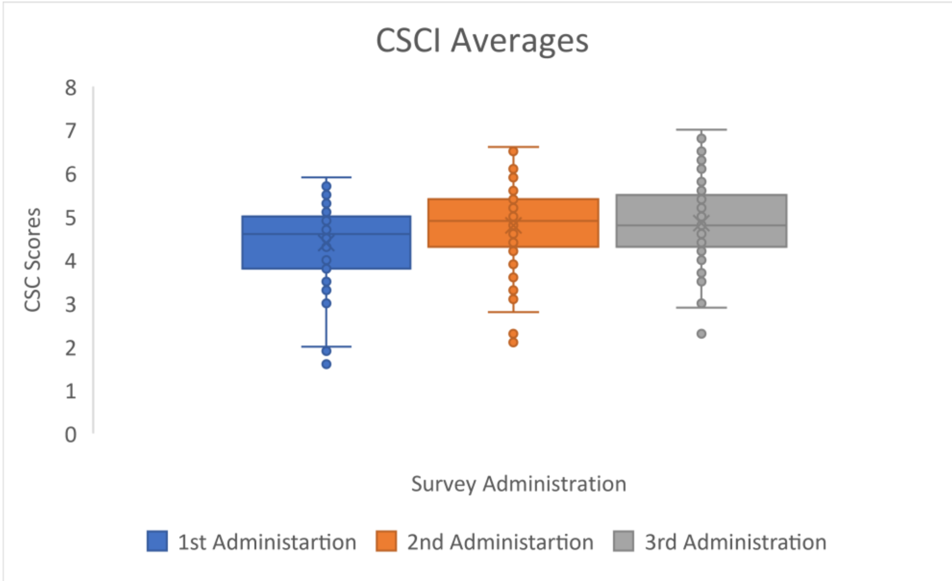
Table 4.4. Summary of CSCI.

	1st Administration	2nd Administration	3rd Administration
Question 1	4.58	4.72	4.89
Question 2	4.42	4.60	4.87
Question 3	5.30	5.31	5.21
Question 4	4.18	4.80	4.83
Question 5	4.37	4.55	4.46
Question 6	4.24	5.00	4.99
Question 7	4.52	5.01	5.05
Question 8	4.24	4.75	4.80
Question 9	3.49	3.97	4.11
Question 10	4.56	5.24	5.22
CSCI Average Score	4.39	4.80	4.84

A paired t-test was run on the sample of 71 sophomore chemistry students' responses to the CSCI to determine whether there was a statistically significant mean difference between the first, second, and third administrations of the CSCI. After students completed their first eight weeks in chemistry from August to October, they showed an increase in their chemistry self-concept from 4.39 ± 0.11 to 4.80 ± 0.12, a statistically significant increase of 0.41 (95% CI, 0.221 to 0.590), $t(70) = 4.3815$, $p < 0.0000$.

A second paired t-test was run to determine if the 71 sophomore chemistry students' chemistry self-concept continued to change as they completed seven more labs from October to December. The second paired t-tested showed that students did not experience a statistically significant difference between the second and third administration of the CSCI, 4.80 ± 0.12 to 4.84 ± 0.11 (95% CI, -0.132 to 0.230), $t(70) = 0.5391$, $p = 0.5915$.

Figure 4.1. Graph of CSCI averages for all three admissions



RQ 1: Over the course of 15 weeks in a laboratory experiment heavy chemistry class, to what extent is the variation in students' post chemistry self-concept explained by their pre-chemistry self-concept, mid-point chemistry self-concept, course grade and gender?

A multiple regression was run to predict students' chemistry self-concept after 15 weeks from gender, initial CSC, mid-point CSC, initial grade, mid-point grade, and final grade. These variables statistically significantly predicted students' final CSC, $F(6, 64) = 10.47$, $p < .0005$, $R^2 = 0.4954$. Only the mid-point CSC added statistically significantly to the prediction, $p < .05$.

Equation 4.1. Estimated model 1

Chemistry Self-Concept Score
= 0.9510205 + 0.0841942* *Survey 1 Score* + 0.5221902 * *Survey 2 Score* – 0.046158 * *Initial Grade* – 0.005373 * *Mid-Point Grade* + 0.063268 * *Final Grade* – 0.0094964 * *male*

RQ 2: Do students with different initial chemistry self-concept (low, mid-low, mid-high, high) experience different variation in their chemistry self-concepts over the course of 15 weeks in a laboratory chemistry class.

To determine if students in each quartile experienced different changes in their chemistry self-concept, a paired t-test was run on each quartile's mean CSC score. The results from each t-test are shown in Table 4.5.

The results show that students in the first quartile experienced the largest statistically significant changes in their chemistry self-concept. Students with CSC scores in the first quartile experienced an increase from their initial their midpoint CSC with an change in mean score to 3.89 ± 0.926 from 3.07 ± 0.735 a statistically significant increase of 0.82 (95% CI, 0.365 to 1.269), $t(17) = 3.812$, $p < 0.0014$.

Students whose initial CSC score was in the first quartile also experienced a statistically significant increase in their CSC score from the midpoint administration to the final administration. Students saw an increase of their CSC scores from 3.89 ± 0.926 to 4.26 ± 1.052 a statistically significant increase of 0.37 (95% CI, 0.213 to 0.520), $t(17) = 5.039$, $p < 0.0001$.

Students whose initial CSC score was in the fourth quartile experienced a statistically significant increase in their CSC score from the initial to the midpoint administration. Students saw an increase in their CSC scores from 5.42 ± 0.248 to 5.57 ± 0.327 a statistically significant increase of 0.15 (95% CI, 0.004 to 0.302) $t(16) = 2.177$, $p < 0.0448$.

No other student groupings experienced a statistically significant change in their CSC scores. All other paired t-test failed to show $p < 0.05$.

Table 4.5. Paired t-test for each quartile means.

Quartile	1st CSCI	2nd CSCI	3rd CSCI	1st to 2nd	p	2nd to 3rd	p

1	3.07	3.89	4.26	0.82	0.0014	0.36	0.0001
2	4.31	4.68	4.78	0.37	0.0831	0.10	0.49
3	4.88	5.14	5.12	0.26	0.1520	- 0.02	0.90
4	5.42	5.57	5.29	0.15	0.0448	- 0.28	0.156

Qualitative Results

An aim of this study is to understand the correlation between students' perception of laboratory work and its effect on the development of students' chemistry self-concept. It was essential to give students a voice to understand how they perceive laboratory experiments' role. A weakness of the Chemistry Self-Concept Inventory is that it does not differentiate between different aspects of a student's chemistry self-concept. It only measures the construct as a whole. To determine if hands-on laboratory work influenced students' chemistry self-concept development, allowing students to share their voices was critical. Sofaer (1999) suggests that qualitative methods allow for rich descriptions of phenomena and allow the participants to provide an understanding and context of events. The qualitative aspect of this study aimed to answer the following research questions.

RQ 3: What do students describe as impacting their level of confidence when doing experiments in a laboratory setting?

During the second and third administrations of the Chemistry Self-Concept Inventory, students were asked the following open-ended questions:

> How confident did you feel while completing the lab yesterday? What do you think impacted your feeling this way?

The data from the survey of 71 student respondents show that students see many different factors that determine how confident they feel during a laboratory experiment. While students' responses varied, the following themes occurred: background knowledge, instructions/procedures, student-perceived difficulty, lab partners, laboratory data, hands-on, and emotions. Table 4.6 shows the frequency of codes placed into each theme.

Table 4.6. Frequency of codes for student survey responses.

Theme	Frequency
Background Knowledge	51
Instructions/procedures	25
Student-perceived difficulty	21
Lab-partners	13
Laboratory Data	11
Hands-on	10
Emotions	6

Background Knowledge

Background knowledge is a student's knowledge before engaging in the current learning activity. Students across all four quartiles reported that background knowledge or lack of background knowledge impacted their confidence level while completing the lab. Students reported having background knowledge in many different ways. For example, Rob (Survey 3) said, “knew what I was doing” or Lincoln (Survey 3) said, “I knew how to do everything and understood the lab.” Students reported that their background knowledge came from two sources, both the non-laboratory and laboratory portions of the class.

Non-Laboratory Sources of Background Knowledge

Students in the fourth quartile of chemistry self-concept were most likely to report that they felt confident in the lab based on what they had been learning in class. For instance, Hank (Survey 2) said "I felt very confident in the lab because I understood the topics as a result of taking notes." Other students in the fourth quartile of CSC also expressed increased confidence stemming from non-laboratory learning. For example, Rowan (Survey 3) reported that "doing the notes and examples impacted" his level of confidence during the lab. While class background knowledge was reported at the highest rate among students in the fourth quartile it was not distinct to that grouping of students. Several students in the third quartile also reported the importance of non-laboratory class work, for example, Benjamin (Survey 3) said "class knowledge from previous lessons to verify if I received the correct outcomes… representation of my course work" helped give him a high level of confidence during the lab.

Students with chemistry self-concepts in the first and second quartile also reported the presence of background knowledge as a source of confidence for their lab but were not specific from where they gained that knowledge. For example, many students commented that they understood the lab but did not provide further explanation as to where they gained their understanding. For instance, Grace (Survey 2) commented "I knew what I was doing and understood the material." Other students expressed similar comments to Grace's and recognized that their knowledge allowed them to feel more comfortable in the lab. Harper (Survey 2) stated her "knowledge of what we were doing made me feel less intimidated." While students did not identify where they obtained the "knowledge" or "understanding" from they did express that it these factors were important to their confidence in the lab.

When students felt that they did not understand the content they expressed a lack of confidence in the lab. For example, Nora (Survey 3) said she “normally enjoy labs, but this unit has been really difficult for me so I didn’t feel confident.” The reason students did not feel confident in the labs was not always apparent from their responses. While some students did not offer a further explanation as to why they struggled with the content, Phoenix (Survey 2) offered his personal experience “I didn’t feel very confident because I missed school and was behind.” Some students also stated that they struggled to see or understand chemical reactions. For example, Elizabeth (Survey 3) explained “ (I) still struggled to understand the actual chemical reactions.” Students tied their perceived level of confidence in their “knowledge” directly to their level of confidence in the lab, such as Emma (Survey 2) stating “I felt mediocre…not knowing everything.”

Background Knowledge Gained from Previous Labs

Students also gained background knowledge from prior laboratory experiences. Students across all quartiles reported that previous labs helped them feel confident with the current lab. For instance, Aurora (Survey 3) said “we had done labs similar to this one.” As students gained experience in the lab they transferred their experiences from previous labs which allowed them to feel more confident. Grace (Survey 3) commented that her confidence in lab increased as the semester went on because she was “more familiar with the methods and chemicals after many other labs.”

Like Grace other students connected their experiences from prior labs to the current labs. For example, Ava (Survey 2) said “I was very confident because it felt similar to labs we have done before, so I was able to use past knowledge to complete it.” While students in the first and second quartiles did not specifically link class background knowledge to the lab, they did recognize a link between previous laboratory experiments and current ones. As exemplified in Nora's (Survey 2) statement "(my) knowledge from prior labs helped me feel like I knew what I was doing."

Laboratory experiences that built background knowledge and confidence were not only limited to hands-on "wet" labs (labs in which students manipulate chemicals). Before the third administration of the survey students completed a virtual pre-lab before completing the hands-on lab. The use of the virtual pre-lab was recorded by students as a reason for their feeling of confidence while completing the lab. George (Survey 3) stated that his lab group "understood what we were doing, online prelab gave me more confidence." Like George, Phoenix (Survey 3) credited his confidence because he was "prepared with a virtual lab first."

The presence of the virtual prelab provided more confidence for students in lower quartiles. Only a single student, Scarlett (Survey 3), in the fourth quartile mentioned the pre-lab as a source of confidence stating that "it helped that we did a simulation of this lab before we completed it… the simulation explained it." All other quartiles had multiple students that stated that the virtual pre-lab helped increase student confidence during the lab.

Instructions and Procedures

The second and third admissions of the survey were given after two different types of labs. The second administration was given after a lab in which students were given a problem to solve and had to write their procedures and the third administration was given after a "cookie-cutter" lab. Cookie-cutter labs are laboratory experiments in which every step a student must follow is written out. After both types of labs students reported that procedures or instructions as being a source or barrier to their level of confidence in the lab.

Students who stated they felt confident in the lab made statements such as Mila's (Survey 2) "the tasks were repetitive and straightforward" or Dallas's (Survey 2) commented that he "knew how to perform the procedures." These comments were not limited to any single quartile, but this theme was present across all groups of students. Students' confidence was higher when they felt the instructions were clear or gave them a clear path. For example, Amelia (Survey 3) said "the lab had clear instructions and was simple to follow along with."

Interestingly this theme was present in both styles of labs. Even when students had to create their own procedures, they reported high levels of confidence as shown by Madison's statement following the second survey administration "directions were clear and I knew what I was doing." The absence of step-by-step procedures did not diminish her feelings of knowing what to do in the lab.

Students also reported gaining a clearer interpretation of the instructions as the lab continued. For instance, Isabella (Survey 2) said she "hesitated a little at first, but once I figured it out it was easy and fun." Mai (Survey 2) felt similar sentiments shared she felt "a little unsure about what I was doing at first. Once I figured out how to do the lab, the lab was fun and I felt more." Not all students needed to interact with the chemicals first to build higher levels of confidence. For example, Amelia (Survey 2) said "reading the procedure and 'backstory' beforehand makes it easier." Students found increased levels of confidence from both the act of completing the lab and through reading the pre-lab instructions.

While most students felt the directions or instructions were clear, students who struggled with the instructions only reported struggles during the lab in which they had to write their own procedures. Emily (Survey 2) reflected the "instructions weren't super descriptive." This lack of description led to Emily only feeling somewhat confident in the lab. Walker (Survey 2) reported struggles with the instructions from the lab because the "teacher didn't explain things super well, so it was a bit harder."

Student-perceived Difficulty

Students across both labs and all quartiles reported that the labs had a low perceived difficulty, which increased their confidence in completing the lab. Students reported that the laboratory tasks were "easy" or that they were confident since the lab was "simple and easy". Most students did not explain why they thought the lab was "easy". Some students explained more thoroughly why a lab might be "easy" or "simple". For example, Madison (Survey 3) stated that the lab was "only mixing chemicals and recording the reactions." Students also related the task completion time to the perception of difficulty. For example, Rob (Survey 2) said "we got our results fast." Both labs were completed during a 50-minute class period.

No students used words such as hard or difficult to describe either lab. Even students who indicated that they did not feel confident or fully confident in the lab did not refer to the perceived difficulty of the task or overall lab as a reason for their level of uncertainty.

Lab Partners

Throughout the reporting of the students' responses, most students used plural pronouns (we, our) when discussing their experience with the lab. The students' responses indicate that the students saw the lab experience not as individuals but as a collective endeavor with their lab partners in which other people impacted their own experience and understanding of the lab. All mentions of lab partners from students provided a reason for increased confidence during the lab.

There were two mechanisms in which students saw having lab partners provided higher levels of confidence. The first was the perception of teamwork. For instance, Keith (Survey 2) said "as a team we were able to come up with a plan." Mila (Survey 2) stated "my whole group got through the lab together." The collective effort of the team helped students feel more confident than the they would have been on their own. George (Survey 2) stated that "I had great partners that helped me make great observations."

The second mechanism by which lab partners increased students' confidence was when students' results matched that of their lab partners. Hannah (Survey 2) said "my partner and myself came up with the same data/results." Students saw other lab groups as resources during the lab and viewed the whole class to compare results. For instance, Nash (Survey 2) said "the other people in class got similar options."

Laboratory Data

Another critical takeaway was students' emphasis on the collection and analysis of laboratory data. Many students noted that this data increased their confidence levels. For example, Ellie (Survey 2) mentioned that when her lab results "agreed with the lab procedure and my hypothesis," she felt more confident about the experiment. Similarly, students expressed greater confidence when they knew what data to collect. Sophia (Survey 3) stated that she felt assured in the lab because "I knew what reactions to look for." Interestingly, Hannah (Survey 3) shared that she "did a couple of reactions twice just to be sure, and I always got the same result." The ability to repeat reactions or compare their data to predicted values helped students feel more confident in their results.

In contrast, when students were uncertain about their data or results, their confidence decreased. For example, Lilly (Survey 2) mentioned struggling to "recognize little reactions." Students also faced challenges when they were unsure how to accurately record their data. Penelope (Survey 2) said, "I enjoyed completing the lab but had some trouble creating my data table." Those who struggled did not report comparing their results with others in the class.

Overall, students found that clear data collection and analysis not only bolstered their confidence but also enhanced their overall laboratory experience, while uncertainty regarding data led to feelings of insecurity. This underscores the importance of data collection in laboratory settings to maximize understanding.

Hands-on

Students reported positive experiences with the hands-on aspects of laboratory experiments. For instance, Benjamin (Survey 2) noted, “This lab being hands-on furthered my interest and understanding of producing chemical reactions. Hands-on labs like this one help me better understand concepts in chemistry.” For Benjamin and others, this practical engagement provided insights that traditional instructional methods lacked.

One key difference between laboratory experiments and traditional instruction is that students can observe chemical reactions occurring in real-time. Aiden (Survey 2) mentioned that seeing the reactions boosted his confidence: “I felt pretty confident while completing the lab yesterday. I think the hands-on activity and seeing the results in front of me made me more confident.”

Additionally, students expressed enjoyment of the hands-on nature of the labs. Jackson (Survey 2) simply stated, “I just like doing hands-on stuff,” a sentiment echoed by several peers. For example, Lily (Survey 2) shared, “I enjoyed doing the lab because of the hands-on experience we get.” These responses highlight a connection between students' confidence levels and their enjoyment of the laboratory experience.

Emotions

An interesting final theme emerged from students in the highest quartile of chemistry self-concept. These students, placed in the fourth quartile of CSC, frequently linked their emotions to their level of confidence during the labs. This connection between emotions and confidence was not observed in students from the other quartiles. Words such as "fun," "enjoyed," "excited," and "love" were used to describe factors that influenced their confidence during the previous day's lab. Although students were not explicitly asked about their emotions, they naturally expressed that their confidence was tied to the positive feelings they experienced during the experiments.

RQ 4: How do groups of students with low, mid-low, mid-high and high chemistry self-concept scores experience and perceive the role of hands-on laboratory work in developing their chemistry self-concept?

To answer research question four and understand how students perceived the role of hands-on laboratory work played in the development of their chemistry self-concept, seventeen students were selected to participate in a single semi-structured interview after the admission of the third chemistry self-concept inventory.

Students were selected from their final quartile placement. Three students were selected from each quartile with four additional students selected for having a highly mobile chemistry self-concept score, two students that moved from the 4^{th} quartile in the first admission to the 1^{st} quartile in the final admission and two students that moved from the 1^{st} quartile in the first admission to the 4^{th} quartile in the final admission. During the interview process one participant, Jackson(Q4), asked if he could also be included in the interviews. All other participants were selected and asked by me to be included in the interviews. No student refused to participate in the interviews.

Table 4.7. Student Quartile Groupings.

CSC Mobility Pre-to-Post	Student Names

Stayed 1st Quartile	Cole, Isla, Penelope
Stayed 2nd Quartile	Archie, Colby, Nora
Stayed 3rd Quartile	George, Hazel, Madison
Stayed 4th Quartile	Austin, Eleanor, Jackson, Oliver
Low to High	Evelyn, Rowan
High to Low	Ava, Emma

*Q1, Q2, Q3, and Q4 refer to the quartile of students pre- and post-CSC scores. Low-to-High refers to movement from Q1/2 to Q3/4 and High-to-Low refers to movement from Q3/4 to Q1/2 from pre-to-post.

Following the semi-structured interviews, all student responses were transcribed and coded. The codes were then grouped into themes using constant comparative analysis. Initial themes were refined and combined, resulting in five final themes. These themes, reflecting students' perceptions of the role of hands-on laboratory work in developing their chemistry self-concept, are: visualization, engagement, enjoyment, interest, and self-concept development outside of the laboratory.

Visualization

During the interviews, students spoke of their own struggles to fully understand concepts presented during lectures and notetaking. However, the laboratory experiments allowed students an opportunity to visualize chemistry concepts uniquely unlike any other presentation method. Students described visualization as supporting a more thorough understanding of chemistry content in four different ways: as a method to remove skepticism, promote a deeper understanding of the content, create a clearer understanding of the readings, and the ability to see the process of chemistry in person. Furthermore, this theme of visualization was more present in the first three quartiles of students CSC score and less present in the fourth quartile~~.~~

Visualization as a Method to Remove Skepticism

When students struggle to understand concepts in chemistry, this lack of understanding of the content can lead to skepticism about not only the content but the teacher as well. However, students described how laboratory experiences allowed them to gain personal experience with the content and weigh their own experiences against the material that is being presented in class. The personal ability for students to visualize the concepts being presented during labs allowed ~~for~~ a path for students to decrease their skepticism. For instance, Cole (Q1), spoke of his own skepticism of what he was learning in class and how his time in the labs allowed him to visualize see the phenomenon that he was skeptical about:

> Sometimes like when Mr. Acid, like, telling us like what to do and stuff, like, I know he's not doing his job wrong, I just feel like it's just kind of like doesn't make sense because I can't really like visualize it… (in lab) you're like seeing like what he's been talking about that, he didn't make it up.

Cole’s contrasting feelings of confusion and understanding were tied directly into his only ability to go back to the laboratory and visualize the chemical process himself. His initial struggle with the concepts being taught in class even led him to be somewhat skeptical of what he was being taught and his teacher. The ability for Cole to go back into a laboratory setting and see the reactions turned his skepticism into belief.

Other students had similar experiences and struggled to believe the ideas presented in chemistry without seeing them in the lab. For instance, Colby (Q2) emphasized the ability to talk about a topic does not give concrete evidence for its existence:

> Because you can always talk about a bunch of things but without doing it you don't have the concrete evidence…like just being able to see what's going on like, like talking about… we can talk about a bunch of stuff, but without actually being able to see it, it’s hard to like believe it I guess or like to visualize it.

Visualization Promotes a Deeper Understanding of Content

While other students did not seem as skeptical of the content that they were learning, they did recount how the visual aspect of the chemistry labs promoted a deeper understanding of the content. For example, Norah (Q2) spoke of her own struggles to understand concepts in class and the critical role that labs played in her ability to see what she was learning:

> It really helped me learn the light about light. Because that was really confusing when he (the teacher) went through the notes I didn't really understand how it worked, but when I actually saw it physically happening and the color and the light actually happening it really helped my understanding… because when you see what you're learning come to live, I think that your brain, the chemistry in your brain is to say, oh wow, this is cool, this is, connects the dots for you.

This sentiment of increased understanding gained from visually seeing the process of chemistry was shared among many students whose CSC scored in the first three quartiles. Students described that they gained increased levels of understanding during the completion of labs. For example, while describing a lab he completed, Archie (Q2), stated, "I don't think I would have understand it well (without the lab), because I mean for me it's easier to visualize it. Whenever I see it like in person, just with numbers and paper it's harder to understand." He further explains that if labs were not an aspect of his chemistry class he would be "…disappointed and I feel like I'd have to really, focus and try to visualize it just in my head without seeing it. I think visualizing is a really good way of like helping you understand things."

Visualization Creates a Clearer Understanding of the Readings

Another critical component of visualization was students' emphasis on the ability of laboratories to visually see what they were reading in class. Many students describe how they struggled to imagine the processes that they were reading about in the course. They did not always describe a difficulty in their ability to understand the concepts but a difficulty in visualizing what they were reading. The labs allowed students to create a clearer picture in their head of what they had been reading during the course. Isla (Q1) spoke of this process when she spoke generally about labs:

> You get to see for yourself instead of just reading about it and actually helps me understand what I am talking about. So just reading I have a picture in my head, and I don't like, it doesn't like connect right away but when I understand what I'm learning and then I do a lab, it actually goes together and I can actually have a better opinion and more understanding.... While reading you don't really understand it because you don't have the best image in your head. Then when you actually do it you're like, okay I see how these work together.

Isla's statement highlights that students perceive a difference between their own ability to imagine chemical processes from solely reading a text and a more complete image that is created when they visually see the chemical process during a laboratory experiment. For Isla and other students there is a difference between reading material and seeing the chemical reactions. For instance, another student, Madison (Q3), described how "instead of, like, reading about the chemical change, like you can actually see it."

Visualization Affords the Ability to See the Process of Chemistry in Person

A final category of visualization was students' discussion of being invited into the process of chemistry. Students' participation in the lab gave them the unique ability to see the phenomenon with their own eyes. The ability to "see" chemistry in front of them was important for not only their understanding of the content, but gave them a new interaction with the content not presented through any other method. For example, Colby (Q2), highlighted this interaction with chemicals by stating that through labs students are able "to look at it instead of just talk about it." Students emphasized this ability to see the chemical reactions take during real time in front of them as a critical piece of their own understanding of the content.

Engagement

A critical takeaway from students’ interviews was the ability of laboratory experiments to provide high levels of engagement with chemistry content. Students spoke of labs' ability to engage them with chemistry in ways not present solely in direct instruction and practice. Here, students described engagement through the lens of labs providing “hands-on” experiences and opportunities to work collaboratively with peers.

Hands-on Experiences to Promote Positive Engagement

During the interviews, many students presented labs as a method to unlock “hands-on” experiences with chemistry and chemical ideas. For example, Hazel (Q3) said, "I like doing the labs the most. I like having hands-on stuff." Students did not describe the other activities in class (e.g., lecture, practice worksheets, etc.) as “hands-on” but reserved this physical interaction with chemistry as a district property of the laboratories themselves. Austin (Q4) highlighted this distinction when he said “I enjoy labs because like you're actually getting to like actually do something. A lot of it is theory rather than (hands-on), like, but labs you’re like actually doing it and observing the reactions.”

The distinction of labs providing a “hands-on” experience with chemistry was present across all quartiles of students. Students provided positive statements about their level of engagement when learning in a “hands-on” method. For instance, George (Q3) described how “labs actually helps me a lot more than just doing like problems because it engages me more.”

These sentiments of positive engagement from laboratory days were shared by multiple students such as Isla (Q1) who said she experienced high engagement during lab days because, “I think it’s fun to do hands-on,” and Ava (High-to-Low) when she said, "It's just like hands-on experience so … it just helps."

Laboratory experiments provide an opportunity for students to be invited into chemistry through the "hands-on" nature of working directly with chemicals. With this experience, students understand that they have a part in the process of science through experiments. For example, Hazel (Q3) said "I'm just, like, more involved. I can like actually see something happening. I have more of a part in it. I feel like it helps my attention span."

Laboratory Work provides Opportunities for Peer Collaboration to Increase Engagement

A second way in which students spoke of labs providing increased engagement was through collaboration with their peers. Students spoke of the collective nature of laboratory learning, with the efforts of the group highlighted not just the individual's experience. Through this description of engagement, students noted that they were better able to learn and engage with the content when they were able to have shared experiences with their peers. For example, Nora (Q2), stated:

> I enjoy working with my partners, my lab partners. Because I get to see how my fellow peers' brains operate and what they're learning in the class. And it helps me feel more confident too. Because I'm like, okay, this is where I'm standing this is where I might be lacking and if I don't understand it gives me the opportunity to have peer help, which sometimes can be even better than a teacher in some situations, because kids-on-kids we communicate different ways.

While students mostly spoke positively of the collaborative nature of laboratory work. A student, Ava (high-to-low) did note that the makeup of the lab group played an important role in her engagement in the lab when she shared "in the right group, like people that I'm like decently friends with and then also like that will work with me."

Other students shared similar sentiments as Ava, stating that they enjoyed being placed in groups with their friends. While students did not mention that they were disengaged when placed in particular lab groups they did recognize the importance of the presence of their "friends" in their engagement in labs.

Enjoyment

Student enjoyment formed from the labs was a recurring theme present across all quartiles of students. Many students presented labs as having an intangible "fun" aspect to them that led to increased enjoyment with chemistry. Additionally, students described enjoyment from labs as they offered a change of pace from traditional learning. While students from all quartiles spoke of high levels of enjoyment during labs, students in the first two quartiles saw the labs as a more integral aspect impacting their enjoyment of their chemistry learning.

Labs as a source of "Fun"

Many students described that a major source of their enjoyment of chemistry was found through participating in labs. In the lower quartiles, students gave negative responses in interviews when asked how their enjoyment in chemistry would change if labs were taken away from the class. For instance, Penelope (Q1) said that if labs were removed from the course she would feel, "Sad because it wouldn't be as fun anymore." Colby (Q2) shared similar feelings stating, "Be probably a lot worse. More negative feelings towards it. Because I feel like labs are a huge part of science in general." Together these students show that not only were labs providing enjoyment, but also were necessary piece contributing to their positive feelings towards chemistry learning.

Students in higher quartiles did not experience the same necessity of labs for their enjoyment in the course. While students in the upper quartiles still spoke positively about their time in the labs they did not possess the same negative feelings about the possibility of the removal of labs from the second semester of chemistry. When asked how he would feel if labs were removed second semester, Oliver (Q4) stated, "I mean, I wouldn't be too upset because I still like doing the math part of stuff and like figuring things out." Madison (Q3) expressed similar sentiments stating, "I would probably be fine without it (labs), but I think my mood might shift a little bit because, like, the class may be more boring. So I might not be as excited to, like, learn about it, maybe." This perception that Oliver might not be as excited was elaborated on when he described contrasting levels of enjoyment between days when labs are or are not conducted in chemistry class:

> I don't really, like, I'm not excited but I'm not mad, just like, 'eh,' you know? Then (lab days) I am happy. I like labs. They're cool and I like to experiment stuff…I just like to be surprised with whatever I'm doing, and I like to see explosions and stuff.

Oliver highlights a common perception among students that labs as "cool" or "fun". Student interaction with chemicals in the lab provided increased enjoyment with their interaction with chemistry that was not present outside of lab work.

Enjoyment from a change of course pace

Another category in which laboratory experiments lead to enjoyment was students' perception of labs as a change in pace from lectures and guided practice. Many students described labs as offering more enjoyable activities than direct instruction methods. For instance, Ava (High-to-Low), stated that without labs "I think it would take all the fun out of it, just because it's like then you're sitting through notes the entire class." Similarly, Rowan (Low-to-High) stated instead of just sitting down and like, taking notes, I get to like, I don't know, apply."

When investigating these contrasting methods of instruction students even noticed the presence of labs versus direct instruction as extending into past experiences in other science classes. For instance, Oliver (Q4), compared the direct instruction he experienced in Biology and the lab experiences in chemistry:

> I thought it would just be another science class and we would just study over things because that's what biology was. We just studied all day and took notes and it was really boring. (In) chemistry we kind of took notes at the start .... but now I can't remember the last time we took notes because we don't really need to because it kind of just comes to mind to us. And we get to do a lot more labs and I don't think we ever did a lab in biology class.

Many students also presented contrasting opinions of chemistry versus other science classes based on the presence of labs. Students stated that they could not remember completing many labs in their freshman biology class and that the presence of labs in chemistry allowed them to interact with the science at a different level than allowed solely by traditional instructional methods. The change in instructional method provided by labs increased their enjoyment of the content.

Interest

A final theme presented during students' interviews was the emphasis on laboratories' unique role in building student interest in chemistry. For example, Isla (Q1) reflected on the how her interest in chemistry changed and was influenced by her engagement with labs over the course of the first semester:

> Its changed a bit. I mean, now, I like chemistry more than I did at the beginning. I just like all of like the labs we did. Those were really fun… without the labs my interest in chemistry would be negative.

The ways in which participation in labs piqued students' interest in chemistry was echoed by several students who even indicated they would reenroll in honors chemistry if given the chance. For instance, Archie (Q2), stated that he would reenroll in honor chemistry, "Because I really enjoyed doing labs and learning like hands-on, and how to apply what I've learned in class… to real-life scenarios." Some students even indicated that participating in labs would be a key component in their interest in continuing to learn chemistry. For example, Penelope (Q1), explained that she would be interested in taking more chemistry classes in the future if "I knew that we did labs." Penelope's response highlights how participation in labs during high school has the ability to draw students into chemistry and sustain their interest, providing experiences that lead them wanting more

Self-Concept Development Outside of Labs

Many of the themes so far attribute laboratory experiences as a component of students' development of their CSC. However, the interviews indicated that CSC development also occurred outside of the laboratory setting. This was more commonly seen in students from Q3 and Q4 who credited their high mathematic self-concept as well as their success in the class as factors that strengthened their CSC.

Mathematics Self-Concept as a Contributing Factor for Chemistry Self-Concept

Students in the higher two quartiles also viewed themselves as strong math students and saw their high mathematic self-concept as a contributing factor to their high chemistry self-concept. For example, Eleanor, (Q4), experienced satisfaction from the mathematical aspect of chemistry when learning about chemical reactions, stating:

> I'm more of a data person… I'm more like numbers and like statistics and stuff. I didn't actually need to do a lab to see what was happening. Because I understand it more like on paper for those types of stuff.

Similarly, Austin (Q4) viewed chemistry as an extension of math: "Chemistry is more just applied math, that is kind of how I see it. And I've been, always been pretty strong at math." Austin's belief that his math skills assist him in chemistry also led him to observe how peers who struggled in chemistry were most likely to struggle with the math portion of the course, which was not the case for himself. Furthermore, one students' interview stood out as an exception to their peers in how they viewed laboratory learning as an influence on their CSC, Evelyn.

Evelyn had a highly mobile CSC score, moving from the first quartile during the first administration of the CSC to the third quartile in the final administration. During her interview, Evelyn was the only student who expressed solely negative feelings toward chemistry labs. When asked how she feels when she knows there is a lab during class, Evelyn described how she was, “Not very excited. Labs, just don’t have like a clear answer in the end. So, like you just have to, like, make your own idea of what’s happening, which I don’t really like, because it’s like open-ended thinking.” When asked how she would feel if labs were taken out of class for the second semester Evelyn said that she would be, “Excited, excited!”

This was because while other students saw the labs helping them visualize chemistry concepts, Evelyn experienced the opposite. During her interview, Evelyn expressed that she was much more comfortable with chemistry when she felt sure of the answers. The unknown aspect of laboratories left her feeling like there was, “No clear answer.” Contrasting with her feelings during laboratories, Evelyn said she most enjoyed completing “worksheets, like, when we’re doing equations and stuff… because it is just like math, so it's just easy.”

Evelyn did not attribute her increase in chemistry self-concept to her participation of laboratory experiments, but instead to her increased understanding of the content through traditional learning methods like lecture and worksheets. When asked about the number one factor that led to her increase in her CSC she responded, “Just participating in class and doing the worksheets.” Evelyn commented that she viewed herself as a *math person* and her ability to relate chemistry to math led to more understanding and enjoyment in the course. The certainty of answers present during the mathematical aspect of chemistry led to concrete answers for Evelyn, which she did not view as present during labs

Chemistry Self-Concept Influenced by Student Success

Many students also presented the idea of their overall success in the course as a contributing factor in forming their CSC. Students explained that as they moved throughout the semester they moved from very little exposure and knowledge to a deeper understanding of chemistry content. While not indicating labs as a factor, during their time in the course these students saw their overall success as a factor in strengthening their chemistry self-concept. For example, Eleanor, (Q4), stated her own improvement and understanding of the content provided a framework for her to define herself as a successful chemistry student when she said “Being able to see that, I have improved over time, just being able to understand it, even more like, as I go further throughout the class. So, building on that previous success.”

Students in lower CSC quartiles also contributed their success in the course as a factor for their CSC. For example, Emma, (High-to-Low) defined success as reflective of her grades “my test grades, like they used to be like C's and B's and now I get like A's.” Other students also spoke of their success in chemistry as demonstrated by their course grades. Here, it’s not the labs, lectures, or worksheets that contributed to students’ CSC, but rather their letter grades and personal definitions of success.

Summary

This chapter presented the findings of this mixed-methods study that explored the relationship between participation in chemistry laboratory experiments and the development of high school students’ chemistry self-concept. This mixed methods study used quantitative and qualitative data to address the four research questions.

Quantitative Findings

The quantitative phase of the study examined variations in students' chemistry self-concept over the course of 15 weeks. Results from the Chemistry Self-Concept Inventory (CSCI) indicated a statistically significant increase in chemistry self-concept after the first eight weeks, with the average score rising from 4.39 to 4.80. However, no statistically significant change was observed between the second and third administrations of the CSCI. A multiple regression analysis revealed that the mid-point self-concept score was the strongest predictor of students' final self-concept, while variables such as gender and course grades did not significantly contribute to the model.

Additionally, students with lower initial chemistry self-concepts experienced the largest increases in self-concept over time, with statistically significant changes between both the initial to midpoint admission and the midpoint to the final admission. Students in the fourth quartile experienced a statistical increase in their chemistry self-concept between the initial and midpoint administration. No other quartile groups experienced a statistically significant change in their chemistry self-concept between the administrations of the CSCI.

Qualitative Findings

The qualitative data of this study sought to give students a voice to explain how they understood the role of laboratory work in shaping their chemistry self-concept. Students in this study conceptualized the laboratory as a significant aspect of their chemistry class. Students identified several areas where the laboratory intersected with traditional classroom teaching to give them a deeper understanding of chemistry. The students in this study saw laboratories as a multifaceted activity that crossed into cognitive, affective, and psychomotor learning domains.

Students in the lower quartiles stated that laboratories played a critical factor in determining their chemistry understanding. The ability of laboratories to give students a hands-on and visual representation of chemistry contents led to a deeper understanding of the topics and, at times, removed skepticism. In addition to laboratories' ability to increase knowledge acquisition, students commented on the ability of laboratories to increase engagement and interest in chemistry. The prospect of removing laboratories from chemistry elicited negative responses from all participants with lower chemistry self-concepts.

Students in the high quartiles also reported of the ability of laboratories to enhance their understanding of chemistry. Students with higher chemistry self-concepts reported more connections between labs and their notes in class, leading to increased confidence in both laboratory and class settings. Additionally, students with higher chemistry self-concepts reported that while they enjoyed laboratories they did not find them essential to their enjoyment and understanding of chemistry.

Lastly, the students talk about laboratories as an essential aspect of chemistry. During the first 15 weeks of school, students regularly experienced labs—this high exposure level integrated laboratories as a critical component of chemistry in their minds. Students expressed how chemistry was different from other science classes on the basis of the laboratory component. Students of all quartiles expressed laboratories as a significant aspect of their chemistry class. The findings suggest that participation in laboratory experiments significantly shaped students' chemistry self-concepts, particularly for those starting with lower chemistry self-concepts. The hands-on nature of lab work and the opportunity for peer collaboration and visualization of concepts contributed to increased self-concept and engagement with the subject.

Chapter 5 - DISCUSSION AND IMPLICATIONS

This study aimed to examine the impact of laboratory learning on the development of secondary students' chemistry self-concept and explore how students perceive the role of lab work in shaping their self-concept. The findings highlight how a group of honors chemistry students viewed the influence of laboratory learning on their chemistry self-concept. The final chapter of this dissertation begins with a discussion that situates this study within the broader context of educational research and addresses both practical and theoretical implications. It concludes with recommendations for future research and a summary.

Discussion

Quantitative Results

The purpose of the quantitative phase of this study was to examine how students' chemistry self-concepts (CSC) changed over the course of a 15-week, laboratory-intensive chemistry course. This study used a modified version of Bauer's (2005) Chemistry Self-Concept Inventory (CSCI) to measure students' CSC. The CSCI was modified to reduce the class time required for its administration, thus minimizing the burden on the cooperating teacher. Results showed that the modified CSCI still accurately predicted students' CSC scores, as the Rasch measurements and Cronbach's α remained consistent with values reported in previous literature (Werner et al., 2021).

One issue identified with the modified CSCI was related to item 7 ("Chemistry does not intimidate me"), which displayed an underfit, indicating unusual response patterns. The underfit of this item suggests students may have struggled with how to respond to this item. While still within acceptable fit limits, item 4 ("When I run into chemical topics in my courses, I always do well on that part") on the modified CSCI exhibited more predictable patterns than other factors.

It is important to note that removing these two items did not improve the overall reliability of the CSC measure. These results suggest that the modified CSCI produced reliable outcomes for assessing students' chemistry self-concepts.

The quantitative analysis revealed statistically significant variations in the growth of CSC across different student groups during the 15-week course. There was significant growth in CSC from the initial to the midpoint administration, but there was no statistically significant change between the midpoint and final administration. These findings align with previous literature suggesting that students tend to form stable self-concepts early in their engagement with a subject (Nielsen and Yezierski, 2015).

Notably, students in the lowest quartile of initial CSC scores showed the most significant variation across the administrations. Students in this group experienced statistically significant changes in their CSC scores between each administration of the CSCI. Although their CSC continued to increase from the midpoint to the final administration, the change was smaller than the initial growth, supporting the notion that students form a stable self-concept relatively quickly in their interaction with the subject matter.

Interestingly, the multiple regression analysis showed that student gender did not have a statistically significant effect on CSC. This finding contrasts with existing literature that has documented a gender gap in chemistry self-concept, with male students often showing stronger self-concepts than female students (Ziegler and Heller, 2000; Chan and Bauer, 2015). Rüschenpöhler and Markic (2020) suggested that cultural backgrounds might explain gender differences in CSC, hypothesizing that students with a Turkish migration background may view chemistry as a field equally accessible to both genders. Although the sample in this study was largely homogenous, it is possible that these students did not perceive chemistry as a gender-specific domain.

Furthermore, the analysis of CSCI results found no statistically significant correlation between students' grades and their CSC. This finding is unexpected and contrasts with the reciprocal effects model (REM). According to REM, self-concept and achievement have a bidirectional relationship (Marsh & Craven, 2006). Previous research by Marsh and colleagues (2018) emphasized that grades are a particularly salient source of feedback for students and strongly correlate with academic self-concept (ASC).

This result suggests that students in this study may conceptualize academic success in ways not directly tied to their course grades. Throughout the study, the students' average grades remained high, between 92 and 93 percent. It is possible that, with such high grades, students did not view their letter grades as an accurate reflection of their understanding of chemistry. The literature has indicated that students often measure academic success beyond test scores, focusing on factors such as enjoying the learning process, overcoming setbacks, reducing lab anxiety, and finding enjoyment in the subject (Flaherty, 2020; Kang et al., 2021; Kurbanoglu & Akim, 2010; Rüschenpöhler & Markic, 2019). With most students obtaining high-class grades, students might have looked at these other measures to define their academic success in chemistry.

Qualitative Results

The purpose of the qualitative phase of this study was to investigate students' conceptualization of their chemistry self-concept in relation to lab work. Not only did this study provide findings that showed laboratory learning emerged as a central factor in students' development of CSC, but the data provided a deeper understanding of students' perception of laboratories as a multifaceted and multidimensional learning experience. These learning experiences in the lab helped students construct their knowledge and perceptions of chemistry, shaping their chemistry self-concept.

This study was built around Novak's Theory of Human Constructivism, which argues that education must consist of experiences that empower students to construct knowledge (Novak, 1993). Novak proposed that new knowledge is created at the intersection of thinking, feeling, and acting and placed these activities into three domains: cognitive, affective, and psychomotor. While literature shows the importance of learning experiences crossing all three domains for learning, it does not give voice to students' understanding (Bretz, 2001).

At the onset, this dissertation intended to give a voice to secondary students. The wealth of literature surrounding CSC and laboratory research has been quantitative research (Flaherty, 2020; Gericke et al., 2023). Due to the absence of qualitative and mixed methods studies, the current literature is missing the voice of students and the ability to understand the essence of laboratory learning from their perspective. This study adds to the literature on the student experience of learning chemistry through laboratory experiments and provides a voice to how they understand the development of their CSC.

Laboratories Access the Cognitive Domain

From the findings, it is apparent that students understand the ability of laboratories to access the cognitive domain. Many students recounted specific lab activities that served as turning points in their perception of chemistry. For example, students frequently referenced experiments involving visible chemical reactions as moments where abstract textbook concepts became concrete. This is consistent with Hofstein and Lunetta's (2004) emphasis on the cognitive learning domain that laboratory work can activate. These visual representations of their textbook allowed students such as Colby and Cole to remove their skepticism that was present before seeing the chemical reaction take place.

Another point that appeared throughout the data was the importance that students placed the intersection between the classroom background knowledge and laboratory practices. Students repeatedly referenced the importance of their own background knowledge and its ability to increase their confidence in the laboratory setting. This was especially evident for students in the higher CSC quartiles. Students with higher CSC saw the laboratory setting as an extension of their notes and lectures, whereas students with lower CSC showed departmentalization of their background knowledge. Students with lower CSC were more likely to talk about previous labs' influence on the current laboratory experiment rather than the content from traditional instruction methods.

Laboratories Access the Affective Domain

The findings of this study give students a voice to the importance of laboratory learning in engaging students in learning chemistry and enhancing their enjoyment of the content. It is apparent from the findings that the majority of students enjoyed lab days more than traditional instructional methods. This finding is in line with previous literature that has indicated that laboratory experiments are the number one method to increase enjoyment and engagement from students in chemistry education (Ben-Zvi et al., 1976; Hofstein, 2004). Students across all quartiles of CSC described labs as having an almost indescribable "fun" or "cool" characteristic.

This was especially true for students in the first two CSC quartiles. When students in the first and second CSC quartile were asked how they would respond if laboratories were removed from the class during the second semester, all students who participated in the interviews responded negatively. One student, Nora, would even say that she could speak for her entire class, saying that all students would have a negative outlook on chemistry without labs. Contrasting with lower quartile students' responses, students in the higher quartiles commented that they would still like chemistry without the labs. This point of divergence can be attributed to the hierarchical nature of self-concepts, as proposed by Marsh and Shavelson (1985).

The Marsh and Shavelson model proposed that science self-concept maps onto a higher-order math self-concept. Students in the higher quartiles of this study indicated that they saw chemistry as an applied math course and that the absence of labs would not be detrimental because of their strong math ability. In contrast, Penelope and Isla, who were both in the first quartile, reported that they would consider themselves more of an English person than a math person. Students in this study are sophomores in high school, and they have relatively stable math self-concepts; as such, students with weaker math self-concepts placed a higher importance of the ability for labs to provide interest and enjoyment in chemistry.

It was interesting to see the importance of the affective domain from all quartiles of students. Even though students in the higher quartiles commented that they would still be successful in chemistry without laboratories, several students commented that they would find the class more boring. In line with previous studies, students of all chemical abilities viewed conducting experiments positively (van Vorst, 2018). A critical finding of the study was the impact of emotional engagement on students' chemistry self-concept. Many students reported feelings of excitement, curiosity, and accomplishment when conducting successful experiments. These positive emotions were strongly linked to increased CSC, suggesting that emotional responses in laboratory environments can significantly influence students’ perceptions of their chemistry abilities.

These positive perceptions of chemistry were absent in students who experienced frustration or confusion during labs, leading to lower reported levels of CSC. For some students, these negative experiences created anxiety around laboratory work, mainly when they were unable to complete experiments successfully. This aligns with research on self-concept and affective factors (Bandura, 1997; Marsh & Martin, 2011), emphasizing that repeated negative experiences can erode self-concept over time.

Laboratories Access the Psychomotor Domain

The findings highlight the significant impact of laboratory experiments on the psychomotor domain**,** particularly concerning students' CSC development. The psychomotor domain, which involves the physical manipulation of materials and the coordination of hands-on tasks, plays a critical role in helping students engage with and understand abstract chemical concepts. Students spoke of their preference for “hands-on” learning during the interviews. Through the physical manipulation of chemicals in the labs, students were able to visualize and interact with reactions and chemical processes in a way not available outside of labs. This “hands-on” process built their confidence for future labs and contributed to their overall confidence in chemistry. Through the physical nature of experiments students are invited to participate in the process of chemistry. This invitation to do the process of chemistry supports Bertz’s (2001) assertion that psychomotor engagement is essential for meaningful learning in chemistry.

Laboratories as Cooperative Learning Experiences

Another point that appeared throughout the data was students' perception of the laboratory as a cooperative learning experience. Peer collaboration during experiments allowed students to feel less isolated when encountering complex concepts, creating a supportive learning environment. In survey responses, the students chose to use plural pronouns while explaining their experiences in the lab. The responses express that students did not see the laboratory setting as an individualistic learning endeavor but instead as a collective group effort. Students in the interviews also reported mostly positive experiences with their lab groups. Literature has shown that cooperative learning pedagogy is more effective in increasing students' CSC than individual work (Agwu & Nmadu, 2023).

It is important to note that students found the makeup of the lab group to be an influencing variable in their experience. When students, such as Ava, were in groups, they were not comfortable. They experienced more laboratory anxiety and commented that they had pulled away from the laboratory experience.

Overall, this study highlights the complex and vital role that laboratory learning plays in students' understanding of chemistry and the development of their chemistry self-concept (CSC). By adopting the perspective of the student, this research provided a nuanced view of how laboratory experiences contribute to students’ perspective of their development of chemistry self-concept. Students do not perceive laboratories as single-dimensional tasks but rather as multifaceted learning opportunities that engage multiple domains—cognitive, affective, and psychomotor. Through their interactions in the lab, students build meaningful experiences that shape their CSC, although these experiences alone do not fully determine their self-concept.

As this study suggests, self-concept is a complex, multidimensional, and hierarchical construct that evolves from a variety of experiences. The formation of CSC cannot be attributed to any single factor, such as laboratory work, but is influenced by a combination of learning experiences. While labs play an essential role in shaping students' confidence and understanding of chemistry, they are one of many critical components in the broader development of students' academic self-concept.

Theoretical and Practical Implications

This dissertation provided a student perspective on the impact of laboratory learning on the development of secondary students' chemistry self-concept. Considerations for theoretical and practical connections to the dissertation study are presented in the following sections.

Theoretical Implications

This dissertation contributes to education theory in three ways. First, it provides the neglected perspective of the student in chemistry self-concept research. The vast majority of research on chemistry self-concept has focused on quantitative measurements of the construct (Flaherty, 2020). This study's qualitative aspects allowed students to voice what aspects of chemistry increase their chemistry self-concept. Bauer (2005) conceptualized chemistry self-concept as an individual's knowledge and perceptions about themselves concerning concepts in chemistry. The findings from this study indicate that students understand chemistry as both a theoretical and application-based science. The students clearly understood that they gained chemistry knowledge through traditional classroom instruction and participation in hands-on laboratory work. For instance, Austin talked about both the mathematical aspects of chemistry and his experiences in the lab as factors that influenced his chemistry self-concept. Austin's perspective of chemistry as an intersection of theory and practical laboratory work was shared by students across all quartiles of chemistry self-concept.

Students' understanding of chemistry was significantly impacted by the participation of 15 labs during the semester. This study positioned itself from a Constructivist lens, arguing that the experiences that students have in the classroom will help shape their chemistry self-concept.

During the study, students participated in many different labs. In doing so, the students built an understanding of chemistry that was based upon the combination of laboratory and non-laboratory learning. Thus, students saw the connection between the multiple aspects of chemistry. This connection was displayed by students reporting that the presence of background knowledge gained from traditional classroom instruction increased their level of confidence in the laboratory setting. For example, Hank and Rowan reported increased confidence in the laboratory because of their notes taken during class lectures. Students saw that the knowledge built between traditional learning methods and laboratory experiments was reciprocal. For instance, multiple students, Norah, Colby, and Cole, spoke of the understanding they gained from visualizing the chemical experiments. These students reported struggles with understanding concepts in chemistry, but seeing the experiments in the lab increased their comprehension and confidence in chemistry. By allowing students to voice what aspects of class shape their chemistry self-concept, this study shifts the focus from solely measuring students' self-concepts to understanding how students conceptualize their chemistry self-concept.

Second, while many studies explore the outcomes of a positive chemistry self-concept, this study shifts the focus from outcomes to experiences in the classroom that can help shape chemistry self-concept. Studies have shown that students with high chemistry self-concepts are more likely to have academic success and pursue chemistry in the future. This study allowed students to voice what aspects of their chemistry class shaped their desire to pursue chemistry in the future. For example, Penelope, whose chemistry self-concept was in the lowest quartile of students, expressed that she would be willing to take more chemistry classes in the future if they had a laboratory component. Students in the lower quartiles of chemistry self-concept placed higher importance on the presence of laboratories for developing their chemistry self-concept.

Students in these quartiles expressed that they would form a more negative view of chemistry if laboratories were not included in chemistry. More recently, Schechtel and Bongers's (2024) study calls on chemical education research to use ethnography to understand the culture of chemistry. This study positions the laboratory environment as a critical component of the culture of the chemistry classroom.

Finally, this study provides evidence that students can form stable chemistry self-concepts before they have any interactions with the content. Nielsen and Yezierski (2015) reported that students established stable chemistry self-concepts around the completion of the first semester. This study further moves up the stability of chemistry self-concept. Students in the low-mid and mid-high quartiles showed no statistical change in their chemistry self-concept during the course of the semester. A key component of self-concepts is its hierarchal nature (Shavelson et al., 1976). This study provides evidence that self-concepts from a higher, less domain-specific level, such as science self-concept, could significantly influence lower, more domain-specific levels.

Practical Implication

There are several practical implications that are a product of this study. First, this study provides a better understanding of the role that students place in laboratories on the shaping of their chemistry self-concept. Supporting the work of Agwu and Namadu's (2023) study that students develop higher chemistry self-concepts when they engage in cooperative learning activities, the current study highlights that students view labs as a cooperative learning experience. Students reported their experiences in the laboratory as a collective endeavor that is completed through not only their own experience but also the presence of their peers and group members. Teacher educators can begin to think of labs as not only a means for content delivery but as a means to help shape students' chemistry self-concept. By providing a new frame for educators to view labs, this study can provide a rationale for teachers to understand the increase in chemistry self-concept as a positive outcome of laboratory learning.

Second, this study highlights how students with different levels of chemistry self-concept experience labs. Thus, it is important for classroom teachers to understand that not all students experience laboratories in the same way. This gives the opportunity for classroom teachers to scaffold labs differently for students based on their chemistry self-concept. Students with higher chemistry self-concepts struggled with the ambiguity of laboratory answers. In contrast, students with lower chemistry self-concepts reported the importance of the visual and hands-on aspects of labs. These findings allow classroom teachers to plan for laboratory experiments that meet the needs of students with all levels of chemistry self-concept.

A final implication is the need for curriculum developers to support the role of laboratory learning in developing students' chemistry self-concept. Historically, curriculum developers have placed an important role of labs for understanding chemistry (Hofstein & Mamlok-Naaman 2021). Curriculums have highlighted the ability of labs to increase student affective measures such as engagement, enjoyment, and interest. Yet, laboratories' role in increasing chemistry self-concept has largely been omitted (Gericke et al., 2023). As curriculum developers move toward including more simulations in STEM education (Rosenberg & Lawson, 2019), it is critical for them to investigate if simulations produce the same positive effects on students' chemistry self-concept as traditional laboratory methods.

Recommendations for Future Research

This dissertation study leads to four recommendations for future research. First, the study used a modified version of Bauer's (2005) CSCI, with changes based on Werner and colleagues' (2021) work. Future studies should expand the sample size of students to reassess the reliability and validity of the shortened and modified instrument.

Second, further research should explore teachers' understanding of laboratories' role in shaping students' chemistry self-concept. Since teachers ultimately decide how content is presented to students, future studies could investigate the reasons behind teachers' choices to include or exclude labs from their chemistry curriculum and how they perceive the use of laboratories in influencing students' chemistry self-concept.

Third, there is a need to investigate students outside of honors chemistry. Nielsen and Yezieski (2015) demonstrated that students in different levels of chemistry courses experience varying levels of chemistry self-concept. Expanding the research to include students outside of honors chemistry would provide a broader understanding of the role laboratories play in the development of students' chemistry self-concept.

Finally, further research should examine whether different types of labs influence students' chemistry self-concept. This study highlights that laboratory experiments are complex, multidimensional activities but does not differentiate between lab types. Laboratories can generally be categorized as either inquiry-based or teacher-centered. Previous research (Gericke et al., 2023) has shown that students experience these types of labs differently, making it essential to investigate whether these differences affect students' chemistry self-concept.

Conclusion

Throughout the interview process, I was struck by how students' demeanor changed when they talked about laboratory experiments. Their attitudes noticeably shifted when discussing their lab experiences. This reminded me of a time when I was teaching physical science, and a student while conducting a chemistry experiment, exclaimed, "I feel like a real scientist." Like many teachers, I am passionate about my subject and strive to pass on that passion to my students. Over the years, I have often been surprised by how many adults dislike chemistry, which has made me wonder why my experience with the subject differs so much from theirs.

This dissertation aimed to explore the role chemistry laboratories play in shaping students' chemistry self-concept. The findings show that labs have a significant impact on how students perceive chemistry. Students viewed labs as multidimensional learning experiences that provided opportunities in chemistry they wouldn't have had otherwise. It can be concluded that labs are essential in fostering a positive chemistry self-concept in students.

The results of this study align with a constructivist view of students' development of chemistry self-concept. The students in this study saw chemistry not only as an abstract science but as a hands-on discipline where experiments are central to learning. Interestingly, many adults who dislike chemistry often do not recall completing labs during their high school years.

In closing, I encourage researchers and educators to continue investigating the causes and effects of chemistry self-concept. As we continue to advance science in the coming century, it is crucial to help students develop positive STEM self-concepts. By understanding students' perspectives, we can continue to create educational experiences that shape their understanding of the subject matter.

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Appendix A - Informed Consent

KANSAS STATE UNIVERSITY
University Research Compliance Office

Institutional Review Board (IRB)
Informed Consent Template Form
comply@k-state.edu | 785-532-3224

PROJECT TITLE:

Laboratory learning's role on chemistry self-concept: A mixed methods approach.

PROJECT APPROVAL DATE:	08/15/2023	**PROJECT EXPIRATION DATE:**	08/14/2026	**LENGTH OF STUDY:**	5 months

PRINCIPAL INVESTIGATOR: Derek Base

CO-INVESTIGATOR(S): Michael Lawson

CONTACT DETAILS FOR PROBLEMS/QUESTIONS:

Derek Base
(316) 841-6283
based@ksu.edu

IRB CHAIR CONTACT INFORMATION:

Lisa Rubin, Chair, Committee on Research Involving Human Subjects
203 Fairchild Hall, Kansas State University,
Manhattan, KS 66506, (785) 532-3224

Brad Woods, Associate Vice President for Research Compliance
203 Fairchild Hall, Kansas State University
Manhattan, KS 66506, (785) 532-3224.

PURPOSE OF THE RESEARCH:

The purpose of the research is to determine if there is a relationship between students' involvement in chemistry lab experiments and the development of their chemistry self-concept. Chemistry self-concept is the perceptions that a student has about themselves with regard to chemistry (e.g. I am good at chemistry, I enjoy chemistry, I could see myself in a chemical field). The goal of the research is to inform teaching practices on how chemistry teachers can best use hands-on laboratory learning to promote positive student development of their chemistry self-concept.

PROCEDURES OR METHODS TO BE USED:

The students will be asked to fill out a 10-question survey at three different points during the first semester. The survey will ask students about their attitudes toward chemistry. After the third completion of the survey, 10 students will be selected and asked to complete a 30-minute to hour interview. During the interview, students will be asked about their perceptions of chemistry and how the chemical experiments they conducted during class helped formed those perceptions. The interviews will be audio recorded. In addition to survey and interview data students' demographic and grade data will be collected.

RISKS OR DISCOMFORTS ANTICIPATED:

During the process of filling out the survey or interview process, students might feel that they need to put the "correct" answer or the answer that will best help their teacher. In addition, filling out the survey at three different times might cause survey fatigue.

BENEFITS ANTICPATED:

Benefits to students may include personal reflections on their interactions with chemistry and the ability to think about how laboratory experiments are used during their course. In addition to personal benefits, the study looks to inform chemistry teachers on effective ways to use hands-on experiments to increase students' chemistry self-concept.

EXTENT OF CONFIDENTIALITY:

All data collected will remain confidential. Any reporting of the data will include pseudonyms. Personal and identifiable data will only be accessible to the researcher. All data will be stored on a password protected computer and be retained for 3 years after the completion of the study. Student responses will not be seen by the classroom teacher. The responses given will have no impact on student grades.

The information or biospecimens collected as part of the research, even if identifiers are removed, will not be used or distributed for future research studies.

PARENTAL APPROVAL FOR MINORS:

PARENT/GUARDIAN APPROVAL SIGNATURE:		**DATE:**	

Terms of participation: I understand this project is research, and that my participation is voluntary. I also understand that if I decide to participate in this study, I may withdraw my consent at any time, and stop participating at any time without explanation, penalty, or loss of benefits, or academic standing to which I may otherwise be entitled.

I verify that my signature below indicates that I have read and understand this consent form, and willingly agree to participate in this study under the terms described, and that my signature acknowledges that I have received a signed and dated copy of this consent form.

(Remember that it is a requirement for the P.I. to maintain a signed and dated copy of the same consent form signed and kept by the participant).

PARTICIPANT NAME:			
PARTICIPANT SIGNATURE:		**DATE:**	

Appendix B - Student Assent Form

KANSAS STATE UNIVERSITY
University Research Compliance Office

Institutional Review Board (IRB)
Informed Assent Form
comply@k-state.edu | 785-532-3224

Laboratory learning's role on chemistry self-concept: A mixed methods approach.
Assent Form

My name is Derek Base. I am a graduate student at Kansas State University. I am inviting you to participate in a research study about the role completing chemistry experiments has in the development of your chemistry self-concept (e.g. I am good at chemistry, I enjoy chemistry, I could see myself in a chemical field). Your parent(s) know we are talking with you about the study. This form will tell you about the study to help you decide whether or not you want to take part in it.

If you agree to be in the study, I will ask you to fill out a survey at three different periods during the first semester. The survey contains 10 questions to be answered. After the completion of the surveys, 10 students will be selected to participate in a 30-minute to hour-long interview. During the interview, your answers will be audio recorded. The recording will not be started without your permission and can be stopped at any time.

If you take part in this study, you will be able to reflect on your learning in chemistry and gain some insight in how you are interacting with the content. While taking part in this study may not have direct benefits for you, it will help me learn how to better engage students in learning chemistry through laboratory experiments.

There are no foreseeable risks however some students might experience boredom, anxiety, or fatigue. If you participate in the interviews we can take breaks at any time you would like to try to minimize any inconveniences.

Your responses will be confidential. The results of this study may be used in reports, presentations, or publications but your name will not be used. All data collected will be stored on a password protected computer. Members of my research committee will have access to the data. Your classroom teacher will not have access to the data collected during this study. All data collected will be stored for three years after the completion of the study.

Your participation in this study is completely voluntary. No one will get angry or upset if you don't want to do this. And you can change your mind anytime if you decide you don't want to be in the study anymore. This study will have no impact on your grade. Your classroom teacher will not see any results from your surveys or interviews.

What if I have questions?
If you have questions about the study, you can ask me now or anytime during the study. You can also e-mail me at based@ksu.edu. If you have any questions about your rights as a participant in this research or if you feel you have been placed at risk, you can contact the IRB Office at comply@k-state.edu or (785) 532-3224. You will receive a copy of this form for your records.

Signing below means that you have read this form and that you are willing to be in this study.

Your signature: ____ Date _____________

Your printed name: ____ Date _____________

Signature of person obtaining consent: ____________________________ Date _____________

Printed name of person obtaining consent: _________________________ Date _____________

Appendix C - Parent Recruitment Email

Dear Parent or Guardian,

My name is Derek Base and I am a chemistry teacher at Andover High School. I am currently in the process of obtaining my doctorate in education from Kansas State University. As a chemistry teacher, I am always trying to find new ways to get students engaged in chemistry.

My research at K-State is to understand the role that completing chemistry experiments has in developing students' chemistry self-concept (e.g. I am good at chemistry, I enjoy talking about chemistry, I could see myself as a chemist).

In order to complete my research, I am recruiting students to partake in my study. The study will consist of students completing three surveys during the fall. The surveys are ten questions long and ask students questions about their views on chemistry. The surveys will be given as a portion of their post-lab write-up. In addition to the completion of the surveys, I will ask 10 students to partake in a 30-minute to hour interview. The interview will ask students about their views on chemistry and on laboratory experiments in chemistry.

Student participation in the study is 100% voluntary. Choosing to participate or not participate in my study will have no impact on your student's grades. Any answers given to the surveys or interviews will remain confidential to me. Any reporting of student responses will use pseudonyms.

I would love to have your students participate in my study and help me understand how to better build students' passion for chemistry.

I have sent home a consent form for you to complete if you are willing to allow your student to participate in my study.

If you have any questions please contact me at based@ksu.edu or at (316) 841-6283.

Thank you,

Derek Base

Appendix D - Chemistry Self-Concept Inventory

Chemistry Self-Concept Inventory

Student ID Number: ________________________
Hour: __________

	Strongly Disagree	Disagree	Somewhat Disagree	Neutral	Somewhat Agree	Agree	Strongly Agree
I am excited about chemistry most days.							
I participate confidently in discussions with school friends about chemical topics							
I find chemistry concepts interesting and challenging.							
When I run into chemical topics in my courses I always do well on that part.							
I would look forward to enrolling in courses that involve chemistry.							
I am quite good at dealing with chemical ideas.							
Chemistry does not intimidate me.							
I am able to understand arguments that require chemical knowledge.							
I have always done better in courses that involve chemistry than in most courses.							
I understand topics based on chemistry.							

How confident did you feel while completing the lab yesterday? What do you think impacted your feeling this way?

Appendix E - Interview Protocol

Interview Protocol

Hello! My name is Derek Base and I am currently an Ed.D. student at Kansas State University. I am here today to learn about students' perceptions of how they form their chemistry self-concept. Academic self-concept refers to individuals' knowledge and perceptions about themselves in an academic setting. Chemistry self-concept might be viewed as individual thoughts such as I enjoy chemistry, I can see myself in a field related to chemistry. The answers you give today will help inform teachers on what aspects of their class help students build a positive view of chemistry.

Thank you again for taking time from your day to speak with me. There are no right or wrong answers and no more desirable or less desirable answers. I want you to be free to speak with what is on your mind when the question is first asked. Your classroom teacher will not see the results of this interview. This interview has no bearing on your grade in your current chemistry course. If it is ok with you I will be recording these interviews, so that I can go back and review your answers. Your answers will remain confidential and pseudonyms will be used during the reporting of this work.

This interview will be recorded for research purposes. Do you consent to have the interview recorded? I will begin recording now. Please know that you can have the recording stopped at any time.

General Chemistry Class Questions

1. How would you describe chemistry to a freshman who has never taken a chemistry course?
2. Could you tell me about a day that you enjoyed your chemistry course?
3. Could you tell me about a day when you least enjoyed your chemistry course?
4. Are you interested in taking chemistry courses in the future? Why or why not?
5. Do you feel like your interest in chemistry has changed since August? What has caused this change/why do feel that it hasn't?

Education Background

1. When you hear the word school what is the first thing that comes to your mind?
2. Tell me about an experience that has helped form your opinion of school.
3. When you were in elementary school did you have the same view of school?
   a. Why do you think your view has/hasn't changed from that time?
4. What do you get most excited about in school?
   a. Tell me about a time when you were excited to be at school.
5. What aspect of school do you find least enjoyable?

Chemistry Self-Concept

1. When I say chemistry what do you think about?
2. Before this year how much experience would you say you had with chemistry?
   a. Can you tell me about a time in school when you remembered learning about chemistry? What do you remember?
3. Why did you decide to sign up honors chemistry?
   a. If you could go back would you still enroll in honors chemistry? Why/why not?
   b. What other honors classes are you currently enrolled in?

Course Makeup

6. What feelings do you have when you come to chemistry class?
7. Tell me about a day that you were excited after a chemistry lesson.
    a. What made you feel this way?
    b. What do you remember about that day most?
8. Tell me about a day that you were frustrated after a chemistry lesson.
    a. What made you feel this way?
    b. What do you remember about that day most?

Labs

9. When you walk into the classroom and see that you are doing a lab, what do you think?
10. Do you enjoy lab days? If so could you explain why you enjoy them, if not could you explain why you do not enjoy them?
11. How do the labs that you complete tie back to the topic that you are learning in the class?
12. Can you tell me about a lab that helped you visualize or understand a concept better?
    a. Why do you think the lab helped you?
13. How do you think your opinion of chemistry would change if you were not able to complete labs for the rest of the year?

Thank you for your willingness to participate in my study. Your answers today will help me understand how students understand the role that laboratories play in learning chemistry. I just wanted to remind you that your answers will remain confidential. All reporting of this data will use pseudonyms. Your classroom teacher will not see your responses to this interview.

Are there any questions that you have for me?