TRANSFORMATION OF THE ORGANIC CHEMISTRY LABORATORY:

A MOVEMENT TOWARDS AN INQUIRY-BASED LABORATORY EXPERIENCE

A Scholarly Research Project

Submitted in Partial Fulfillment of the Requirements for the Degree Doctor of Education

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ABSTRACT

The traditional methods of teaching organic chemistry laboratories do not seem to effectively promote content retention, communication skills, or valuable soft skills. The purpose of this convergent triangulation mixed-methods, scholarship of teaching and learning action research study was to differentiate the impact of expository laboratory experiences and guided inquiry laboratory experiences on college students' perceptions of their knowledge and understanding, communication skills, and confidence levels related to organic chemistry. The overarching questions answered by this research study were (1) how do expository laboratory experiences impact college students' perceptions of their knowledge and understanding, communication skills, and confidence levels related to organic chemistry? And (2) How do guided inquiry laboratory experiences impact college students' perceptions of their knowledge and understanding, communication skills, and confidence levels related to organic chemistry? Students in the study completed a pre- and post- course survey, semi-structured interviews, oral and written laboratory reports, and a soft skills survey. The findings of this study revealed that students' perceptions of their knowledge and understanding increased as well as their persistence, motivation, and confidence levels much more as a result of the guided inquiry instruction when compared with the traditional, expository method of instruction. The findings from this study suggest that educators can deviate from traditional laboratory instruction to help students foster deeper, more meaningful connections while also nurturing critical transferable soft skills.

Keywords: Scholarship of Teaching and Learning (SoTL), organic chemistry, laboratory instruction, constructivism, guided inquiry, mixed-methods, survey research, student learning, soft skills

DEDICATION

This research is dedicated to my loving wife, Claire Montag, for her unfaltering support for me. Thank you for all the inspiration and motivation that you have provided me throughout the years. To my mom, Beverly, and my dad, Daniel, thank you for the sacrifices that you have made to help me accomplish my goals. To my grandma, Annis, thank you for always standing in my corner and listening to me with unwavering kindness. To all my students, past, present, and future, I am grateful for the trust you have placed in me as your guide, teacher, and mentor. Your curiosity, commitment to excellence, and relentless pursuit of knowledge fuels my passion for teaching.

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Chapter 1: Introduction

Organic chemistry is the study of carbon containing compounds. Since all living creatures and organisms contain carbon, organic chemistry can also be known as the study of life. At the university undergraduate level, organic chemistry has been known to be a notoriously difficult course for students to grasp concepts, knowledge, and an appropriate level of understanding associated with the material. The laboratory time that typically accompanies organic chemistry courses can be equally as daunting for students. Unfortunately, these challenges have given organic chemistry the reputation of being a “weed-out” course, meaning a foundational course that many students fail, drop, or withdraw. This chapter introduces the challenges of teaching organic chemistry and the researcher’s experiences and assumptions about teaching organic chemistry before stating this study’s research problem, purpose, and questions and briefly discussing the significance of the study.

The Challenges of Teaching Organic Chemistry

DFWI rates, which are used to designate the number of students who either receive a D or F letter grade or withdraw from the course or earn an incomplete. These DFWI rates are some of the ways colleges and universities identify which courses are very difficult for students. The higher the DFWI rate, the more difficult the course. The American Chemical Society (ACS) reported the DFWI rate for general chemistry averages around 29.4% across the United States (Arnaud, 2020). For organic chemistry, the reported DFWI rates are between 20-50% at reporting institutions throughout the country (Mooring, Mitchell & Burrows, 2016). This means that many students with goals of becoming a researcher, doctor, nurse, or teacher of chemistry are falling short before they even complete their first-year undergraduate courses (Arnaud, 2020). These DFWI rates show that there is a disconnect between the students and the material associated with the course, even though the organic chemistry material has not really changed in over 50 years. A study conducted by Weston and colleagues (2019) reported that 43% of college students switched from a science, technology, engineering, or mathematics (STEM) major to a different major due to consequences and negative experiences directly shaped by a weed-out course. Careers in the STEM field are vital to the economic, medicinal, and industrial growth of the United States.

What often gets forgotten by the scientific community is how difficult organic chemistry is to teach. Organic chemists across the nation refer to organic chemistry as a new language because the material associated with it is so different from the knowledge transmitted in general chemistry (Holman, 2004). The typical organic chemistry curriculum outlines several laboratory skills that students should be able to demonstrate such as the ability to collaborate and work as a team, the ability to think critically and formulate hypotheses, and the ability to communicate effectively. According to Zippia (2020), these skills are highly desirable in research and industry professions and include being able to analyze samples with various spectroscopic instrumentation, which refers to the chemistry instruments used to gather information about the chemical structure, properties, or behavior of a molecule. Some forms of instrumentation are Gas Chromatography (GC), Mass-Spectrometry (MS), Nuclear Magnetic Resonance Spectroscopy (NMR), Infrared Spectroscopy (IR), and High-Performance Liquid Chromatography (HPLC). Aside from instrumentation, students should also have knowledge of Thin-Layer Chromatography (TLC), Column Chromatography (CC), and other basic separation techniques (2021). Therefore, organic chemistry laboratory is packed with techniques, instrumentation, and synthesis on top of all the material that students must try to absorb in the organic chemistry class, making it difficult to both teach and learn.

Conscientious instructors usually try to relate content that is being learned in the organic chemistry lecture sessions with an experiment in the laboratory sessions (commonly referred to as labs) in an effort to reinforce the material. Connecting the organic chemistry lectures and labs should lead students to try to learn why a reaction behaves in a certain way as well as how to safely perform that reaction (Kim et al., 2018). This instructional model seems to work in theory, but the recent push by educators at many institutions across the country for alternative teaching pathways that deviate from traditional or expository labs could potentially indicate that connecting organic chemistry lectures and labs may not be as effective in practice as some instructors believe. Expository labs, or traditional laboratory sessions, are labs where students are given step-by-step instructions that require little cognitive thought to achieve a predetermined result (Domin, 1999). Because expository laboratory experiments are inherently simplistic and heavily guided by step-by-step instructions for the students to perform, they are often referred to as “cookbook chemistry” (Domin, 1999, p. 543). Combining “cookbook” expository lab experiences with students who just want to get a grade and finish the reaction quickly increases the risk of ineffective transmission of information and underdeveloped soft and technical skills (Santos-Diaz et al., 2019). This traditional style of teaching organic chemistry laboratories seems to fail at communicating real-world applications of chemistry and often does not effectively show the interdisciplinary nature of the science that students are learning.

Some studies confirm reports that even students with high overall grade point averages (GPA) do not usually perform to their own expectations the first time they are introduced to organic chemistry (Szu et al., 2011). Even high achieving students tend to focus on getting good grades and finishing the lab exercises as quickly as possible, rather than gaining knowledge, techniques, and critical thinking skills associated with the laboratory experience. Some of my own colleagues say that students also fail to see that there is often more than one “correct” answer in organic chemistry and that students typically focus solely on their results rather than the path used to achieve those results, a phenomenon that I call “not thinking about what is happening to the molecules inside the beaker.” Independent research is challenging for a single instructor to manage due to the time commitment as well as keeping the lab projects interesting with real world applications. Additionally, projects must be rotated so that students cannot simply use previous years’ work or data. For all of these reasons, I became motivated to conduct this study.

Researcher Experiences and Assumptions

From ten years of experience teaching expository organic chemistry laboratory sessions at various universities, I was able to determine additional challenges associated with teaching labs in the traditional way. One thing I noticed was that many labs only have one or two techniques for a student to try and learn, and then students rarely use that technique again. For example, in a 15-week first semester organic chemistry lab course, students would perform simple or fractional distillation in week two, and then would not encounter distillation again for the remainder of the semester. This also holds true for column chromatography, which students perform in week six, and then do not perform again for the remainder of the first or second semester organic chemistry lab. These two techniques are fundamental to organic chemistry, and yet they are not given their proper respect because of the nature of how the traditional laboratory session is set up. There are some techniques that students usually perform more than once, such as melting point analysis, TLC, IR spectroscopy, NMR spectroscopy, and reflux. While TLC, IR, NMR, and reflux are essential to the organic chemistry experience, students often struggle to maintain the confidence and/or knowledge to perform the techniques on their own. Moreover, melting point analysis is quickly becoming outdated and is generally seen as a poor method of determining whether or not the reaction or isolation was successful. In my opinion, redesigning what is taught and when it is taught in today's organic chemistry laboratory sessions would likely increase student learning and decrease DFWI rates.

The second challenge that I have noticed from my experience teaching organic chemistry labs is that even after completing two concurrent semesters of organic chemistry lab, students often seem to lack the confidence or retain the knowledge required to apply what they learned from lab in a real world setting or in their upper-level labs or research. For example, a colleague explained to me that some of his research students - who had successfully completed my lab courses - often failed to keep a well-written laboratory notebook and also did not remember how to perform fundamental isolation techniques, such as liquid-liquid extraction. As a result, I added more lab exercises that used liquid-liquid extraction and placed greater emphasis on keeping an organized, professional laboratory notebook. Unfortunately, the results of my efforts to improve the traditional laboratory experience were insignificant, as research students still tended to struggle with applying their knowledge and demonstrating confidence in the laboratory. This leads me to believe that small changes to the traditional laboratory experience simply results in more of the same, which does not result in the level of student learning that is needed for subsequent application of organic chemistry concepts in settings such as research.

A third and final challenge that I noticed was that students often do not learn to "write or speak like a scientist" in the organic chemistry lab, which often leads to poor written reports and low-quality oral presentations. Some universities where I have taught do not require formal lab reports or oral presentations, but I believe the communication skills associated with written lab reports and oral presentations are essential to becoming a well-rounded scientist. Lab reports were often written in the format of introduction, results, discussion, and conclusion, with no emphasis on proper scientific formatting, the opposite of how chemistry research is published in scientific journals. For example, *Angewandte Chemie*, *Journal of the American Chemical Society*, *Science*, and *Nature* all use different formats for publications in their respective journals. Because our students are required to read scientific literature, it should not be too much of a stretch to write similarly to the scientific literature. By simply changing from what needs to be taught to how and why something should be taught, educators can promote more effective scientific communication.

Guided inquiry is an evidence-based practice in which student inquiry can be facilitated. Students can formulate their own hypotheses in a safe and secure environment, allowing them to develop the ability to think like a scientist or researcher (FitzGerald, 2021). I believe that the use of a guided inquiry laboratory experience will benefit organic chemistry students more than the traditional, expository laboratory approach.

Statement of the Research Problem

The traditional methods of teaching organic chemistry laboratories do not effectively promote content retention, communication skills, or valuable soft skills. Despite recent advances made to the organic chemistry curriculum at many universities across the nation, studies on organic chemistry retention, student engagement during organic chemistry lab, and soft skill development appear to be quite limited.

Setting of the Study

The selected university of focus for this study will be referred to as the Carbon University or CU. Carbon University has a large body of students where organic chemistry and the organic chemistry laboratory are required, including chemistry, biochemistry, chemical engineering, pre-health, pre-pharmacy, chemistry education, chemistry business, and biology majors. Because of the large number of disciplines where organic chemistry is required, 60 to 80 students enroll in the organic chemistry laboratory each year. At CU, I teach five first semester organic chemistry labs each fall semester and two second semester organic chemistry labs each spring semester. All labs are currently being taught traditionally, where students come to the lab each week and perform a step-by-step reaction based on what they may be learning in class. After finishing the lab, the students write a lab report that is extremely dissimilar to how chemistry research is actually written in scientific journals.

Scholarship of Teaching and Learning (SoTL)

Currently, at Carbon University, the DFWI rate for Organic Chemistry is between 15% and 25%. This number is too high to dispel the notion that organic chemistry and its associated lab are gatekeepers to students' education. Traditional, expository methods of teaching organic chemistry laboratory are widely renounced by the national organic chemistry instructional community; however, reports of utilizing an inquiry-based methodological approach in the organic chemistry lab are few in comparison (Auchincloss et al., 2014; Schoffstall & Gaddis, 2007).

Through this Scholarship of Teaching and Learning (SoTL) study, I hope to convince my colleagues at both CU and nationally that a guided inquiry approach to teaching organic chemistry labs is more likely to result in student learning than the traditional, expository approach. The desired outcomes of this effort are to reduce the DFWI rate, improve on the development of essential soft skills such as confidence and communication, and increase the retention of content knowledge through repeated exposure to laboratory techniques, experimentation, and instrumentation.

Research Purpose and Questions

The purpose of this research was to differentiate the impact of expository laboratory experiences and guided inquiry laboratory experiences on college students' perceptions of their knowledge and understanding, communication skills, and confidence levels related to organic chemistry. The overarching questions of this research study were:

a) How do expository laboratory experiences impact college students' perceptions of their knowledge and understanding, communication skills, and confidence levels related to organic chemistry?

b) How do guided inquiry laboratory experiences impact college students' perceptions of their knowledge and understanding, communication skills, and confidence levels related to organic chemistry?

Significance of the Study

The importance of the transition from traditional methods of teaching organic chemistry laboratories towards a research driven lab that gives students a more independent, real-world experience, while still maintaining the experimental techniques using instrumentation and technologies that they will need in the future is vital. Such a transition would allow for the creation of labs that require students to use techniques multiple times throughout the lab, to not only improve content retention, but also promote confidence in the laboratory. Such a transition would be of benefit to instructors across the nation because of the ease of adapting traditional laboratory exercises into inquiry-driven experiences that promote student learning, retention, and success. These inquiry-driven approaches would also be a benefit to industrial, research, and economical sectors post student graduation because students that graduate with these experiences will have extremely valuable chemistry and transferable soft skills. This transition is important and is in complete alignment with Carbon University's mission statement to "embrace the generation, application, and interpretation of knowledge" (Carbon University, 2022.)

Organization of the Research Report

This chapter introduced the challenges of teaching organic chemistry and the researcher's experiences and assumptions about teaching organic chemistry before stating the study's research problem, purpose, and questions and briefly discussing the significance of the study. Chapter 2 will present a literature review of the past and present climate of organic chemistry laboratories, including models that have shown promise and student success, such as studio-based learning, problem-based learning, research-based, and inquiry-based laboratory experiences. The design of study in chapter 3 details the tools that are utilized by the instructor for the study, including surveys, anonymized test and quiz scores, rubrics, lab reports, and self-reflective pieces. The results in chapter 4 were derived from pre- and post-course surveys, test scores and comparisons between groups A and B, soft skill determination, evaluations, lab reports, and self-reflections. Chapter 5 offers ways to optimize the laboratory experience further through inquiry-based findings.

Chapter 2: Review of Relevant Literature

D-Failure-Withdrawal-Incomplete (DFWI) rates for organic chemistry emphasize the importance of developing an organic chemistry course and laboratory curriculum that promote knowledge retention and student learning. This chapter delves into instructional approaches to teaching and student learning in general as well as how these approaches can be implemented in an organic chemistry class or laboratory setting to reduce DFWI rates. After foundational instructional theories are discussed, the chapter describes the importance of student confidence and its relation to verbal and written scientific communication. The chapter closes with successful innovative teaching styles and how instructors are seeking to utilize unique laboratory styles in an effort to promote confidence, retention, and communication skills.

Instructional Approaches to Teaching and Student Learning

The transfer of knowledge from instructor to student is central to education. Instructors often have to make the tough decision of how to most effectively promote student learning in their classroom. A debate has been ongoing for a very long time now regarding which of three theories of instructional design works best to promote learning. The three theories take root in psychology and are known as cognitivism, behaviorism, and constructivism.

Cognitivism focuses on how the mind works by attempting to understand how information is received, organized, stored, and retrieved in the brain (Mandler, 2002). This theory of instruction works by observing student behavioral patterns. Jean Piaget explained that the intelligence of an individual adapts and changes as they grow. The cognitive development of a person involves acquiring knowledge as well as developing a mental model of the surrounding environment (Miller, 2011). A teacher using this instructional style may have students reflect on personal experiences, encourage classroom discussions, or use visuals to improve student recall.

Behaviorism is a theory founded by B. F. Skinner that focuses on the idea that human behavior is learned by interacting with the environment and does not need to appeal to thoughts or feelings (Araiba, 2019). This theory emphasizes positive reinforcement as a way students learn to perform desired behaviors. With positive reinforcement, desired behaviors are repeated over and over until they become automatic to the students. In the classroom, an instructor may take a behaviorist approach by forming learning outcomes that are measurable; using rewards and instructive feedback; or by guiding students towards learning specific skills or learning specific procedures. One branch of behaviorism is known as objectivism, which states that truth exists outside the human mind, independent of the beliefs of the learner (Bates & Bates, 2015). Objectivism is the most common approach for learning in the classroom and a teacher using this view would likely believe that a course presents a body of knowledge to be learned.

Lastly, constructivism is the theory that students learn best by constructing knowledge rather than passively absorbing information given by the instructor. This is accomplished when learners build upon their prior knowledge and experiences by incorporating and making sense of new information. Von Glasersfeld summarized constructivism as a theory where learners construct their own understanding rather than simply regurgitating what they read or are told (Watzlawick, 1984). A teacher that uses a constructivist methodology in their classroom may try to pose challenging, open-ended problems, create group activities, and act as a guide in the process of obtaining knowledge rather than serving primarily as a deliverer of material. Experts believe that objectivism and constructivism are on opposite ends of a spectrum, with clashing ideologies. The key assumptions of objectivism and constructivism are outlined in Table 1, originally published by David H. Jonassen (1991) and adapted for the purpose of this review.

Table 1

Objectivism vs. Constructivism

MOTIF	OBJECTIVISM	CONSTRUCTIVISM
REALITY	External to the Learner	Determined by the learner
	Structure can be modeled	Structure relies on experience and interpretation.
MIND	Mirrors nature	Interpreter of nature
	Abstract machine for manipulating symbols	Conceptual system for constructing reality
THOUGHT	Governed by external reality	Grounded in perception
	Manipulates abstract symbols	Imaginative: enables abstract thought
MEANING	External to the learner	Determined by the learner
	Independent of the understanding of an organism	Dependent on understanding
SYMBOLS	Represent reality	Tools used to construct reality

The following section explores the differences between objectivist and constructivist instruction in the organic chemistry classroom and laboratory.

Objectivist Approach in the Organic Chemistry Classroom and Laboratory

The objectivist approach in the organic chemistry classroom or laboratory is essentially the traditional approach to student learning, where reality is given and the structure of the class is predetermined (Vrasidas, 2000). For example, a commonly performed natural product extraction of trimyristin from nutmeg has students perform the tasks associated with lab, determine a percent yield and melting point, and perform infrared spectrometry on the trimyristin. In general, the lab exercise does not allow students to manipulate any variables and all students attain similar results (Collins et al., 1971). The student learning outcomes (SLOs) are outlined in the syllabus and the teacher usually does their best to get through all the material with the hopes that students will retain the knowledge. The content of the lab is formatted to promote independent student learning, and the experience can be seen as competitive in nature because students do not typically communicate the science to one another or work together in a way that facilitates content understanding. In the objectivist approach, the teacher of the lab acts as a giver of knowledge. Success in the course depends on students' prior knowledge (Vrasidas, 2000; Shiland, 1999). Objectivism asserts that educators must try to make sure that their students are being actively engaged with the subject material (Carson, 2006). While very few educators tend to disagree with this notion, it seems a bit strange that the DFWI rates for objectivist organic chemistry labs have remained consistently high for decades.

All of these qualities lead instructors to teach the material so that students may pass a standardized test or use a step-by-step, "cookbook" or expository instructional approach in the organic chemistry laboratory. The use of objectivist principles in the lab are the most popular, yet they are most heavily criticized because they lend themselves to the expository style of instruction. In the lab, the instructor may define a topic to be investigated, attempt to relate the work to previously learned material, and then give the students the necessary instructions to complete the lab (Domin, 1999). The lab procedure is provided so that all students can experience the predetermined outcome that they may or may not already know ahead of time (Tamir, 1977). Thus, the students are rarely forced to "reconcile results, or [be] confronted with challenge to what is naively predictable" (Pickering, 1987, pp. 521-523). In other words, students of a lab may never have to trouble-shoot a problem or deal with the reality that reactions do not always work as intended.

There are valid reasons for instructors choosing the objectivist instructional approach over the years. First, if the lab has a large number of students, it can be difficult for the instructor to answer a lot of questions coming from every corner of the lab; therefore, having a laboratory activity that all students can perform simultaneously with minimal involvement from the professor is often considered preferable. Second, expository labs can be low cost, performed within a two-to-three-hour time span, and use fewer resources such as time, teaching assistants, and equipment that can be expensive to maintain (McKenzie, 2005). Therefore, expository labs that utilize an objectivist instructional approach are often utilized due to their efficiencies.

Although there may be good reasons to use an objectivist instructional approach in the organic chemistry laboratory, one must be careful to keep the experiments and material up to date. For example, the isolation of trimyristin from nutmeg experiment was published in 1971, the extraction of caffeine experiment has been known for decades, and isolation of products such as limonene were first used over 50 years ago (Frank et al.; Moye, 1972; Greenberg, 1968). All of these labs have really interesting applications and students can surely learn from them, but the information from labs such as these is now often posted online, so that students may even know all of the answers prior to coming to the lab. Educators must therefore be diligent about changing aspects of foundational laboratory exercises to keep them modern and interesting to the students.

Constructivist Approach in the Organic Chemistry Classroom and Laboratory

The constructivist approach in the organic chemistry classroom and laboratory is less explored than the objectivist approach. Constructivism in the organic chemistry curriculum would suggest that knowledge of organic chemistry concepts is constructed in the mind of the learner. In constructivist labs, students get to show knowledge through ways that do not always include testing. In addition, the overall content is often cooperative as opposed to the competitive nature of objectivism (Jonassen, 1991). Constructivism also gives students a chance to recognize that there can often be more than one correct solution to a particular problem, which puts an emphasis on cultivating thinking and knowledge construction skills. For example, organic methodologies allowing for variations in the laboratory experiment can allow students to formulate and test their own hypotheses. In contrast with objectivism, the constructivist approach allows the teacher to act as a guide rather than as a giver of knowledge (Shiland, 1999).

There has been a recent push in the chemistry education community to create laboratory experiences for students that are very dissimilar to the traditional model. It is well known in the scientific community that actively participating in early research or research-like experiments increases student persistence in science, technology, engineering, and mathematics (STEM), which has a positive impact on DFWI rates (Graham et al., 2013; Shea et al., 2020; Piunno et al., 2019; Papenfus & Carpenter, 2009). These experiences also show that repeated student exposure to research has measurable benefits (Adedokun et al., 2014; Thiry et al., 2012), fosters student ownership of the researched material (Escoto, 2019), and cultivates diversity in later research experiences (Bangera & Brownell, 2014).

For any person who has studied or taught chemistry, it is well known that active students who are engaged in lab experiences learn much more effectively than passive learners, who are quietly taking on information rather than engaging with the material (Bodner, 1986). As one example, Maxwell and colleagues (2012) developed a student-centered experience that incorporated scaffolding and behaviorism that they later transitioned to constructivism. Their results showed that certain aspects of the organic curricula were challenging for students, but by promoting active learning and by adapting their course to account for this, they were able to increase student confidence levels and lower the overall stress put on the students. In this way, constructivism has allowed organic chemistry instructors to develop their classrooms and laboratories into unique learning environments, including discovery, problem-based, guided inquiry, and studio-based instruction.

The shift in instructional style has opened many potential opportunities for educators to facilitate student learning. For example, Professor X wants to teach his students to perform an extraction of a known natural product, which would allow the students to verify what they learned in class. The experiment in the lab manual contains a pre-lab section, a detailed guide on how to perform the extraction, and a table for all their acquired data. Now compare this with a potential scenario with an example of a guided, inquiry-based laboratory experiment on the same natural product extraction.

Professor Y wants to teach her students to perform an extraction of a natural product. The natural product is hinted at but contains unknown structural information that the students need to elucidate. The lab manual contains a set of objectives and a starting point but does not give conditions for the natural product extraction. Therefore, the students must determine proper solvent, extraction techniques, and characterization methods to perform the proper extraction and classify the unknown natural product.

The use of constructivist principles could aid instructors in modeling more laboratory experiences in this way. An instructor could also model discovery, studio-based learning, or problem-based learning in a similar fashion. Recent research has shown that guided inquiry and discovery-based laboratories are excellent examples that allow for research-like scenarios and problems to be introduced at the freshman and sophomore level of undergraduate courses (Shea et al., 2020; Weaver et al., 2008). In a recent study, an undergraduate lecture-based organic chemistry course was transformed using principles of constructivist theory (Flaherty, 2020). The study was an attempt to generate a theory on how students conceptualize their scientific knowledge. At the end of the study, students concluded that the process of attaining and developing scientific knowledge is rarely predetermined and that memorization of information was insufficient. Through use of constructivist principles, students were able to engage in processes that were superior in helping them apply their prior and current knowledge.

Even though objectivism and constructivism exist on opposing ends of a spectrum, it does not mean that either one is more important or more correct than the other. In reality, a mix of both forms of these instructional theories may provide a solid foundation for the learner. Take the nutmeg lab previously mentioned for example. Perhaps the instructor could have the students perform the lab in the traditional manner, but then be asked to think of ways that the lab could be made more efficient. The next week, students could attempt to test their hypotheses, allowing for a more realistic laboratory experience.

Learning content, however, is only half of the educational battle. Today’s scientist must also be able to exhibit fundamental qualities that demonstrate success in real-world applications, such as the industrial job market. Therefore, it is safe to say that whether an instructor uses an objectivist or constructivist teaching methodology, it is also important for an educator to help students develop into scientists that have transferable soft skills that they can use in their everyday lives, classes, or professions.

Towards the Development of Transferable Soft Skills

The top scientists around the world all display personal attributes that allow them to interact seamlessly with other people, including children, the public, and their peers. These attributes are known as soft skills. There are many examples of soft skills, most notably, communication, confidence, time management, ambition, focus, problem solving ability, work ethic, teamwork, flexibility, and leadership (Birt, 2022; Doyle, 2022). There are many types of employment opportunities for scientists, such as research and development; manufacturing; jobs in the chemical, pharmaceutical, and medical industries; and government. The specific soft skills for each area and profession vary from one to the next, but two skills that they all share are confidence and strong communication skills, both verbal and written. This section of the literature review examines what college chemistry instructors in the United States are currently doing to help their students learn to effectively communicate like scientists as well as what measures are being taken to promote student confidence in the laboratory setting.

Fostering Scientific Communication and Student Confidence

Strong communication is a necessity for most careers in chemistry. When students are able to effectively communicate orally and in a written format, they often become much more confident, inside laboratory and out. Because of this, many chemistry programs outline the importance of effective scientific communication and list it as an essential learning outcome (Applebee et al., 2018; Ashraf et al., 2011; Jones & Seybold, 2015; Kerr et al., 2000; Kondo & Fair, 2017; Marteel-Parrish & Lipchock 2018). The American Chemical Society (ACS) has specific guidelines that state that written and oral communication skills are highly sought after; however, most assessment in organic chemistry laboratory is based on written reports and tests, rather than oral reports or presentations. Although written laboratory reports are extremely important because they promote scientific inquiry, literacy, and communication; students rarely communicate their results in an oral form (Widanski et al., 2020). To address this, science instructors at many institutions encourage their students to present their work viaposter presentations. These poster presentations are often used to promote chemistry and aid in the student learning process (Kennedy, 1985; Liplowitz et al., 1999; Logan et al., 2015; Marino et al., 2000; Menke, 2014; Sisak, 1997; Tamburini et al., 2014; Widanski & Courtright-Nash, 2006; Vogel Taylor et al., 2009).

In a recent study at Muhlenberg College in Pennsylvania, student-to-student collaborations were introduced to enhance students' lab notebook keeping and teamwork skills (Young, 2021). An interesting result stemming from the interlab collaboration model was that students were able to discover their own limitations with respect to their communication, data-keeping, and organizational skills. At the end of the semester, most students reported that the experience helped them to become better listeners and better communicators.

Pontrello (2015) researched ways to enhance skill building through student-led peer review, which is how academics, professionals, and scientists evaluate others working in the same field. Students in this laboratory designed their own procedures constructed from prior data. The students peer reviewed and revised the work and eventually performed the reactions or separations themselves. The experience helped students develop interpersonal communication skills and even though incorrect advice was given occasionally, it ultimately led to a greater understanding and stronger reports.

Another institution's solution to address retention issues associated with organic chemistry and help students learn to be more effective communicators was to use online collaborative assignments. One group of students were located in Canada while the other was located within the United States. This was done with the intention of promoting content mastery while also fostering confidence in chemistry communication skills both symbolically and verbally (Skagen et al., 2019). One student explained:

> I would be afraid to be like 'oh I think something else'. I [would] just agree with them until we realize we're wrong even though in the back of my mind I was questioning it. Now, I'm like, 'well, we have clashing answers,' but I'm not going to pretend I agree with her, I'll just say why. Now I'm more open to speaking my opinion and [saying] what I think is right. (Skagen et al., 2018, p. 572)

This result shows that confidence and communication reinforce each other. The transformation from being scared to disagree to being able to express themselves is proof that confidence can be learned in the organic chemistry laboratory.

While looking for ways to improve students' verbal communication skills in organic chemistry is important, instructors must also seek to improve their students' written communication skills. There are numerous strategies provided in the literature that seek to improve student writing in the sciences (Tilstra, 2001; Deiner et al., 2012; Weaver et al., 2014; Gragson & Hughes, 2010; Jacobs et al., 2016; Robinson et al., 2008; Cooper, 2005; Greenbowe et al., 2007; Wenzel, 2007; Browne & Blackburn, 1999; Coppola & Lawton, 1995). These strategies fall under the writing across the curriculum movement, which advocates that writing should be an "integral part of the learning process throughout a student's education" (Wackerly, 2017, p. 76). Many college science instructors are seeking reform due to problems with how students are writing lab reports, including incorrect vocabulary, lack of concision, formatting/organizational issues, lack of audience interpretation, lack of substantiating claims, and lack of general writing abilities (Rosenthal, 1987; Alaimo et al., 2009; Wallner & Latosi-

Sawin, 1999; Carr, 2013; Sherwood & Kovak, 1999; Bailey & Markowicz, 1983, Van Bramer & Bastin, 2013; Pyle & Trammell 1982; Steiner, 1982; Schepmann & Hughes, 2006).

One solution to these problems associated with student scientific writing is an approach that slowly transitions students into writing in a style found in the peer reviewed *Journal of Organic Chemistry* (JOC) (Wackerly, 2017). Students exposed to this model start by writing their results in a fill-in-the-blank format for one week. The next week, students write their own results and abstract. The following week, the students write their results, abstract, and an abbreviated discussion. The course continues week by week until the students eventually build up to writing a full chemistry lab report including the abstract, introduction, results, discussion, experimental details, and conclusion. It is worth noting that the *JOC* does not require supporting information of any kind, which can be used to promote organization of the students' data. This example does an effective job at showing that just by simply altering the format of chemistry lab reports, the instructor can have a positive impact on a student's ability to communicate scientifically through writing.

Innovative Laboratory Instruction Styles: A Break from Tradition

In seeking a solution to problems associated with poor retention in organic chemistry, research by Fung and Watts (2019) at the University of Singapore revealed that for meaningful learning to occur, students must learn cognitive, affective, and psychomotor skills integrated with the content necessary for success in lab. This aligns with a statement from Piunno and colleagues (2019) that their ultimate goal as instructors "is to have our students develop critical thinking and metacognitive skills, allowing them to become effective problem solvers and self-learners" (p. 1896). Over time, it seems that there has been a slight paradigm shift from a "content first" methodology to a "students first" methodology that incorporates the importance of students enhancing soft skills through the use of the content they learn (Burnham, 2019).

A debate in education that has been ongoing for decades hinges on the assumption that teaching soft skills will ultimately detract from the scientific content knowledge being taught (Fadel et al., 2015). If knowledge is learned passively without engaging skills of any kind, then that knowledge is only truly learned on a superficial level and not readily utilized in other areas or disciplines (Fadel et al., 2015). Reinforcing this fact, the ACS has outlined several soft skills for scientific success that students should develop throughout their laboratory experience. Briefly, these skills are interpersonal, flexibility, leadership, problem solving, work ethic, communication, and teamwork (Meadows, 2020).

Reinforcing content and helping students develop soft skills can feel like a hindrance to improving teaching methods in the lab due to an increase in time required for laboratory set-up, development, training, and implementation. However, due to some of the negative student experiences related to organic chemistry, often leading to higher DFWI rates, many institutions and educators have superseded the perceived hindrance and made a movement towards modifying the organic chemistry laboratory experience in an attempt to make for a more positive, improved learning experience that encourages the growth of better chemists and researchers with more retention of knowledge, content, soft skills, and instrumentation skills. Some instructional methods and success stories are described in the next section.

Success Stories from the Organic Chemistry Laboratory

There are many different instructional strategies utilized for the purpose of increasing student success and retention rates in college chemistry courses due to high DFWI rates and outdated cookbook-style models. Some methods that have shown success are studio-based learning (SDL), problem-based learning (PBL), and research-based learning (RBL). All of these instructional approaches differ from traditional approaches and demonstrate varying degrees of success.

Studio-Based Laboratory Examples

Studio-based organic chemistry lab modules have become increasingly important since their inception in the early 1970s. In a studio-based learning experience, students learn critical techniques, not just by performing them, but also by giving and receiving constructive critiques to and from their fellow students (Zollars et al., 2012). Studio-based learning (SBL) has grown in importance to the point of being funded in a National Science Foundation (NSF) grant awarded to Monroe Community College in 2016. The NSF funded work focused on developing, implementing, and studying innovative studio-based lab modules that transform the traditional laboratory into a meaningful learning experience. The study also focused on evaluation of student performance and retention (NSF, 2016).

One specific example of an SBL module that has demonstrated success incorporated student-centered activities to introduce first semester organic chemistry students to the laboratory. The authors refer to this as a “first day” studio module, which incorporated learning objectives, safety, and how to keep a professional lab notebook (Collison et al., 2015). This module was particularly successful at removing the stress associated with the first day of lab for both students and the instructor. The authors heavily emphasized partner work, class discussion, and set the tone for future labs by using the whole lab time to illustrate that it is not a race to finish lab first.

Another example of an SBL approach, also by Collison and colleagues (2015), was through the development of a novel S_N1-S_N2 lab. Substitution chemistry is of vital importance to the student as it is some of their first exposure to real world chemical reactions and mechanisms. Assessments by the authors showed that 94.4% of students who performed the lab with an SBL approach were confident in their observations while only 71.4% of students who performed the lab using the traditional instructional teaching style were confident in their observations (2012). The SBL approach was demonstrated to show increased awareness, critical thinking, observations, and collaboration as opposed to the traditional approach.

Problem-Based Learning

Problem-based learning (PBL) has gained more traction in recent years than its studio-based learning counterpart. PBL is a student-centered approach where students work in groups to solve open-ended problems. Effective PBL can take either an objectivist or constructivist approach depending on the instructor's preference (Duch et al., 2001). This versatility is beneficial to the instructor of a lab because it allows for more freedom to develop and implement different styles of chemistry labs.

Problem-based learning has shown success in ensuring a higher level of student learning and critical thinking. Constantino and Barlocco (2019) implemented a PBL approach in their Synthesis and Extraction of Drugs laboratory course that they deemed an appropriate "compromise between inquiry and expository learning" (pp.888-889). The organic chemistry lab activities were changed from "recipe-driven" to an open-ended, research driven approach which promoted inquiry and scientific discovery. Performance evaluations and course assessments were used, and students reported positive feedback, saying that the course was educational, stimulating, interesting and intriguing.

Latimer and colleagues (2018) demonstrated a hybrid model of PBL fused with aspects of guided inquiry learning and peer-led team learning to ease the transition between organic lab and research labs. In this experiment, students had to tackle a very difficult problem, characterization of a mixture of camphor and p-coumaric acid, involving advanced NMR experiments, TLC, and CC as well as coupling constant analysis. Students in this lab were able to enhance deductive reasoning skills with minimal guidance from the instructor. The authors reported that every student was able to be successfully guided through separation and characterization of the molecules. The authors also reported that about half of their students who performed the experiment were able to successfully transition into a research lab, whether the project was an honors, masters, or doctoral research project. PBL is a very effective teaching motif that allows students to gain a deeper understanding of procedures, develop teamwork skills, and gain confidence working independently. Problem-based learning has been a vehicle for curricular reform for decades, albeit to a lesser extent than inquiry-based learning (Domin, 1999).

Course-Based Undergraduate Research Experiences (CUREs)

Over the last few decades, course-based undergraduate research experiences have gained a lot of momentum in the development of student-centered curricula. Course-Based Undergraduate Research Experiences (CUREs) have been designed to involve students in the use of scientific practices, discovery, broadly relevant research, collaboration, and iteration (Auchincloss et al., 2014). CUREs vary from introductory level to advanced level classes and have the hallmark of using research questions that provide a unique experience of discovery for both the student and the course instructor, since neither know the outcome of the experiments. This gives the student ownership over the research experience and yields opportunities for many experimental iterations (Staub et al., 2016; Auchincloss et al., 2014; Williams & Reddish, 2018). Research has shown that labs with a more modern, research driven approach paves the way for higher retention and students with increased knowledge, confidence, and overall success rates (Carpenter & Papenfus, 2009).

Working in collaboration with the University of Minnesota – Morris, Carpenter and Papenfus (2009) introduced a substitute model for second semester organic chemistry lab known as Intro to Research (ItR). This course model provided a research-like experience that gave students the opportunity to work with a selected professor of their choosing on their research to get a better understanding of what it means to be a scientist. The quantitative study allowed for eight years of numerical data and alumni surveys which rated ItR as the class which they benefited the most from (Carpenter & Papenfus, 2009). In this experience, students were able to develop valuable social skills whilst learning conceptual and content knowledge related to organic chemistry at the same time. Using all of the faculty in the research process also allowed us to display the interdisciplinary and interconnected nature of chemistry.

In research from Newton and colleagues (2006), the instructors derived a model of organic laboratory instruction in which they took one faculty member's research and used it for both semesters of organic laboratory. The students would perform a multi-step synthesis of specific compounds related to the research which allowed for variation of student experiences from semester to semester. The overall student experience, as expected, also varies from year to year. However, it is noted that students were able to excel at mastering fundamentals of basic research, collaboration, chemical analysis, and written skills (Newton et al., 2006).

Another example of a CURE based experience comes from the University of Toronto, where Piunno and colleagues (2019) started a program called Launching Your Research, designed to engage students in research at early stages of their academic careers. Through this course, students were able to develop time management, teamwork, and project management skills along with critical thinking and metacognitive skills. The researchers used their data to prove that research early in a student's career would help them gain professional and marketable skills transferable to other disciplines or jobs.

Lastly, Wenzel and Karukstis (2004) noted that "research activities at predominantly undergraduate institutions benefit the discipline, the student and faculty participants, and the institution" and by introducing their research-based organic chemistry laboratory course, they are confident that "exposing students to a culture of research early in their career results in improved learning and a higher likelihood of future participation in scientific research" (pp.468-469). The Council on Undergraduate Research (CUR) program engaged students in research in their first-year chemistry course. This yielded an increase in summer research for these students, strengthened partnerships with local academics and businesses, and improved community engagement. Students were able to demonstrate basic chemical techniques and benefited from quantitative data and remained engaged and eager due to familiarity of the topics (Wenzel & Karukstis, 2004). These CUREs are valuable to enhancing the student laboratory experience and can be adapted to target specific chemistry skills or soft skills that students should improve on.

Another benefit to CUREs is that an instructor can adapt fundamental organic chemistry laboratory motifs into an open-ended research project. For example, an instructor can focus on labs that are collaborative in nature and allow for students to work together to develop communication skills to solve scientific problems, rather than just looking up the answers. A few examples of organic chemistry labs that could be adapted into CUREs could be natural product isolations (McLain et al., 2012), synthesis of biologically relevant organic compounds with bioactivity (Thoin & Grover, 2017), and applications of easily synthesized molecules (Shea et al., 2020).

CUREs allow for reactions that carry material forward from week to week, promoting sustainability and green chemistry. Rather than making or isolating a molecule and throwing it in the waste, students can take the molecule and use it in the weeks following, whether for reactions or monitoring bioactivity, or other scenarios. These labs put emphasis on experimental, spectroscopic, and instrumental techniques that students would undoubtedly encounter in their professional careers. CURE based labs vary far from the traditional methodologies to teaching organic chemistry and allow students to become more familiar with instrumentation and techniques due to repeated use and experimentation.

Inquiry-Based Laboratory Experiences

There are numerous examples of inquiry-based laboratory experiences reported in the scientific education literature. Inquiry-based learning experiences in the laboratory, whether guided or open, differ slightly from CUREs since most inquiry driven projects have scientific conclusions that may or may not be predetermined, whereas CUREs usually allow for students to work on more novel, faculty led research projects. The table below, adapted from Auchincloss and colleagues (2014) notes some more key similarities and differences between the two teaching methodologies.

Table 2

Inquiry-based vs. CURE-based Pedagogies

	Inquiry-based	**CURE**
Use of scientific practices	Multiple scientific practices. Student driven	Multiple scientific practices. Student or instructor driven
Discovery	Purpose: Student Defined Outcome: Varied	Purpose: Student or instructor defined Outcome: Unknown
Relevance or importance	May be novel, but is limited to the course	Novel and extends beyond the course
Collaboration	Amongst students	Amongst students, teaching aids, and instructor
Iteration	Risk of generating messy data: Significant Built into process: Occasionally	Risk of generating messy data: Inherent Built into process: Often

The similarities and differences between inquiry-based learning and CUREs.

The type of inquiry can also vary, between confirmation, structured, guided, or open inquiry models. In the present study, guided and open inquiry are the primary focus. Guided inquiry is defined as a scientific process that promotes exploration and uses critical thinking, logic, and creative thinking to answer scientific questions whilst being guided by an instructor. Open inquiry is defined as a scientific process that centers on the student and begins with the student asking a question, followed by the design and implementation of a research experiment, and ending with the communication of the result (Banchi and Bell, p. 27). Many instructors see inquiry laboratories as a way to allow students the freedom to experiment and even fail while trying to answer real-world problems (Shea, 2020). Of course, this means that the obvious disadvantage with this form of instruction is that it is much more time consuming that expository learning (Domin, 1999).

Some examples of guided inquiry found in the literature include student's experiments to determine a mechanistic pathway or stereoselectivity of a reaction, solve an unknown reaction, solve the structure of an unknown or unanticipated byproduct, and determine trends in scientific methodologies. Instructors can also choose to transform well known lab experiments (Bodner et al., 1998; Jarret et al., 1997; Jarret et al., 2001; Holden & Crouch, 2001; Cabay et al., 2001; Ciaccio et al., 2001; Wachter-Jurcsak et al., 2001; Adrian & Hull, 2001; Sgariglia et al., 2000; Krishnamurty et al., 2000; Bosch, 2000; Mohrig et al., 2003; Schoffstall et al., 2004). If the instructor chooses, they also have the freedom to develop their own expository laboratory experiments into discovery-based inquiry learning experiments.

One such example comes from Schoffstall and Gaddis (2007), who stated that science laboratories have around 1,500 specific goals, which can be broadly grouped into four succinct categories. Students should be able to a) improve conceptual understanding, b) develop scientific inquiry skills, c) develop technical skills, and d) develop motivational skills (2007). To this end, the researchers transformed existing expository labs on Aromatic Substitution and Catalytic Transfer Hydrogenation into a guided inquiry experience. The study showed that students developed an improved conceptual understanding and showed greater interest in the chemistry experiments (Schoffstall & Gaddis, 2007).

Inquiry based activities have been found to enforce higher order thinking processes made by the students, such as hypothesizing, explaining, analyzing, judging evidence, inventing, and evaluating (Raths et al., 1986). The proven success of inquiry-based learning in the organic chemistry laboratory combined with the lack of success using traditional, expository laboratory exercises only exacerbates the dire need for a shift in teaching methodology in the organic chemistry lab.

Chapter Summary

This chapter opened by discussing foundational instructional theories. The chapter then described the importance of student confidence and its relation to verbal and written scientific communication. The chapter closed with successful innovative teaching styles and how instructors are seeking to utilize unique laboratory styles in an effort to promote confidence, retention, and communication skills. Chapter 3 will describe the study's research methodology and methods.

Chapter 3: Research Methodology and Methods

Introduction

The purpose of this study was to differentiate the impact of the traditional, expository laboratory experiences and guided inquiry experiences on college students' perceptions of their knowledge and understanding, communication skills, and confidence levels related to organic chemistry. The two overarching questions guiding the study were:

1. How do expository laboratory experiences impact college students' perceptions of their knowledge and understanding, communication skills, and confidence levels related to organic chemistry?
2. How do guided inquiry laboratory experiences impact college students' perceptions of their knowledge and understanding, communication skills, and confidence levels related to organic chemistry?

This chapter describes the research methodologies and methods utilized in the study, including the study's research methodology, research context, data collection procedures, and data analysis procedures.

Research Methodology

Scholarship of Teaching and Learning

This study utilized a research methodology known as Scholarship of Teaching and Learning (SoTL). Ernest Boyer (1990) was credited with laying the groundwork for SoTL with publication of his book titled, *Scholarship Reconsidered*. Since then, many definitions of SoTL have arisen (Healey, 2003; Hutchings & Cambridge, 1999; Pan, 2009). For the purposes of this study, SoTL was defined using the definition provided by Hutchings and Cambridge (1999), who define SoTL as "problem posing about an issue of teaching or learning, study of the problem through methods appropriate to the disciplinary epistemologies, application of results to practice, communication of results, self-reflection, and peer review" (p. 7). It is worth noting that typical action research methodologies seek to investigate and improve teaching and learning in K-12 education (Kirk, 1986; McNiff, 2002; Tinning, 1992), whereas SoTL is typically used in post-secondary education. Because this study was conducted at the college level, SoTL was selected over action research as the study's primary research methodology.

Mixed Methods Research Design

This SoTL study used a mixed methods research design. Mixed methods is defined by the National Institutes of Health (NIH) as a research methodology that draws on the strengths of both qualitative and quantitative research (Kolessin, 2021). In an effort to further define mixed methods research, Chen's definition that "mixed methods research is a systematic integration of quantitative and qualitative methods in a single study for purposes of obtaining a fuller picture and deeper understanding of a phenomenon" (Chen, 2006, as cited in Johnson et al., p. 119, 2007) was used. Mixed methods research has the benefit of utilizing the strengths of both qualitative and quantitative methods by providing connections between data points that are not obvious using qualitative research or quantitative research independently (Creswell & Creswell, 2018). Ultimately, mixed methods research has the goal of gaining heightened levels of knowledge and validity. To this end, the design of a research methodology should be able to achieve multiple validities and legitimation (Johnson and Christensen, 2017; Onwuegbuzie and Johnson, 2006).

Convergent Triangulation Mixed Methods

Convergent triangulation mixed methods was the specific mixed methods approach used to collect and analyze data. *Convergent* triangulation mixed methods is a research design where quantitative and qualitative data are collected and analyzed and then compared to one another to determine whether or not the data collected confirms or contradicts other data (Creswell & Creswell, 2018). *Triangulation* is a research strategy that is used in mixed methods research to enhance the validity and credibility of one's research findings by correlating the data using multiple different research tools. Berg (2007) explains that researchers generally have a preference for a particular research method and each method provides a different axis directed towards the same reality or conclusions. By converging quantitative and qualitative methods and triangulating data collection, the researcher can obtain a richer, more complete picture (Berg, 2007).

Survey Research

Surveys have the advantage of allowing a researcher to question hundreds, if not thousands, of students (Bishop-Clark & Dietz-Uhler, 2003). Surveys are cost efficient and the data provided can be gathered across large distances, allowing a researcher to analyze different populations with ease (Creswell & Creswell, 2018). In SoTL research, questions in surveys generally fall into four distinct categories: open-ended, closed-ended, partially open-ended, and Likert scales (Jackson, 2008). A Likert scale is a rating scale which assesses opinions, attitudes, or behaviors in a way that can be quantitatively measured. In this study, qualitative and quantitative data were collected through a Likert scale pre- and post- survey. Most of the survey questions used in this study were reported and developed previously in a study performed by Galloway and Bretz (2015), where survey questions were used to measure student meaningful learning through the integration of cognitive, affective, and psychomotor domains into the chemistry laboratory.

Students participating in the study answered questions related to the pre-survey before taking part in their first semester organic chemistry laboratory course and answered the post-survey questions once the course was finished for the semester. Students then repeated this process for their second semester organic chemistry laboratory course. An open ended, soft skills survey, directly related to the students' experiences in the course was administered at the end of each laboratory course as well. Surveys have the advantage of allowing a researcher to question hundreds, if not thousands, of students (Bishop-Clark & Dietz-Uhler, 2012).

As one relevant example of survey research, Denton and colleagues (2000) studied whether problem-based learning changed graduate performance outcomes in a physical therapy program. Surveys were used to compare learning outcomes of a group who experienced a problem-based learning curriculum to a group whose members experienced the curriculum without problem-based learning (Denton et al., 2000). Student's perceptions of problem-based learning approaches were obtained through a 10-point Likert scale after the students had graduated from the program. The research comparing student perceptions of their learning outcomes utilizing a different learning curriculum through the use of a survey is similar to this research study.

It is worth noting that surveys have inherent disadvantages, such as the possibility of low response rate, instructor bias, and inaccurate answers due to a various number of factors. To lend more credibility to this study, student identities were concealed by anonymizing the data and having an instructor other than the researcher assign random numbers to each student and storing the identifiers in a locked cabinet. Also, to ensure students were reading the questions and being genuine with their responses, one of the survey questions told the students to select *"disagree* *slightly"* to allow the researcher to disregard that student's data if he/she did not select the correct response for that question.

Semi-Structured Interviews

This study also employed interviews as a means of data collection. Semi-structured interviews were conducted on a small, randomized sample of students to determine student perceptions of their laboratory experiences. Interviews are valuable as they allow the researcher to understand detailed perceptions of the research participants (Bishop-Clark & Dietz-Uhler, 2012). According to Kvale (1996), the primary goal of interviews is to understand the meaning of what the interviewees say. In SoTL research, this allows the instructor to better understand the students' perspectives in a different way than survey responses can provide.

There are many different forms of interviews, most notably, conversational, structured, and in-depth interviews. The benefit of semi-structured interviews is that they sit in between structured and conversational interviews, allowing the researcher to collect information in a detailed, but more flexible way (Bishop-Clark & Dietz-Uhler, 2012). As one example, Randall, Buschner, and Swerkes (1995) used interviews to better understand systemic differences amongst the various learning style preferences of physical education majors. The interviews were audiotaped and transcribed to identify common themes amongst the student answers to the interview questions. This allowed the researchers to use methods of comparison to place the data into categories.

One disadvantage of using interviews in research is that the interviewer must be careful not to slant a question in a way that may elicit a certain response. The researcher must also be able to accurately interpret interview responses and thus, one of the most important skills of a researcher conducting interviews is to be able to listen carefully (Bishop-Clark & Dietz-Uhler, 2012). In this study, semi-structured interviews were used in combination with the survey to help minimize these limitations.

Rubrics

Oral and written communication rubrics were used in this study to determine whether the students' perceptions of their communication skills matched with the curriculum aligned communication goals for sophomores in chemistry. Rubrics are the foundation of an instructor's scoring process; therefore, using rubrics effectively is of the utmost importance in accurately interpreting or assessing student performance (Janssen et al., 2015). Scoring rubrics help the instructor articulate the goals of a specific program or assignment. In short, rubrics help "explain terms and clarify expectations" (Crusan, 2010, p. 43) for both instructor and students. In both teaching and research, the principled use and choice of rubrics is critical to the process of gaining valuable information because the score is ultimately used to make decisions and inferences about a set of students, class, or curriculum (Weigle, 2011).

ELIPSS, an acronym for Enhancing Learning by Improving Process Skills in STEM has a website dedicated to providing excellent quality rubrics to educators in the fields of Science, Technology, Engineering, and Mathematics. The site offers many examples of analytical rubrics as well as feedback rubrics designed to gain access to student aptitude on a range of process skills, lists types of behaviors that each process skill embodies, and offers suggestions for improvement directly (ELIPSS, 2023). Overall, rubrics have a lot of use in a variety of educational contexts, such as research papers, group projects, portfolios, or presentations.

In the context of chemistry education, rubrics have a history of being used to improve student performance in many areas, such as experimental problem solving (Shadle et al., 2012; Towns et al., 2020), experimental skills in organic chemistry (Chen et al., 2013), critical thinking

(Oliver-Hoyo, 2003), and process skills (Cole et al., 2020; Cole et al., 2019; Reynders et al., 2019). In terms of implementation, using rubrics usually requires some sort of normalization to ensure consistency and validity in terms of the actual assessment of students. To ensure consistency in assessing the student performance for this study, multiple instructors scored each student's oral presentation, and the scores were compared to make sure that the rubric allowed for consistent, accurate ratings, even with multiple instructors having differing perspectives.

Research Context

Research Setting

The research for this SoTL study was performed at a university located in the Midwest region in the United States under the pseudonym Carbon University. The university is a primarily undergraduate-serving institution that has around 5,000 students comprised of many different backgrounds. The acceptance rate is around 75%, and around 30% of students are students of color. Forty-nine percent of the students at Carbon University are male while 51% are female. The Carbon University website also lists that 70% of its student population receives financial assistance of some sort.

The chemistry program at Carbon University typically has around 80 to 100 chemistry majors. The DFWI rates in General Chemistry vary from 15% to 50% based on the year. The students who make it through General Chemistry are placed into Organic Chemistry, which has a DFWI rate of around 18%. According to data collected over the past 13 years , 839 first semester organic chemistry students passed with a C or better, while 208 students received a failing grade, held incomplete status at the time final grades were submitted, or withdrew from the class before the end of the semester, resulting in a DFWI rate of around 20%. For the students who passed and moved on to the second semester organic chemistry course, the DFWI rate decreased, on average, to around 14%. One explanation for these DFWI rates is that the laboratories for these classes are closely linked to the classroom material. Therefore, a failure to grasp the content in the classroom typically results in a failure to grasp the content in the laboratory as well.

Researcher Positionality

Researcher positionality is defined as the “disclosure of how an author’s racial, gender, class, or other self-identifications, experiences, and privileges influence research methods” (Massoud, 2022). In terms of this research, the researcher performing the SoTL study was the instructor on record for all the organic chemistry laboratories. Therefore, the study must be carefully conducted to reduce possible instances of bias, whether in rubrics, observations, or data collection. One example of how the researcher tried to reduce bias and enhance the validity of the data and its theoretical contribution was to have five members of the faculty grade students with the same rubrics that the lead instructor graded from for both written and oral communication. Once this data was collected, it was pooled and statistical analyses were performed to determine that the instructors grading rubrics matched with the rest of the departments grading, confirming the validity and reliability of the rubrics as well as a high degree of inter-rater reliability. By doing this, the researcher sought to establish more credibility with regards to this study.

Participant Recruitment and Selection

Potential participants were selected using a convenience sampling method described by Creswell (2012). Notably, the 36 students asked to participate in this study were all students enrolled in my own organic chemistry laboratory. During the first week of class, beginning in the spring 2023 semester, I used laboratory time to explain the study to students, distribute informed consent forms, and invite them to participate in the study. Participation in the study was optional;

however, students were required to complete all required course material specifically related to the chemistry laboratory, even if they chose not to participate. The students were given the first week of class to consider taking part in the research. The informed consent forms were then collected and stored in a sealed folder by a faculty colleague until final course grades were posted at the end of the spring and fall semesters of 2023. After final grades were posted, the data from consenting students were analyzed.

The timeline for all of the procedures involved is listed in Table 3 below.

Table 3

Timeline for implementation of procedures and data collection

Timeline	Activity
January 2023; August 2023	Informed consent to participate in the study was gathered
January 2023; August 2023	CUR-TP Student Survey – Pre Survey was administered
April 2023; November 2023	Oral Presentations performed and oral communication rubrics were administered
April 2023; November 2023	Student written reports were gathered and written communication rubric was utilized
May 2023; December 2023	Soft skills survey and critical self-assessment were administered
May 2023; December 2023	CUR-TP Student Survey – Post Survey was administered
May 2023; December 2023	Soft Skills Assessment and Interviews were administered
January 2024 to August 2024	Data was analyzed
September 2024 to December 2025	A Final Research Report was written

Research Participants

In January 2023, 36 of the 44 students enrolled in the organic chemistry laboratory chose to participate in the study. All 36 students completed all the material required for the course and for the study and passed the course. Of the 36 students who participated in the first semester study, 33 chose to participate in the second semester portion of the research study, while the remaining 3 students did not have to take the lab as part of their major. The demographics of the

36 students who participated in the first semester of the study appeared as follows: 23 Caucasian students, 2 Black students, 4 Hispanic students, and 7 students who do not fit into these categories. The participants were composed of 15 male and 21 female students in the first semester laboratory. The demographics of the 33 students who participated during the second semester of the study appeared as follows: 22 Caucasian students, 2 Black students, 4 Hispanic students, and 5 students who do not fit into these categories. The second semester participants consisted of 14 males and 19 females. This is all summarized in Table 4 below.

Table 4

Participant Demographics

	Caucasian	Black	Hispanic	Other	Male	Female	n
First Semester Organic Lab	23	2	4	7	15	21	36
Second Semester Organic Lab	22	2	4	5	14	19	33

Data Collection

Data collection began by gaining informed consent from the student participants. At the beginning of the first semester, students were read a recruitment script that invited them to participate in a research project led by the instructor of the laboratory, which can be found in Appendix A. The students were then handed and Information and Consent form, which can be found in Appendix B and shows the informed consent form that students signed if they chose to participate in the study. The informed consent forms were collected by an independent faculty member and stored in their office until grades were submitted and data was ready to be analyzed. As a means of triangulation, quantitative pre- and post- survey results, a qualitative soft skills survey, semi-structured interviews, researcher observations, and oral and written communication rubrics were all used to collect data for the study, and the data were analyzed at the end of both first and second semester organic chemistry laboratory to determine if the qualitative and quantitative data established credible correlations.

Quantitative and qualitative data on student assessment of chemistry knowledge and skills were collected from the CUR-TP Student Survey at the beginning and the end of both first and second semester organic chemistry laboratory, respectively (see Appendix C). The pre/post surveys were collected for all students, but during the second semester, only the survey responses and other assignments of the 33 students who had given consent to participate in the study were collected and used in the research while the other 3 students did not have to take second semester organic chemistry lab. Other data collected included that of oral and written assessment rubrics during the capstone experiences at the end of the semester and results were compared to previous iterations of first and second semester organic chemistry lab to determine whether the new form of instruction is more or less effective than the previous form. Written laboratory reports were de-identified and used to provide examples of critical instruction that worked and examples of what did not work.

Semi-structured interviews were given to 10 select students at the end of each laboratory experience and transcribed to look for common themes. The formal questions given at the end of first semester organic chemistry laboratory were: (1) How did your laboratory experience in [first semester organic lab] impact your perceptions of your knowledge and understanding? And (2) How did your experience impact your communication skills and confidence? The questions given at the end of second semester chemistry lab were (1) How did your laboratory experience in [second semester organic lab] impact your perceptions of your knowledge and understanding? And (2) How did your experience impact your communication skills and confidence? It is worth noting that the course numbers were replaced with “first semester organic lab” or “second semester organic lab" to help ensure anonymity of the university. Once the two main questions were asked, students were then asked to share what they liked or did not like about each laboratory experience as well as anything else they would like to share. This was used in tandem with quantitative statistics to determine trends and correlations with each set of data and their relationship with the overarching research questions of this work.

My research observations were noted at the end of each week and verified by the teaching assistant in the lab. The researcher observations were analyzed at the end of each semester and used to help confirm or deny some of the quantitative research findings. For example, I would note things such as student confidence when working with glassware or when talking about chemical reactions.

Lastly, course evaluations were collected and used to determine whether or not there were any similarities or notable differences with respect to each laboratory experience. The benefit of the course evaluations was that students do not feel compelled to answer a certain way and therefore, can be perceived as genuine. If the genuine comments and feedback line up with the statistical and other qualitative data, then the established trends can be confirmed.

Instruments

Qualtrics

The pre- and post- survey information was collected from the students using Qualtrics – a software designed to allow a user to create surveys and generate reports that is commonly used in mixed methods research (Cruice et al., 2020). The survey itself used a Likert scale with the terms, *strongly disagree, disagree slightly, neutral, agree slightly,* or *strongly agree.* The survey answers provided were then given a numerical value (1 = strongly disagree to 5 = strongly agree) and used to help determine student perceptions of their knowledge and understanding, communication skills, and confidence levels related to organic chemistry laboratory in both first semester organic chemistry lab (taught in the traditional, expository style) and second semester organic chemistry lab (taught in the guided inquiry style). The statements in the pre-survey were worded slightly differently than the statements of the post-survey. For example, in the pre-survey, one of the statements was "In this chemistry laboratory, I expect to learn how to implement safe laboratory practices." The post- survey had a statement worded "In this chemistry laboratory, I learned how to implement safe laboratory practices." This made comparing the students' expectations before the semester versus their realities after the semester possible. In Appendices C and D, all of the pre-survey statements and post- survey statements are provided.

Student Soft Skills Reflection Survey

To provide students with an opportunity to reflect at the end of each semester on which soft skills they thought the laboratory experience helped them to develop, a soft skills survey was created and administered by the researcher. The survey was given to students at the start and end of each first and second semester organic chemistry lab, and used to determine what similarities and differences in student perceptions of their soft skill development there were between the expository laboratory experiences versus the guided inquiry experience. The soft skill assessment can be seen below in Table 5.

Table 5

Assessment of Critical Soft Skills

From this course, which soft skill(s) do you feel you gained experience in? Circle.

Communication	Teamwork	Time Management	Critical Thinking	Decision Making	Organization	Stress Management
Adaptability	Conflict Management	Leadership	Creativity	Resourcefulness	Persuasion	Openness to Criticism

Rubrics

Oral presentation and written report rubrics created by the Department of Chemistry at Carbon University were used in this study to determine whether the students' perceptions of their communication skills matched with the university's curriculum-aligned communication goals for sophomores in chemistry. The rubrics were carefully constructed so that they clearly communicated all expectations of the oral presentation and written report to the students. The students were given access to each rubric ahead of time and allowed to utilize the rubrics to complete their assignments. The oral presentations given by the students were scored by multiple members of the chemistry faculty using the oral presentation rubric found in Appendix E.

The scores were analyzed to determine consistency amongst assessment of the students by the researcher and other members of the chemistry department. The main categories assessing the students' oral communication skills were content, organization, visual aids, and presentation. Students are marked on a 0 to 5 scale in each subcategory. A score of 1 indicates the introductory, freshman level; a score of 3 indicates the reinforced, sophomore level; and a score of 5 indicates the proficiency level that seniors should achieve prior to graduation. The organic chemistry laboratory is a sophomore-level class, so students should have attained scores of mostly 2s and 3s if the laboratory experience was having the intended effect. Scores of 4 and 5 were possible, although they are rare and usually attained by students who started research their freshman year. Because there are 11 subcategories on the oral presentation rubric, a score of 33 signifies a student who meets all expectations in the oral presentation.

The written chemistry reports were graded and assessed by the written communication rubric found in Appendix F. The main categories assessing students' written communication skills were content and writing style. Similar to the oral presentations, students in the organic chemistry laboratory would meet the “reinforced” stage if the laboratory experience is having the intended effect on student learning. Because there are 8 subcategories, a score of 24 signifies students who meet all of the expectations in the written report. Again, it is possible for students to score higher than a 24, but this is typically rare at the sophomore level. It is worth noting that students were only graded by the researcher with the written report rubric and no other faculty because written reports in organic chemistry are typically harder to grade without an organic chemistry background.

Researcher Observations

Because the researcher for this study was also the laboratory instructor and shared a close proximity to the laboratory exercises, formats, and students, researcher observations allowed for firsthand information on the differences and similarities of the students when they undertook the expository laboratory experience the first semester versus the guided inquiry experience in their second semester. In SoTL research, observations are important because the researcher may notice things that are not quantifiable, such as a student’s body language, class participation, eye contact, or confidence when asking questions (Bishop-Clark & Dietz-Uhler, 2012).

In the case of the chemistry laboratory experiences, the instructor wrote down open-ended observations on student behavior every week and verified his observations with the teaching assistant for the lab. For example, if the instructor noticed a set of students getting frustrated about a chemistry procedure, it was written down and later verified with the teaching assistant. If the teaching assistant confirmed this, then the observation was verified and saved in a Microsoft Word document. These types of observations lead to valuable insight that may or may not be quantifiable, but the researcher maintained the importance of not changing the situation in any way so that the students would behave as they normally do. The observations made by the instructor were used to either verify or contradict student perceptions of their learning experiences, communication skills, and confidence levels related to each laboratory experience.

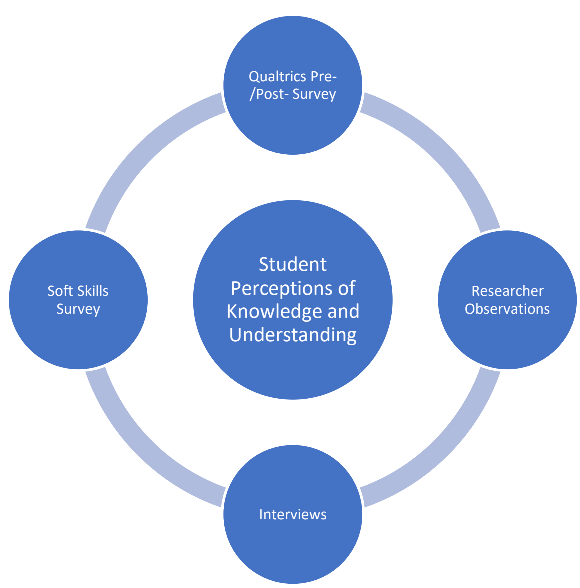
Triangulation of Research Instruments and Observations

In an attempt to address the overarching research questions of this study, the triangulation of qualitative and quantitative data was critical. The research questions only differed by the instructional style, so the same instruments and collection methods worked to address both research questions.

Student perceptions of knowledge and understanding for each laboratory experience were addressed through data analysis of the Qualtrics pre-/post-survey triangulated with data from the soft skills survey, researcher observations, and the semi-structured interviews as shown below in Figure 1.

Figure 1

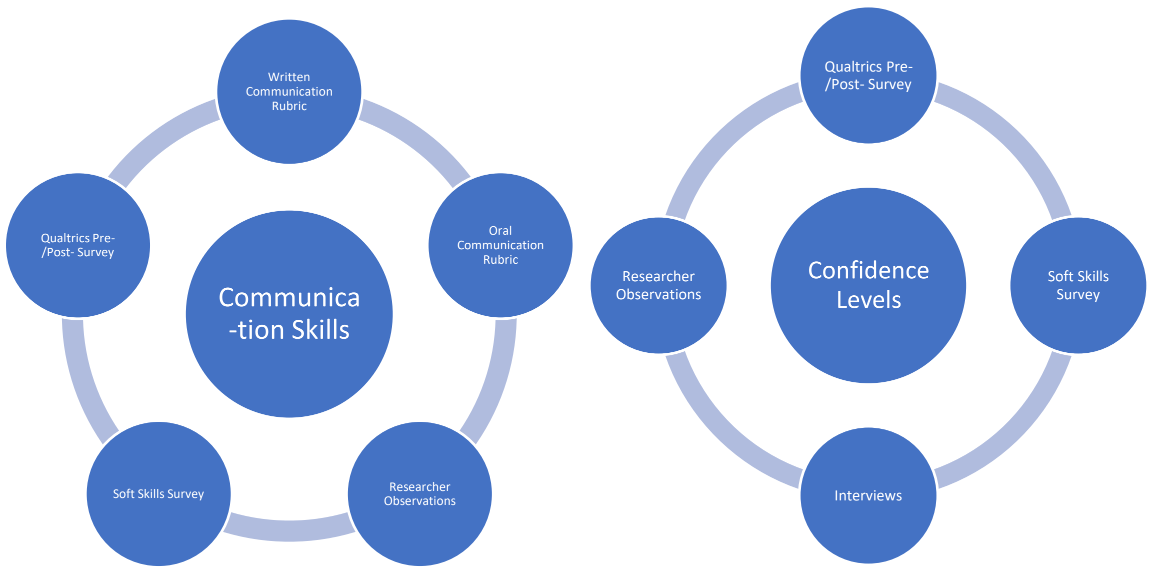
Triangulation of student perceptions of knowledge and understanding with research tools



Written communication rubrics, oral communication rubrics, observations, soft skills survey, and the pre-/post- survey were all used to support student communication skills through each laboratory experience (Figure 2).

Figure 2

Triangulation of student perceptions of communication skills and confidence levels with research tools



Lastly, Figure 2 also shows the triangulation of student confidence levels with the pre-/post- survey, soft skills survey, interviews, and researcher observations. Therefore, all of the datasets and methods sought to address the research questions and each aspect of the research question is addressed with at least four different research tools or methods.

Data Analysis

This study utilized a convergent mixed methods design in which qualitative and quantitative data were collected in parallel as described by Fetters and colleagues (2013). The quantitative data were statistically analyzed through means and paired *t*-tests. The qualitative data were analyzed, coded, and used to determine similarities and differences in student perceptions as they relate to both the first and second semester organic laboratory experiences. A mixed methods analysis of both the quantitative and qualitative data sets was then utilized to give a side-by-side comparison of the findings to yield stronger, more robust correlations and conclusions with respect to the data. This approach follows closely with Creswell and Creswell's (2018) explanation that convergent mixed methods data analysis occurs when quantitative statistical results are established and then the qualitative findings are discussed and used to either confirm or disconfirm the statistical results.

Analysis of the data from the pre-/post- survey, the soft skills survey, student interviews, and researcher observations were used to determine if there was a statistically significant difference in student perceptions of their knowledge and understanding with respect to each different laboratory experience. The data from the pre-/post- survey, the soft skills survey, student interviews, researcher observations, and written and oral communication rubrics were used to determine whether or not there was a significant difference in the development of communication skills with respect to each laboratory experience. Lastly, data from the pre-/post- survey, the soft skills survey, student interviews, and researcher observations were used to determine if there was a significant difference in student confidence during each laboratory experience.

Quantitative Analysis

Some of the questions from the pre-/post- survey were chosen to be neglected for the purposes of this research due to them being curriculum specific, not emphasized in either laboratory experience, or taught in different parts of the curriculum. For full transparency, each question will still be provided in the appendix. The prompts chosen to be neglected for this study were coded as C, AB, AC, AF, and AI. Below is an abbreviated table showing 5 of the pre-/post-survey prompts. The full table can be found in Appendix G

Table 6

Pre- and Post- Survey Prompts

In this chemistry laboratory course, I expect...		In this chemistry laboratory course, I…
A	to learn how to implement safe laboratory practices	learned how to implement safe laboratory practices
B	to collaborate effectively with classmates to solve problems	collaborated effectively with classmates to solve problems
C	to recognize the importance of finding ways to reduce waste, conserve energy, and discover replacements for hazardous substances	recognized the importance of finding ways to reduce waste, conserve energy, and discover replacements for hazardous substances
D	to effectively present the details of my lab work in writing	effectively presented the details of my lab work in writing
E	to make mistakes and try again.	made mistakes and tried again.

Each student response was then transferred to Microsoft Excel and converted to a Likert scale as described previously. The data for each question was analyzed individually for each semester by using paired *t*-tests to determine the statistical significance of the students' expectations versus realities with regards to each prompt. Paired *t*-tests were used to determine whether the mean difference between two related sets of observations is zero (Oh & Pyrzak, 2018). A paired *t*-test gives a mean (the average), variance (the spread), standard deviation (variability), and a p-value (probability level). In general, a probability of less than 0.05 means that there can be confidence that the result is unlikely to have occurred by chance.

A reflective assessment of critical soft skills was also given at the end of both semesters to each student to identify which soft skill(s) each student felt was/were developed through each laboratory experience. These data were analyzed side-by-side and analyzed through paired *t*-tests as well to determine if there was a difference between the soft skills developed through each laboratory experience.

Lastly, quantitative data in the form of oral presentation and written communication rubrics was attained and analyzed to determine whether the students' communication skills were improving and reaching a "reinforced" level of a sophomore in chemistry as a result of the guided inquiry laboratory experience. This data was analyzed by giving students a raw score in each subcategory specific to each rubric, found in Appendix E and F. To increase the validity and robustness of the rubric, the oral and written presentations were graded by three different professors and the scores in each section were compared to determine whether there was any significant difference in grading. After it was determined that all three professors graded similarly, the rubric scores were averaged and used to determine whether students were meeting the level appropriate for a sophomore organic chemistry laboratory. The results were transferred to an Excel spreadsheet, anonymized, and used to determine if there was a statistical significance in the grade given by each instructor. Once validity was established, each student score was established by taking an average score from each professor grading the presentation and analyzed to determine the percentage of students who were meeting the reinforcement level with respect to communication. The rubrics used were established by the department of chemistry at Carbon University and are the exact same rubrics used for every chemistry laboratory offered. The quantitative scores were recorded to determine the degree to which students were meeting their expectations with respect to communication skills as well as the department's expectations.

Qualitative Analysis

There are several steps to take when attempting to analyze qualitative data, such as getting to know your data, staying mindful of the research question, looking for categories or themes, examining the data for patterns and connections between themes, and interpreting and explaining the data (Taylor-Powell & Renner, 2003). For this research, qualitative data in the form of semi-structured interviews, researcher observations, and student evaluations were attained each semester to support the quantitative data underpinning each research question.

The semi-structured interviews were transcribed and used to look for themes or trends in the student responses by identifying key words or phrases that appeared multiple times throughout each interview. These themes were then cross-referenced with researcher observations and student evaluations at the end of the semester to triangulate the data and confirm or reject the common themes. By combining and comparing quantitative, statistical analysis with the qualitative data, additional insight was gained beyond that of just using qualitative or qualitative methods on their own. As discussed by Creswell, running both in parallel was able to minimize the limitations of each (2018). This research study benefitted from detailed, contextual insights from the qualitative data as well as generalizable insights provided by the quantitative data. By using both methods in tandem, a more complete picture and interpretation of the research was able to be drawn allowing for more valid conclusions.

Chapter Summary

This chapter described the research methodologies and methods utilized in the study, including the study's research methodology, research context, data collection procedures, and data analysis procedures. Chapter 4 will report and discuss the study's findings in an effort to answer the two overarching research questions for this study.

Chapter 4: Data Analysis and Results

Introduction

The purpose of this mixed methods action research study was to differentiate the impact of the traditional, expository laboratory experiences and guided inquiry experiences on college students' perceptions of their knowledge and understanding, communication skills, and confidence levels related to organic chemistry. This chapter reports the results and analysis of the study using pre-/post- survey data, a soft skills reflection survey, written and oral communication rubrics, student interviews, and researcher observations. The chapter details the results of the analysis in three different sections: student perceptions of their knowledge and understanding, student communication skills, and student confidence. For each section, the quantitative and qualitative results for the expository organic chemistry laboratory experience will be presented first, followed by the quantitative and qualitative results for the guided inquiry laboratory experience. Then, a combined summary of qualitative and quantitative findings comparing both laboratory experiences was used to triangulate the data to offer a comprehensive overview of the results.

Research Questions

The two overarching questions guiding this research study were as follows:

1. How do expository laboratory experiences impact college students' perceptions of their knowledge and understanding, communication skills, and confidence levels related to organic chemistry?
2. How do guided inquiry laboratory experiences impact college students' perceptions of their knowledge and understanding, communication skills, and confidence levels related to organic chemistry?

The study examined the following hypothesis:

H_o: There will be no significant difference in pre-/post survey data, reflection data, written and oral report scores, student interviews, and researcher observations between student perceptions of their knowledge and understanding, communication skills, and confidence levels related to organic chemistry during the expository laboratory experiences versus the guided inquiry laboratory experiences. The null hypothesis, by definition, suggests minimal to no difference between two variables (Pearson, 2010). All of the data collected were used to either confirm or deny this hypothesis.

Student Perceptions of their Knowledge and Understanding

Quantitative Results for Expository Laboratory Experience

The pre-/post- survey consisted of 35 questions formatted using a Likert scale that relate to different areas of student growth and learning. The questions were grouped into three broad categories: soft skills, communication skills, and scientific skills. The survey questions that were used to determine student knowledge and understanding were A, I, M, N, O, T, W, AA, AD, AE, AH, and AJ. The full prompts are given in Table 7.

Table 7

Pre- and Post- Survey Prompts Related to Perceptions of Knowledge and Understanding

	In this chemistry laboratory course, I expect...	In this chemistry laboratory course, I…
A	to learn how to implement safe laboratory practices	learned how to implement safe laboratory practices
I	to consider whether my data make sense	considered whether my data made sense
M	to read and understand the primary literature	read and understood the primary literature
N	to learn critical thinking skills	learned critical thinking skills
O	to identify and use primary literature to interpret and solve scientific problems	identified and used primary literature to interpret and solve scientific problems
T	to use my observations to understand behavior of atoms and molecules	used my observations to understand behavior of atoms and molecules
W	to use chemical concepts I know from other courses	used chemical concepts I know from other courses
AA	to record details of my work thoroughly, accurately, and in an organized fashion	recorded the details of my work thoroughly, accurately, and in an organized fashion
AD	to interpret my data beyond only doing calculations	interpreted my data beyond only doing calculations
AE	to learn problem solving skills	learned problem solving skills
AH	to make some decisions about how to carry out experiments	made some decisions about how to carry out experiments
AJ	to think about what the molecules are doing	thought about what the molecules are doing

The mean, standard deviation, t-score, and *p* value related to each prompt was determined using a paired, two tailed t-test. Mean scores closer to 5 show strong agreement while mean scores closer to 1 would show strong disagreement. The full results of the quantitative analysis ordered from most significant to least significant using the pre-/post- survey is given in Table 8. For Table 8 and all future tables related to the pre-/post- surveys, positive trends will be highlighted in green whilst negative trends will be highlighted in red.

Table 8

Statistical Analysis of Student Perceptions of their Knowledge and Understanding with the Expository Laboratory Experience

Survey Prompt	Pre Expository Experience		Post Expository Experience			
	M	*SD*	*M*	*SD*	*t(35)*	*P*
AA	**4.69**	**0.67**	**4.14**	**0.76**	**3.08**	**<0.01**
AJ	**4.39**	**0.69**	**3.89**	**1.01**	**2.71**	**0.01**
O	**4.33**	**0.72**	**3.86**	**0.93**	**2.35**	**0.02**
A	4.86	0.35	4.58	0.10	1.71	0.10
AE	4.72	0.51	4.50	0.74	1.60	0.12
N	4.64	0.54	4.39	0.73	1.55	0.13
M	4.33	0.76	4.05	1.06	1.50	0.14
T	4.44	0.61	4.19	0.92	1.36	0.18
AD	4.47	0.74	4.61	0.69	-1.04	0.30
I	4.69	0.67	4.58	0.55	0.85	0.40
AH	4.11	0.85	4.03	0.84	0.40	0.69
W	4.61	0.73	4.58	0.81	0.16	0.88

Note: Negative trends are highlighted in RED while positive results are highlighted in GREEN.
**For this data set, there was an absence of positive trends.*

The results from the paired t-test of the student responses from the pre-/post- course survey show that there was an overall negative trend with respect to student perceptions of their knowledge and understanding in the organic chemistry laboratory when performed in an expository, traditional style. There was a statistically significant difference in students' perceptions of their ability to record details of their work thoroughly, accurately, and in an organized fashion before the semester (M = 4.69, SD = 0.67) compared to when they finished the semester (M = 4.14, SD = 0.76; t(35) = 3.08, p = <0.01). This result is interesting as it shows that even though students agreed that the lab helped them record details of their work thoroughly, accurately, and in an organized fashion, the reality was that the lab did not meet their high expectations.

There was also a statistically significant difference in students' perceptions of their ability to think about what the molecules were doing during experiments before the semester (M = 4.39, SD = 0.69) compared to when they finished the semester (M = 3.89, SD = 1.01); t(35) = 2.71, p = 0.01). This result shows that even though the students agreed with the statement, they were not in strong agreement that they thought about what the molecules were actually doing during each lab. Lastly, there was a significant difference in whether or not the students thought that they were able to identify and use scientific literature to interpret and solve scientific problems before the laboratory experience (M = 4.33, SD = 0.72) compared to when they finished the semester (M = 3.86, SD = 0.93; t(35) = 2.35, p = 0.02). Once again, this shows that the students' realities regarding the laboratory experience did not meet their expectations. To summarize, for this analysis, there was no statistically significant difference in students' perceptions of their knowledge and understanding with respect to any of the other survey prompts, although on average, the means tended to be lower on the post-laboratory survey, except for prompt AD.

Qualitative Results for Expository Laboratory Experience

Semi-structured interviews of eight students were recorded, transcribed, and used to look for trends in student responses as they related to perceptions of their knowledge and understanding of organic chemistry. Table 9 shows the themes for the common student responses when asked about the pros and cons of the first semester organic chemistry laboratory experience.

Table 9

Interview Response Trends for Pros and Cons of Expository Laboratory Experience

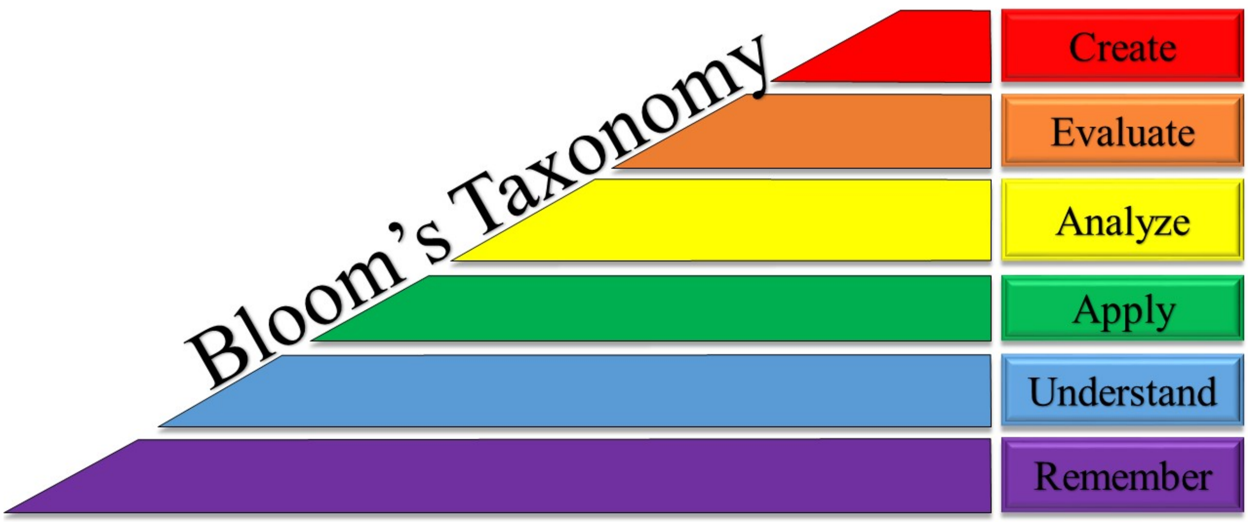
Pros	Cons
Structured	Overwhelming
Ability to get "correct" data	Experiments lack variety
New material each week	Time consuming
Clear direction	Not enough practice on each technique
Reactions are supposed to work	One mistake ruins experiment
Told what to do	Too scripted

Common responses for positive aspects of the expository laboratory experience were that students liked that the lab was structured and that they could attain the "correct" data. Many students enjoyed the clear direction and that reactions were supposed to work. When asked what they liked about the first semester laboratory, one student commented that they "liked the structure, being able to follow the rules, and being told what to do." In fact, amongst the students who preferred the expository style, many of them made similar remarks. As for the negative aspects of the expository lab, students found it to be a bit overwhelming with a lot of new techniques to learn every week. Many found the lab "time consuming" and some were stressed and felt as if "one mistake would ruin the whole experiment." As a consequence to the way traditional laboratories are set up, if a student makes a mistake, oftentimes they are not able to make up for it as they are typically onto a new experiment the next week.

When considering student learning, Bloom's Taxonomy is often taken into account. According to Arizona State University's Website, Bloom's Taxonomy is a hierarchical ordering of skills from low to high that details effective cognitive learning in students, starting from “remembering” and ending with “creating” (2018). Bloom’s Taxonomy is often depicted as a pyramid, with the easily attained cognitive skills located towards the bottom, as shown in Figure 3.

Figure 3

Bloom’s Taxonomy



In analyzing the common pros and cons associated with the expository laboratory experiences and thinking of the student responses with respect to this Bloom’s Taxonomy, expository laboratory experiences are often quite pre-determined, requiring only the first few levels, remembering and understanding. For example, in one expository lab, students were asked to duplicate an experimental setup, run the experiment, identify sources of error, and maybe calculate reaction yields. The students never had to perform the higher cognitive functions of the taxonomy, such as examining the reactions in depth, evaluating or testing their own hypotheses, or creating their own reaction conditions.

The results of the interviews and researcher observations show that the reason students had a particular proclivity for the expository experience stems from the fact that they like, and are used to, being told what to do and having reactions that are supposed to work in the lab. Students who made mistakes in this first semester sequence said that they were often "discouraged" and "quite frustrated" when they attained results that went against their own expectations, (i.e., "the reaction did not work as intended.")

Quantitative Results for Guided Inquiry Laboratory Experience

The pre-/post-test survey analysis was done on the same set of students for the guided inquiry laboratory experience using the exact same questions/prompts. The statistical analysis for students' perceptions of their knowledge and understanding is provided in Table 10 and ranges from most significant to least significant.

Table 10

Statistical Analysis of Student Perceptions of their Knowledge and Understanding with the Guided Inquiry Laboratory Experience

Survey Prompt	Pre Guided Inquiry Experience		Post Guided Inquiry Experience			
	M	*SD*	*M*	*SD*	*t(32)*	*p*
T	**4.42**	**0.71**	**3.79**	**1.08**	**5.60**	**<0.001**
AA	**4.48**	**0.90**	**4.21**	**0.85**	**3.03**	**0.004**
O	**3.88**	**1.11**	**4.09**	**0.98**	**-2.93**	**0.006**
AE	**4.56**	**0.56**	**4.76**	**0.43**	**-2.67**	**0.01**
I	**4.54**	**0.62**	**4.73**	**45**	**-2.67**	**0.01**
AH	**4.52**	**0.75**	**4.70**	**0.53**	**-2.67**	**0.01**
AD	**4.58**	**0.71**	**4.76**	**0.43**	**-2.25**	**0.03**
A	4.91	0.29	4.82	0.39	1.79	0.08
N	4.54	0.62	4.61	0.50	-1.44	0.16
AJ	4.21	1.08	4.09	0.98	1.28	0.21
W	4.73	0.62	4.79	0.41	-1.00	0.32,
M	4.06	0.90	4.03	0.88	0.57	0.57

Note: Negative trends are highlighted in RED while positive trends are highlighted in GREEN.

The results from the paired t-test of the student responses from the pre-/post- course survey show that there were two areas that did not meet students' expectation and five areas that exceeded students' expectations with respect to student perceptions of their knowledge and understanding in the organic chemistry laboratory when performed in the style of guided inquiry. There was a statistically significant difference in students' perceptions of their ability to use observations to understand the behavior of molecules from the pre-survey (M = 4.42, SD = 0.71) compared to the post-survey (M = 3.79, SD = 1.08; t(32) = 5.60, $p < 0.001$). This result shows that even though students typically agreed that they could use their observations to understand molecular behavior, they still did not meet their expectations in this area. There was also a negative statistically significant difference in which students' pre-survey scores regarding keeping record of their work thoroughly, accurately, and in an organized fashion (M = 4.48, SD = 0.90) did not meet their expectations, as shown by the post-survey scores (M = 4.21, SD = 0.85; t(32) = 3.03, p = 0.004).

In contrast to the expository teaching style, students had five areas that exceeded their expectations with respect to their knowledge and understanding. There was a statistically significant difference in students' ability to identify and use primary literature to solve problems before the guided inquiry experience (M = 3.88, SD = 1.11) compared to after the guided inquiry experience (M = 4.09, SD = 0.98; t(32) = -2.93, p = 0.006). A positive statistical significance was also observed in students' perceptions of their knowledge and understanding with respect to problem solving, consideration of data, making decisions to carry out experiments, and data interpretation. There was no statistically significant difference displayed in any of the other sets of survey questions/prompts regarding knowledge and understanding.

Qualitative Results for Guided Inquiry Laboratory Experience

Semi-structured interviews of the same eight students from first semester organic chemistry lab were recorded, transcribed, and used to look for trends in student responses as they related to perceptions of their knowledge and understanding, this time focused on the guided inquiry methodology. Table 11 shows the themes for the common student responses when asked about the pros and cons of the second semester organic chemistry laboratory experience.

Table 11

Interview Response Trends for Pros and Cons of Guided Inquiry Laboratory Experience

Pros	Cons
More Freedom	Lost in Planning
More Independence	No Obvious Structure
More Decision-Making	Time Management Difficult
Confidence and Problem Solving Skills	Not as Many Different Labs
Felt Comfortable Making Mistakes	Easy to Make Mistakes
Builds Communication Skills	Requires Classroom Knowledge

Student responses yielded a few trends and themes for both pros and cons for the guided inquiry laboratory experience. There were many reasons students tended to respond well to this type of instruction, amongst them were that it offered more freedom, independence, decision-making, and room for mistakes. While students tended to agree that it was easier to make mistakes with this kind of instruction, they also agreed that they were much more comfortable doing so. Some common themes in negative responses were that time management was essential, there was not as much structure, and some students got lost trying to plan out their experiments.

Overall, when thinking back to Bloom's Taxonomy, decision-making and problem solving skills are amongst the higher levels of the cognitive pyramid. This guided inquiry instruction pressed the students to develop a hypothesis and test it by designing experiments, evaluating results, assessing whether or not their results made sense, and communicating their results to an audience of their peers. One student explained that they liked the second semester more because it "allowed me to think rather than just blindly following the instructions" and another explained that they "really got to understand what you were doing and why. Plus, you [were able to] design the experiments." Other trends in responses related to ownership of the independent projects and self-efficacy, such as responses that included the following statements "…allowed me to think," "…was able to improve," "…got to understand," "…made me apply," and "…analyze and make our own." The student responses during the guided inquiry experience seemed much more introspective than the responses from the expository sequence.

Integrated Analysis of Instructional Styles on Knowledge and Understanding

When comparing the quantitative findings at the end of each laboratory experience with respect to students' perceptions of their knowledge and understanding, a trend was elucidated that showed a positive overall change when going from the expository style to the guided inquiry style. Table 12 shows a statistical difference of means comparing average values post-expository style with average values post- guided inquiry style. The results are displayed starting from the most significant difference to the least.

Table 12

Statistical Analysis of Student Perceptions of their Knowledge and Understanding Post Expository vs. Post Guided Inquiry Laboratory Experience

Survey Prompt	Post Expository Experience	Post Guided Inquiry Experience	Difference of Means
	M	*M*	$\lvert M_{Exp} - M_{GI} \rvert$
T	4.42	3.79	0.63
AH	4.03	4.70	0.63
AE	4.50	4.76	0.26
A	4.58	4.82	0.24
O	3.86	4.09	0.23
N	4.39	4.61	0.22
W	4.58	4.79	0.21
AJ	3.89	4.09	0.20
AD	4.61	4.76	0.15
I	4.58	4.73	0.15
AA	4.14	4.21	0.07
M	4.05	4.03	0.02

One positive finding in support of the expository teaching style is that students believed that they used observations to understand the behavior of the molecules more when a different lab was conducted each week, with step-by-step instructions given, rather than when students worked on one major project in the guided inquiry style. This could be due to their inability to confidently think and apply their chemistry at the sophomore level on their own, as is required through a guided inquiry approach.

When analyzing the remaining data in Table 12, the means were shown to increase overall in the guided inquiry format. Most notably, the students believed that they were able to make more decisions about how to carry out the experiments during the guided inquiry experience. Students also believed that they learned more problem-solving skills, implemented safe laboratory practices, used primary literature, learned critical thinking skills, used concepts from other courses, and thought about what the molecules were doing more than when they performed labs using the expository approach.

The data from the semi-structured interviews seems to confirm these findings. One student explained that the guided inquiry format “really allowed [me] to understand what experiment we need to run and why the experiment was important.” Another student explained that the reason they liked the second semester organic chemistry laboratory better was because they were able to “build on concepts that [I] learned in general chemistry and first semester organic chemistry and really understand certain reactions worked while others did not.” Table 8 shows that there were no significant positive changes with respect to the expository experience while it does indicate negative trends for three responses. In contrast, Table 10 shows that there were five positive changes and only two negative trends discovered in students’ answers to the survey prompts during the guided inquiry experience.

The qualitative findings of this study revealed that the reasons a student preferred one instructional style over another varied drastically. Many students who preferred the expository laboratory style commented that they “liked how structured the lab” was and that they were able to attain the “correct” answer while the students who preferred the guided inquiry style enjoyed the “freedom” and “independence” associated with the lab, as well as their ability to “develop critical thinking and problem solving skills.” While there are merits for each instructional style, it is important to teach students that some reactions are not meant to work and that it is okay to make mistakes and learn from them, which is something that the qualitative findings showed students do not learn in the expository instructional style.

Student Perceptions of their Communication Skills

Quantitative Results for Expository Laboratory Experience

The quantitative results for student perceptions of their communication skills during the expository laboratory instruction were determined using the pre-/post- survey as well as a written communication rubric. The survey questions that were used to determine student communication skills were B, D, J, and K. The full prompts are given in Table 13.

Table 13

Pre- and Post- Survey Prompts Related to Perceptions of Communication Skills

	In this chemistry laboratory course, I expect...	In this chemistry laboratory course, I…
B	to collaborate effectively with classmates to solve problems	collaborated effectively with classmates to solve problems
D	to effectively present the details of my lab work in writing	effectively presented the details of my lab work in writing
J	to effectively present the details of my lab work orally	effectively presented the details of my lab work orally
K	to communicate effectively with my classmates about the methods, data, etc.	communicated effectively with my classmates about the methods, data, etc.

The mean, standard deviation, t-score, and *p* value related to each prompt was determined using a paired, two tailed t-test as shown previously. Once again, mean scores closer to 5 show strong agreement while mean scores closer to 1 show strong disagreement. The full results of the quantitative analysis for the expository learning style ordered from most significant to least significant using the pre-/post- survey is given in Table 14.

Table 14

Statistical Analysis of Student Perceptions of their Communication Skills with the Expository Laboratory Experience

Survey Prompt	Pre Expository Experience		Post Expository Experience			
	M	*SD*	*M*	*SD*	*t(35)*	*p*
J	**4.28**	**0.81**	**2.75**	**1.25**	**6.35**	**<0.001**
B	4.72	0.51	4.64	1.05	0.39	0.66
D	4.61	0.87	4.53	0.77	0.41	0.69
K	4.64	0.54	4.67	0.48	-0.25	0.80

Note: Negative trends are highlighted in RED while positive results are highlighted in GREEN.
**For this data set, there was an absence of positive trends.*

The results from the paired t-test of the student responses from the pre-/post- course survey questions showed that there was a statistically significant difference in students' perceptions of their ability to effectively present the details of their lab work orally before the semester (M = 4.28, SD = 0.81) compared to when they finished the semester (M = 2.75, SD = 1.25; t(35) = 6.35, *p* = <0.001). This drastic difference in students' expectations on oral presentations going into the semester versus finishing the semester is due to the fact that the laboratory taught in the expository style does not contain a formal oral presentation at the end of the semester. The students were still required to discuss the details of their work verbally to other students throughout the semester, but this proved to be ineffective at meeting their expectations, likely because they did not want to explain things to their classmates incorrectly and were not confident with their own interpretations of their lab work. The results of the paired *t*-tests showed no significant difference between students' perceptions of their communication skills regarding collaboration, communication, and their ability to present the details of their work in writing.

The students' final written laboratory reports were graded using the rubric provided in Appendix F. All of the grades for each section of the rubric were totaled and an average and standard deviation was used to determine whether or not the students were communicating at a level appropriate for sophomore organic chemistry. The rubric was scored from 0 to 5, with a value of 1 corresponding to where students in a freshman laboratory should score, 3 corresponding to where sophomore students should score, and 5 being a senior level written laboratory report.

Table 15

Average Rubric Scores for Final Written Laboratory Reports (Expository)

Section	*Mean*	*SD*
Introduction	2.41	0.61
Methods	2.85	0.55
Illustrations	2.42	0.77
Results/Conclusions	2.71	0.41
References	2.92	0.33
Mechanics	2.67	0.61
Content/Style	2.54	0.81

Overall, the average score for each category showed that the students' writing skills were approaching a level that is acceptable for the sophomore organic chemistry lab. The rubric scores showed that the students tended to score highest in the methods and references sections of the reports while they scored the lowest in illustrations and the introduction. For many of the students, it was their first time writing an introduction that utilizes outside sources to support the purpose of the lab.

Qualitative Results for Expository Laboratory Experience

Semi-structured interviews of the eight students were recorded, transcribed, and used to look for trends in student responses as they related to perceptions of their communication skills. Most commonly, students explained that they were happy with how the laboratory “allowed them to communicate the lab work with their peers” and “see whether [we] attained similar results to our peers.” Students also felt like they were able to get better at asking questions. Two of the eight students did not mention communication at all in their responses while one student felt as if the expository style “did not aid in building communication skills at all.” When probed as to why this may be, the student explained that they felt as if their partner did not communicate with them enough and failed to do much of the work required.

During the interviews, three students from different groups expressed similar sentiments that they felt their written work could have been “better planned out” if they had managed their time a little better or had more effective communication between them and their partner. Over the course of the semester, it was emphasized by the instructor that communication between partners and time management is key in scientific writing, this result shows that this sentiment was either not taken seriously or that students underestimated the challenges associated with scientific communication.

Quantitative Results for Guided Inquiry Laboratory Experience

The pre-/post-test survey analysis was done on the same set of students for the guided inquiry laboratory experience as well using the exact same questions/prompts. The statistical analysis for students’ perceptions of their knowledge and understanding is given in Table 16 and ranges from most significant to least significant.

Table 16

Statistical Analysis of Student Perceptions of their Communication Skills with the Guided inquiry Laboratory Experience

Survey Prompt	Pre Guided Inquiry Experience		Post Guided Inquiry Experience			
	M	*SD*	*M*	*SD*	*t(32)*	*p*
D	**4.76**	**0.50**	**4.88**	**0.33**	**-2.10**	**0.04**
B	4.75	0.43	4.79	0.41	-1.00	0.32
J	4.48	0.62	4.51	0.62	-1.00	0.32
K	4.64	0.55	4.64	0.55	N/A	1.00

*Note: Negative trends are highlighted in RED while positive results are highlighted in GREEN. *For this data set, there was an absence of negative trends.*

The results from the paired *t*-test of the student responses from the pre-/post- course survey questions showed that there was a positive statistically significant difference in students' perceptions of their ability to effectively present the details of their lab work in writing before the semester (M = 4.76, SD = 0.50) compared to when they finished the semester (M = 4.88, SD = 0.33; t(32) = -2.10, *p* = 0.04). This result shows that the students exceeded their expectations with respect to their ability to communicate their work in written format. There was no significant difference in their perceptions of their own abilities to communicate with classmates to solve problems, present details of their work orally, or communicate effectively with classmates about the methods, data, etc. The students not exceeding their expectations in either prompts B or K makes logical sense because of how close in nature those two prompts are. Interestingly, the students felt as though the met their expectations regarding the oral presentation of their scientific findings in the guided inquiry format, whereas they did not in the expository format. This most likely is due to the presence of an oral presentation in second semester laboratory.

For direct comparison, students' final written laboratory reports were graded using the rubric provided in Appendix F, which is the same rubric used during the expository, first semester organic laboratory. All of the grades for each section of the rubric were totaled and an average and standard deviation was used to determine whether or not the students were communicating at a level appropriate for sophomore organic chemistry. Once again, the rubric was scored from 0 to 5, with a value of 1 corresponding to where students in a freshman laboratory should score, 3 corresponding to where sophomore students should score, and 5 being a senior level written laboratory report.

Table 17

Average Rubric Scores for Final Written Laboratory Reports (Guided Inquiry)

Section	*Mean*	*SD*
Introduction	2.63	0.73
Methods	2.91	0.42
Illustrations	2.70	0.81
Results/Conclusions	2.87	0.48
References	2.95	0.21
Mechanics	2.78	0.55
Content/Style	2.63	0.73

Students in the second semester, guided inquiry laboratory scored higher on average in each category. Of course, some of that must be due to the students simply having more experience in scientific writing, therefore the nature of the significance of each change is difficult to determine. Students once again scored highest in methods and references. The scores for illustrations, results/conclusions, and the introduction provided the areas with the most improvement, which once again, could be due to the students gaining more experience in their scientific writing.

In contrast to the expository, first semester sequence, the second semester guided inquiry laboratory had a formal, oral presentation that was due at the end of the semester. Each oral presentation was graded using the rubric found in Appendix E. Like the written rubric, each section was scored from 0 to 5, with a value of 1 corresponding to where students in a freshman laboratory should score, 3 corresponding to where sophomore students should score, and 5 being a senior level written laboratory report.

Table 18

Average Rubric Scores for Final Oral Presentations

Section	*Mean*	*SD*
Presented at Level Appropriate for Audience	2.81	0.73
Significance	2.81	0.80
Methods	2.68	0.81
Illustrations	2.72	0.90
References	2.15	1.37
Delivery	2.60	0.89
Data Explanation	2.60	0.94
Results/Conclusions	2.40	0.94
Sequence of Ideas	2.69	0.82
Relationship b/t Data and Questions	2.38	0.94
Slide Design	2.76	0.95

For many of the students, it was their first time giving an oral presentation that was scientific in nature. Overall, students scored the highest in the sections involving presenting at a level that is appropriate and in describing the significance of their work. The score was lowest on average in the section for references because for many, it was their first time citing references in a format that does not include a list of works cited, but rather including full citation on the slide that contains the data being referenced. Overall, it appears that in most categories, students are meeting the expectations consistent with a sophomore organic chemistry laboratory where they are reinforcing prior knowledge and skills gained from general chemistry. Future studies in determining whether or not implementing an oral presentation in the first semester, expository lab would have a positive effect similar to that shown by the written reports are needed.

Qualitative Results for Guided Inquiry Laboratory Experience

Semi-structured interviews of the same eight students were recorded, transcribed, and used to look for trends in student responses as they related to perceptions of their communication skills gained during the guided inquiry laboratory experience. Two students noted that communication skills were directly developed through close collaboration with their partner while one explained that "communicating my mistakes helped me better understand the reactions happening in my project." One student felt as though communication was "difficult at times" because their group did not understand how to proceed.

A few students made comments on the oral presentations at the end of second semester organic chemistry laboratory. A few of those comments were that "oral presentations at the end of the semester really showed all of the unique projects and experiments [my] peers were working on" and that it was "cool seeing and learning about all of the different projects and chemistry other groups were doing in tandem with [our] own." The different projects are a function of how easily the guided inquiry format lends itself to their implementation. It would be very difficult to run several different projects at the same time using the traditional expository methods.

With regards to written communication, one student commented on how “professional” the final report looked and noted that they were “proud” to have written it. This could be related to the ownership aspect that the projects provide. If a student has more ownership over the work that they’ve accomplished, they tend to be more invested. Another student mentioned that “staying organized was vital to the written report” and that the “guided inquiry format allowed [me] to stay much more organized, which was not possible last semester.” Therefore, the ability to communicate and stay organized seems closely related.

Integrated Analysis of Instructional Styles on Communication Skills

When comparing the quantitative findings at the end of each laboratory experience with respect to students’ perceptions of their communication skills, a trend was elucidated that showed a positive overall change when going from the expository style to the guided inquiry style. Table 19 shows a statistical difference of means comparing average values post-expository style with average values post- guided inquiry style. The results are displayed starting from the most significant difference to the least.

Table 19

Statistical Analysis of Student Perceptions of their Communication Skills Post Expository vs. Post Guided Inquiry Laboratory Experience

Survey Prompt	Post Expository Experience	Post Guided Inquiry Experience	Difference of Means
	M	M	$\lvert M_{Exp} - M_{GI} \rvert$
J	2.75	4.51	1.76
D	4.53	4.88	0.35
B	4.61	4.79	0.18
K	4.67	4.64	0.03

The biggest change is in prompt J, involving oral presentations. This result is likely due to the fact that there is no formal oral presentation at the end of the expository lab while there is a formal presentation at the end of the guided inquiry lab. Another positive change is students' perceptions on their ability to effectively present the details of their work in writing, where a mean difference of 0.35 was observed.

The overall change in written reports was a positive one, showing that students were better at scientific written communication at the end of the guided inquiry experience than they were at the end of the expository sequence. This could be a result of several factors, such as their ownership to a specific project, their ability "to stay organized," or could simply be from students naturally progressing through the scientific curriculum from first semester organic chemistry lab to second semester organic chemistry lab. More studies need to be performed to determine whether the same trend would be true of students' abilities to communicate scientific findings in an oral presentation format.

Confirming some of these findings, qualitative data suggest that students felt more comfortable communicating science when they were "more familiar with [their] project" during the guided inquiry lab, whereas they did not get the same comfort in the expository lab because a new, different lab was performed each week. It was also noted that students tended to talk to other groups about their projects more and more as the semester went on, rather than in the first semester, when students typically only talked amongst their own group. The questions asked by the students to the professor or teaching assistant also showed a vast improvement. For example, in the first semester laboratory, students typically asked "does this look right?" or "how do I know when it's finished?" These kinds of questions show a lack of confidence, but also just demonstrate a student wanting the "right answer." Questions noted in the second semester laboratory were shown to have a little more thought and insight behind them, such as "am I able to try this reaction with…" or "what happens if I did [X] instead?"

Student Perceptions of their Confidence Levels

Quantitative Results for Expository Laboratory Experience

The quantitative results for student perceptions of their confidence levels during the expository laboratory instruction were determined using the same pre-/post- survey as before. The survey questions that were used to determine student confidence levels were E, F, G, H, L, P, Q, R, S, V, X, Y, Z, and AG. The full prompts are provided in Table 20.

Table 20

Pre- and Post- Survey Prompts Related to Perceptions of Confidence Levels

	In this chemistry laboratory course, I expect...	In this chemistry laboratory course, I…
E	to make mistakes and try again	made mistakes and tried again
F	to feel unsure about the purpose of the procedures	felt unsure about the purpose of the procedures
G	to experience moments of insight	experienced moments of insight
H	to be excited to do chemistry	was excited to do chemistry
L	to be confident about my ability to design and carry out experiments	was confident in my ability to design and carry out experiments
P	to be nervous when handling chemicals	was nervous when handling chemicals
Q	to be confused about what my data mean	was confused about what my data meant
R	to be confused about how to use the instruments	was confused about how to use the instruments
S	to be confident when using the equipment	was confident when using the equipment
V	to be nervous about making mistakes	was nervous about making mistakes
X	to be interested in learning how to use the instruments	was interested in learning how to use the instruments
Y	to be frustrated most of the time	was frustrated most of the time
Z	to worry about getting good data	was worried about getting good data
AG	to feel intimidated	felt intimidated

The mean, standard deviation, t-score, and *p* value related to each prompt was determined using a paired, two tailed t-test. As before, mean scores closer to 5 show strong agreement while mean scores closer to 1 would show strong disagreement. The full results of the quantitative analysis ordered from most significant to least significant using the pre-/post- survey is given in Table 21.

Table 21
Statistical Analysis of Student Perceptions of their Confidence Levels with the Expository Laboratory Experience

Survey Prompt	Pre Expository Experience		Post Expository Experience			
	M	*SD*	*M*	*SD*	*t(35)*	*p*
AG	**3.89**	**0.92**	**2.89**	**1.39**	**3.55**	**0.001**
Q	**3.25**	**1.16**	**2.61**	**1.05**	**2.67**	**0.01**
F	3.25	1.27	2.64	1.29	1.91	0.06
R	3.00	1.24	2.44	1.27	1.76	0.09
P	3.42	1.23	3.00	1.37	1.46	0.15
Y	2.64	1.22	2.25	1.34	1.28	0.21
X	4.58	0.64	4.44	0.84	0.96	0.34
G	4.36	0.76	4.47	0.65	-0.78	0.44
S	4.14	0.93	3.97	0.84	0.73	0.47
V	3.94	0.95	3.75	1.18	0.69	0.49
E	4.58	0.55	4.47	0.91	0.63	0.54
H	4.11	1.06	4.00	1.04	0.50	0.62
L	4.11	0.85	4.03	0.84	0.40	0.69
Z	3.83	0.91	3.92	1.00	-0.40	0.69

Note: Negative trends are highlighted in RED while positive results are highlighted in GREEN.
**For this data set, there was an absence of negative trends.*

The results from the paired t-test of the student responses from the pre-/post- course survey show that there were two areas that exceeded students' expectations with respect to their perceptions of their confidence levels in the organic chemistry laboratory when performed in the expository style. The results show that students thought that they would feel intimidated in the laboratory (M = 3.89, SD = 0.92) when in reality, students actually were not very intimidated in the laboratory (M = 2.89, SD = 1.39; t(35) = 3.55, p = 0.001). The results also show that students thought that they would be confused about what their data meant (M = 3.25, SD = 1.16) when in reality, they actually felt as though they were not confused about their data upon completion of the laboratory (M = 2.61, SD = 1.05; t(35) = 2.67, p = 0.01). There was a moderate significance between students' perceptions of their confidence regarding their understanding the purpose of procedures and ability to feel confident when using the instruments. Overall, the survey scores of the students taught in the expository style lacked negative trends and can therefore be viewed as a positive result.

Qualitative Results for Expository Laboratory Experience

The semi-structured interviews were used to look for trends in student responses as they related to their confidence levels in the laboratory. Three students mentioned that performing different labs every week was "stressful" or "overwhelming" and that they were very concerned with getting the "correct" data, even if they were unsure of what the correct data were. When compared with the pre-/post- survey prompt Z, students tended to agree overall that they were concerned about getting good data. The teaching assistant and instructor observational notes also confirm this sentiment as it was noted that students "were often frustrated if their reactions failed." Adding to this, students often asked the teaching assistant or instructor if their reaction "looked right." This seems to be linked to an inherent lack of confidence, which could be why a few students made comments saying that they "liked the structure" provided by the expository laboratory and that they "enjoyed seeing if other students' reactions and experimental setup matched [their own]." Researcher observations mirrored student responses and also noted that students "typically tried to compare their results with other groups in the lab to verify whether or not the results matched." Students also seemed to prefer more instructions given in the laboratory handout, which helped leave less room for error. When students were asked to reflect on what went wrong during a certain experiment, the most common error mentioned was "human error."

Quantitative Results for Guided Inquiry Laboratory Experience

The pre-/post-test survey analysis was done on the same set of 33 students for the guided inquiry laboratory experience as well using the exact same questions/prompts. The statistical analysis for students' perceptions of their confidence levels is given in Table 22 and ranges from most significant to least significant.

Table 22

Statistical Analysis of Student Perceptions of their Confidence Levels with the Guided inquiry Laboratory Experience

Survey Prompt	Pre Guided Inquiry Experience		Post Guided Inquiry Experience			
	M	*SD*	*M*	*SD*	*t(32)*	*p*
P	**3.12**	**1.27**	**2.33**	**1.36**	**10.90**	**<0.001**
R	**2.73**	**1.28**	**1.94**	**0.86**	**6.12**	**<0.001**
Y	**2.48**	**1.20**	**1.91**	**0.84**	**5.39**	**<0.001**
Z	**3.58**	**1.03**	**4.00**	**0.83**	**-4.86**	**<0.001**
S	**3.97**	**0.98**	**4.42**	**0.61**	**-4.23**	**<0.001**
AG	**2.85**	**1.18**	**2.51**	**1.23**	**4.00**	**<0.001**
E	**4.54**	**0.62**	**4.79**	**0.41**	**-3.20**	**0.003**
X	**4.30**	**1.04**	**4.64**	**0.55**	**-2.97**	**0.005**
G	**4.12**	**0.86**	**4.36**	**0.60**	**-2.77**	**0.01**
F	**3.15**	**1.20**	**2.21**	**1.19**	**-2.77**	**0.01**
Q	**2.97**	**1.10**	**2.76**	**1.25**	**2.51**	**0.02**
H	**4.15**	**1.15**	**4.36**	**0.70**	**-2.03**	**0.05**
L	4.36	0.74	4.33	0.89	0.44	0.66
V	3.61	0.90	3.58	1.09	0.37	0.71

*Note: Negative trends are highlighted in RED while positive results are highlighted in GREEN. *For this data set, there was an absence of negative trends.*

The results from the paired t-test of the student responses from the pre-/post- course survey show that students' expectations with respect to their perceptions of their confidence levels in the organic chemistry laboratory were exceeded in almost every prompt when performed in the guided inquiry style. Students were unsure of whether or not they would be nervous when handling chemicals before the semester started (M = 3.12, SD = 1.27); however, after the semester was over, students expressed that they were not as nervous as they thought they would be when handling chemicals throughout the laboratory experience (M = 2.33, SD = 1.36; t(32) = 10.90, p <0.001). Students were also unsure of whether or not they would be confused when handling the instruments prior to the semester starting (M = 2.73, SD = 1.28), but after the semester was over, students determined that they were not confused when handling the instruments (M= 1.94, SD = 0.86; t(32) = 6.12, p < 0.001). Students trended towards disagreement that they would be frustrated most of the time in the laboratory before starting the semester (M = 2.48, SD = 1.20), and confirming that, after the semester was over, students actually were trending towards strongly disagreeing that they were frustrated most of the time (M = 1.91, SD = 0.84; t(32) = 5.39, p < 0.001).

There were also statistically significant differences showing a positive trend in students' perceptions of their confidence levels with respect to worrying about getting good data, feeling intimidated, confidence when using the equipment, experiencing moments of insight, wanting to use the instruments, feeling unsure about the purposes of the procedures, and being excited to do chemistry. Importantly, students expected to make mistakes and try again (M = 4.54, SD = 0.62), and after the semester, they were in strong agreement that they made mistakes and tried again (M = 4.79, SD = 0.41; t(32) = -3.20, p = 0.003). Another important result is that there was a statistically significant difference related to students being excited to do chemistry prior to the lab (M = 4.15, SD = 1.15) when compared with their responses after the semester was finished (M = 4.36, SD = 0.70; t(32) = -2.03, p = 0.05). No statistical significance was found regarding students' confidence levels about their abilities to design and carry out experiments on their own or with regards to being nervous about making mistakes.

Qualitative Results for Guided Inquiry Laboratory Experience

Semi-structured interviews were recorded, transcribed, and used to look for trends in student responses as they related to perceptions of their confidence levels during the guided inquiry laboratory experience. One student explained that he "liked having a guided project to work on throughout the lab that allowed [him] to improve on [his] hands-on abilities." Another student noted that they "appreciated the freedom" that the guided inquiry experience provided, giving them a chance to "think critically about solutions to any problems posed throughout the lab." Two students explained that the oral presentations towards the end of the semester helped them gain more confidence communicating science to an audience of their peers. All of the interview responses were overwhelmingly positive for the guided inquiry experience and many responses had themes related to self-efficacy and ownership.

Some negative aspects related to guided inquiry were that it was easy to get lost in developing a plan in the lab to "reach the ultimate goal" of each project and that one mistake "can lead to something going wrong later in the project." Students also noted that organizational skills and time management were "absolutely critical" and sometimes this resulted in certain organic chemistry concepts to be difficult to follow. Interestingly, it appeared that students tended to be less frustrated if something went wrong during their experiment during the guided inquiry laboratory experience than they were if something went wrong during the expository experience. Although human errors were still common, students had a chance to correct and learn from their mistakes.

Integrated Analysis of Instructional Styles on Confidence Levels

When comparing the quantitative findings at the end of each laboratory experience with respect to students' confidence levels, the results showed a positive overall change when going from the expository style to the guided inquiry style. Table 23 shows a statistical difference of means comparing average values post-expository style with average values post- guided inquiry style. The results are displayed starting from the most significant difference to the least.

Table 23

Statistical Analysis of Student Perceptions of their Confidence Levels Post Expository Vs. Post Guided Inquiry Laboratory Experience

Survey Prompt	Post Expository Experience	Post Guided Inquiry Experience	Difference of Means
	M	M	$\lvert M_{Exp} - M_{GI} \rvert$
P	3.00	2.33	0.67
R	2.44	1.94	0.50
S	3.97	4.42	0.45
F	2.64	2.21	0.43
AG	2.89	2.51	0.38
H	4.00	4.36	0.36
Y	2.25	1.91	0.34
E	4.47	4.79	0.32
L	4.03	4.33	0.30
X	4.44	4.64	0.20
V	3.75	3.58	0.17
Q	2.61	2.76	0.15
G	4.47	4.36	0.11
Z	3.92	4.00	0.08

The magnitude of the change is greatest for students' confidence levels regarding their handling of chemicals, with a mean difference of 0.67, implying that the guided inquiry experience is more effective at helping students develop confidence in this area. The guided inquiry experience was also more effective in alleviating students' confusion as to how to use the organic laboratory instrumentation while giving them more confidence in using the equipment. The students also perceived that they had a greater understanding of the scientific procedures, felt less intimidated, were more excited to do chemistry, and were less frustrated in the guided inquiry laboratory overall. The students felt as though they were able to make mistakes and try again more with the guided inquiry laboratory instructional style as well. Their confidence in designing and carrying out experiments increased while their nervousness decreased. The students also felt less confused about what their data meant in the guided inquiry format. However, it appears that the expository laboratory format allowed students to experience more moments of insight while also easing student concerns about getting good data. Students' concern about not getting good data in the guided inquiry format could potentially be explained by the presence of an oral presentation at the end of the semester.

Evidence for Soft Skill Development

At the end of each laboratory experience, students were also given a "soft skills survey" where they could select which soft skills they thought were developed during the semester. The students were asked to select as many or as few soft skills as they wanted and could choose from several options, outlined in Table 24. A paired samples t-test was then performed to compare soft skill development during the expository laboratory experience with soft skill development during the guided inquiry experience. For consistency, the same students were surveyed at the end of each experience. The results are shown from most significant to least significant.

Table 24

Statistical Analysis of Student Perceptions of their Soft Skill Development in each Laboratory Experience

Soft Skill	Post Expository Experience		Post Guided inquiry Experience			
	M	*SD*	*M*	*SD*	*t(32)*	*p*
Creativity	**0.08**	**0.29**	**0.50**	**0.51**	**-4.81**	**<.001**
Problem Solving	**0.41**	**0.50**	**0.71**	**0.46**	**-3.71**	**<.001**
Critical Thinking	**0.56**	**0.50**	**0.71**	**0.46**	**-2.38**	**.02**
Adaptability	**0.44**	**0.50**	**0.56**	**0.50**	**-2.10**	**.04**
Resourcefulness	0.65	0.49	0.74	0.45	-1.79	.08
Communication	0.71	0.46	0.65	0.48	1.43	.16
Organization	0.68	0.47	0.65	0.49	1	.32
Teamwork	0.85	0.36	0.82	0.39	1	.32
Decision Making	0.59	0.50	0.62	0.49	-1	.32
Time Management	0.53	0.51	0.53	0.51	0	1.00

*Note. N=34; M * 100 = % of students who agreed that the experience developed that skill.*
**Green color corresponds to a statistically significant positive change in soft skill development from first to second semester.*

The results show that there was a statistically significant difference in creativity between the expository experience (M = 0.08, SD = 0.29) and the guided inquiry experience (M = 0.50, SD = 0.51); t(32) = -4.81, p = <0.001). This result is perhaps unsurprising, due to the "cook-book" nature of the expository laboratory, leading to pre-determined results and leaving little room for change in experimental procedures. The results also show a statistically significant, positive change in students' perceptions of their soft skill development in the areas of problem solving, critical thinking, and adaptability, with the average values all increasing. There was a moderate difference in resourcefulness between the expository experience (M = 0.65, SD = 0.49) and the guided inquiry experience (M = 0.74, SD = 0.45); t(32) = -1.79, p = 0.08.

There was no statistically significant difference determined between the expository experience and guided inquiry experience with regards to development of communication, organization, teamwork, and time management skills. Interestingly, there was also no statistically significant difference in decision-making between the two contrasting styles. This result is particularly interesting because the projects in the guided inquiry format allow for the students to lead their project in any way that they deem appropriate, making decisions along the way, whereas the expository sequence does not really allow for much change to the laboratory experiments. Therefore, this result was unexpected, but could be related to student confidence with respect to having enough chemistry knowledge to make appropriate experimental changes.

Researcher Observations

During each semester, the instructor/researcher made several notes regarding student behavioral patterns in the laboratory. Some of the observed phenomena were difficult to quantify while others were slightly easier. Upon completion of the second semester guided inquiry laboratory, the students were asked which method of instruction they preferred. The result of this poll was near unanimous, with 95% of the students preferring the guided inquiry instruction to just 5% preferring the expository instruction. Along with this, it was noted by both the instructor and the teaching assistant that the level of student effort during the organic chemistry laboratories increased in the guided inquiry format. In an effort to back up these observations, student attendance and student unexcused absences were recorded from the gradebook. The data showed that in the expository experience, there was a total of 18 unexcused absences while during the guided inquiry experience, the number of unexcused absences was found to be 3, a dramatic decrease.

During each semester, there was one week where students came to lab and were told that they could use the laboratory time to complete the lab or use the time to study, work on homework, or just take the week off. During the expository lab, it was found that 70% of the students chose to take the week off, 17% worked on the assigned lab, and 13% chose to do other homework or study for upcoming tests. For the guided inquiry experience, it was found that only 8% of the students chose to take the week off or study, with the other 92% staying and working on their laboratory projects, even though the students had tests coming up during the same week. It is difficult to ascertain reasoning for this phenomenon, but it could be related to the ownership students feel towards their projects or perhaps their excitement to do chemistry, which was shown to increase during the guided inquiry experience compared to the expository experience.

Summary of Results and Discussion

The research questions in this study were answered through comparing the quantitative and qualitative data and using the data to provide insight into student perceptions in three areas: knowledge and understanding, communication skills, and confidence.

The first area was how expository or guided inquiry instruction affects students' perceptions of their knowledge and understanding. The quantitative results associated with knowledge and understanding in the expository setting show that there was a negative trend and significant difference in students' organizational abilities, thoughts about what the molecules were doing, and their use of scientific literature to solve problems. The quantitative results point towards students' expectations not being met with regards to the expository instruction. Confirming this, the semi-structured interviews revealed that students liked having the ability to get the “correct” data and having reactions that were supposed to work but thought that the experiments could be overwhelming at times and never had to think about the reactions in depth or at higher cognitive levels. For the guided inquiry instruction, the quantitative results point towards a positive trend in five areas related to knowledge and understanding, but negative trends in two areas. The qualitative data suggests that students preferred having more freedom and were able to develop more problem-solving skills while feeling comfortable making mistakes with this instructional style. In comparing the mean scores post- expository instruction with the mean scores post- guided inquiry instruction, it was shown that most mean scores increased in the guided inquiry format, with just two exceptions.

The second area was how expository or guided inquiry instruction affects students’ perceptions of their communication skills. The pre-/post- survey showed that both instructional methods met the expectations of the students with respect to communication skills. However, the mean scores were much higher overall with respect to oral communication, written communication, and collaboration in the guided inquiry format. When comparing these perceptions with the rubric scores for written communication, it was found that students met a communication level appropriate for sophomore college students, although it is worth noting that the scores tended to be higher for the guided inquiry laboratory reports, but this could be due to students having more experience with scientific writing by the second semester of their sophomore year of college.

The third area was how expository or guided inquiry instruction affects students’ perceptions of their confidence levels. It was in this area where the most change was observed. Students’ perceptions exceeded their expectations with respect to two out of fourteen prompts regarding confidence levels at the end of the expository laboratory, while they exceeded their expectations in twelve of fourteen prompts at the end of the guided inquiry laboratory. The difference in means was also quite large with students overwhelmingly rating the guided inquiry format higher for development of confidence in the laboratory. The qualitative data reinforces this with student responses pointing towards a preference for the guided inquiry experience due to answers to interview questions related to self-efficacy and ownership.

Lastly, a soft-skills survey combined with researcher observations were used to explain some of the trends that were elucidated during this study. It was found that students felt as though the expository lab helped develop soft skills such as teamwork, communication, and organization whereas the guided inquiry lab helped develop teamwork, resourcefulness, critical thinking, and problem-solving skills. The biggest difference is that 8% of students felt that the expository lab sparked development of their creativity while the number jumped to 50% for the guided inquiry instruction. Big mean score differences were also determined for problem solving and critical thinking, two very important soft skills for future scientists to have.

Chapter Summary

In an effort to address this study's research questions, this work's data analysis findings and results were discussed in three different major sections: Student Perceptions of Knowledge and Understanding, Student Perceptions of Their Communication Skills, Student Perceptions of the Confidence Levels. Chapter 5 will present conclusions in a comprehensive summary, implications for practice, suggestions for future research in this area, and a discussion of this study's limitations.

Chapter 5: Conclusion

Introduction

The purpose of this mixed methods action research study was to differentiate the impact of the traditional, expository laboratory experiences and guided inquiry experiences on college students' perceptions of their knowledge and understanding, communication skills, and confidence levels related to organic chemistry. The overarching questions of this research study were:

a) How do expository laboratory experiences impact college students' perceptions of their knowledge and understanding, communication skills, and confidence levels related to organic chemistry?

b) How do guided inquiry laboratory experiences impact college students' perceptions of their knowledge and understanding, communication skills, and confidence levels related to organic chemistry?

Summary of Results

Summary of Data for Traditional, Expository Laboratory Experience

Student perceptions of their knowledge and understanding from the traditional, expository laboratory experience were that they did not feel that their expectations were met regarding their ability to record details of their work thoroughly, accurately, and in an organized fashion. Students also showed a statistically significant decrease in their perceptions versus their realities regarding thinking about what the molecules were doing and their ability to identify and use scientific literature to interpret and solve scientific problems. With respect to communication skills, a statistically significant decrease in students' perceptions of their oral presentation skills was found. When analyzing students' perceptions of their confidence levels, a statistically significant decrease in student confusion and intimidation in the laboratory was revealed.

Qualitative results from the semi-structured interviews and researcher observations in the expository lab seemed to align with the trends revealed by the quantitative survey tool used in this study. In fact, it was determined that students typically liked the structure associated with the expository laboratory teaching style as well as the ability to get the "correct data." Some students even noted that they preferred being able to follow step-by-step instructions. These results align with research previously published where this style of instruction lends itself towards an over-emphasis on "lower-order skills" (Hilosky et. al., 1998; Rubin, 1996) where students tend to spend too much time focused on attaining the "right answer" (Domin, 1999; Schoffstall & Gaddis, 2007). One of the main complaints about this style of teaching that students in this study explained was that one mistake would ruin the experiment and that the way the lab was set up wouldn't allow them another opportunity to get it right or learn from their mistake.

In terms of communication, some students enjoyed being able to talk amongst other groups to compare results while others mentioned that they lacked communication with their partner and peers. The qualitative data related to confidence showed that students tended to be stressed or frustrated about getting the correct data, even though their grades were not dependent upon this. It was also noted that one of the most commonly asked questions from students to the instructor was, "Does this look right?" This question seemed to be linked to an inherent lack of confidence in the laboratory.

Summary of Data for Guided-Inquiry Laboratory Experience

Student perceptions of their knowledge and understanding from the guided-inquiry laboratory experience were that they still struggled to record the details of their work thoroughly, accurately, and in an organized fashion. There was also a statistically significant decline in students' perceptions of their observational skills. In contrast with the expository approach, students showed an increase in their perceptions of their ability to use scientific literature to interpret and solve scientific problems. The results also showed that students felt as if they exceeded their expectations in their ability to problem solve, interpret their data, and make decisions about how to carry out the experiments under the guided-inquiry instructional style.

With respect to communication skills, students exceeded their expectations in effectively presenting the details of their lab work in writing with a mean post-survey score of 4.88 out of 5.00. Students met their expectations in oral communication and collaboration. When analyzing students' perceptions of their confidence levels, a statistically significant positive trend in 12 of the 14 prompts was revealed where students exceeded their expectations. Students agreed that they made mistakes and tried again, experienced moments of insight, were excited to do chemistry, were confident and interested using the equipment, and worried about getting good data. Importantly, the students did not feel unsure about the purpose of their procedures, were not nervous handling the chemicals, were not unsure of what their data meant, were not frustrated most of the time, and did not feel intimidated. Interestingly, these results show an overwhelmingly positive trend with respect to student persistence, motivation, and confidence in the laboratory.

Qualitative results from the semi-structured interviews and researcher observations in the guided-inquiry lab reinforced many of the trends shown in the quantitative data. Students responded that they liked having more freedom, independence, and ability to make decisions. The students felt like the guided inquiry labs allowed them the opportunity to focus on improving their confidence and problem-solving skills. A few students noted that communication could be difficult at times, especially if their group was unsure of how to proceed. Despite this, students tended to be proud of the written reports that they submitted, which speak directly to the ownership that they felt towards their projects.

The guided-inquiry experience also showed that student confidence, persistence, and motivation could be gained under the right conditions. Students appreciated the ability to think more critically about the chemistry happening in their projects. Students also appreciated how they felt like they could learn from their mistakes and that they could fix what went wrong and try again the next lab period. The overall responses from the interviews revealed themes related to self-efficacy and ownership. Some of the negative responses associated with guided-inquiry instruction were that organizational skills and time management were critical and, when mismanaged, could lead to mistakes in the following weeks. Despite this, students appeared less frustrated when a reaction failed, or something went wrong in their experiments under the guided-inquiry laboratory experience compared to the expository experience.

Summary of Soft Skill Development and Researcher Observations

The results of this study also revealed that there was a difference in soft skills developed by each laboratory experience. Only 8% of the students felt as if they were able to be creative when undertaking the expository lab compared with 50% during the guided-inquiry lab. There was also a statistically significant difference in students' perceptions of their ability to problem solve, think critically, and adapt, which all increased during the guided-inquiry format. There was no significant difference in students' perceptions of their resourcefulness, communication, organization, teamwork, decision-making, or time management between the two instructional styles.

A vast majority of students preferred the guided-inquiry instruction over the traditional instruction. The level of effort appeared to increase from the first semester to the second semester as well. Student unexcused absences plummeted from 18 during the traditional instruction to just three during the guided-inquiry format. When the students were given an opportunity to take a week off or use lab time as they would like, 92% of the students chose to stay and work on their project during the guided-inquiry lab as opposed to 17% in the traditional, expository lab. There were noticeable increases in student motivation, quality of work, effort, and overall satisfaction in the guided-inquiry laboratory when compared to the traditional, expository laboratory.

Implications for Practice

In light of the findings presented in this study, there are several practical implications that emerged that can be used by college chemistry laboratory instructors in the field. The implementation of these findings can equip students with a deeper understanding, not only of organic chemistry concepts and laboratory techniques, but also a deeper understanding of themselves. This would allow students to take ownership of their learning and effectively build on their own strengths and weaknesses. The findings of this research offer specific implications for integrating guided-inquiry principles into the organic chemistry teaching laboratory. Notably, a transition from traditional, expository laboratories to guided-inquiry laboratories would better promote deeper understanding and develop student soft skills, such as confidence, motivation, and persistence.

Organic chemistry laboratory instructors should clearly identify the learning objectives that they want their students to achieve as a result of the laboratory. After this, the instructors could begin to transition the lab away from "cookbook" exercises and incorporate their learning objectives into labs that promote constructivist principles, such as guided-inquiry. As evidenced by this work, the guided-inquiry instruction allowed students to make more decisions about how to carry out their experiments. These decisions gave students a chance to think critically about the reactions they wanted to perform as well as the specific chemical transformations they were seeking to accomplish. These higher order thought processes yield more opportunities for students to build and maintain a deeper understanding of the material while also developing hands-on skills essential to a research scientist.

Laboratory instructors should also seek instructional styles that better stimulate student soft skill development. There are several modern teaching pedagogies that instructors can utilize to aid in this goal, including not only this research's emphasis on guided-inquiry instruction, but also studio-based learning, problem-based learning, and course-based undergraduate research experiences (CUREs). As evidenced by this work, the transition to guided-inquiry instruction through the use of multi-week projects allowed students opportunities to develop and strengthen their own soft skills that far exceeded the traditional, expository instructional counterpart. The main soft skills that were developed were related to motivation, persistence, creativity, problem solving, critical thinking, adaptability, and confidence in the laboratory. The transition away from this traditional method of teaching organic chemistry labs to a more modernized approach gives educators a chance to increase and enhance student engagement, improve upon existing learning outcomes, and better prepare students for real-world applications.

Limitations

Understanding limitations in this study is crucial for contextualizing and assessing the generalizability of the research findings. With a sample of 33 to 36 students, generalizations cannot be made for students beyond this study's sample participants. Extrapolating this study's findings beyond this university would require additional validation and study replication. Future studies are therefore necessary to confirm and validate this study's key research findings.

Another limitation to this study is related to student population size. This specific research into guided-inquiry instruction lends itself to smaller, primarily undergraduate institutions. For example, this study had students in groups of two for each semester, with an average section size of 12 to 16 students per section. During the second semester, seven different ten week guided-inquiry projects were given out to the students, with one project per group. This resulted in each group having a completely different project than their peers in their section. While these projects give students the opportunity to become "experts" on their specific project, it does limit the students' deep exposure to other organic chemistry reactions learned about in class. For undergraduate chemistry labs at research universities, respective section sizes may be too big to effectively implement this study's form of guided-inquiry based instruction.

Lastly, instructor bias can be seen as a limitation to this study. I personally enjoyed teaching under the guided-inquiry methodology more than the traditional methods. If the students were able to perceive this, it could potentially have impacted their survey or the semi-structured interview responses. To limit my own bias, the student pre-/post- and soft skill surveys were de-identified before given to me for use in analysis. In the analysis of communication skills, the oral and written report rubrics were used and scored by multiple different faculty members within the department to increase the validity and robustness of the resulting data. I also used regular student feedback and reflection of my teaching practices to help identify and address my own biases with the hope of continuously improving.

Suggestions for Future Research

Future research will be needed at universities of different sizes as well as at universities that have different student demographics so that the range of findings can be compared across educational literature and tested for generalizability. These future studies could include more student perspectives on their own laboratory experiences as they relate to knowledge retention, conceptual understanding, and soft skills in the organic chemistry laboratory.

More studies are currently ongoing at this university in an attempt to replicate these results with a different sample of students to further increase the validity and reproducibility of this work. In the future, this researcher will use different guided-inquiry methods to see if similar results are attained. For example, there are examples of guided-inquiry based organic chemistry experiments that take place in a much shorter period of time (Lee, 2019; Mistry, N., Fitzpatrick, C., & Gorman S., 2016) as well as some that take place over the course of a whole semester (Kovacevic et al., 2020). The versatility associated with the guided-inquiry teaching methodology is one of its key advantages, which means that different student learning outcomes can be emphasized depending on the preference of the instructor or curriculum or scheduling requirements. However, this means that more research is needed into the overall effectiveness of guided-inquiry instruction with respect to the amount of time students are exposed to this teaching methodology.

Conclusion

The daunting challenges of mastering organic chemistry concepts and the associated laboratory work often result in alarmingly high DFWI rates. This study sought to examine and explain how expository and guided-inquiry laboratory experiences impact college students' perceptions of their knowledge and understanding, communication skills, and confidence levels related to organic chemistry. The research findings of this study are pivotal, offering insights that can revolutionize chemistry education. By enhancing instructional methodologies, fostering deeper real-world connections, and nurturing vital transferable soft skills, educators can work to empower students so that they can excel both in the lab and beyond. While this study's results did not reveal much improvement in student perception of their communication skills in the laboratory, it is my belief that all of the research participants became more effective scientific communicators as a result of this study. These findings highlight the necessity for educators to continuously strive for the highest standards of educational excellence.

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Appendix A

[redacted] UNIVERSITY

Information and Consent Form

Study Title: Transformation of the Organic Chemistry Laboratory: A Movement towards an Inquiry-Based Laboratory Experience

Invitation to be part of a research study:

You are invited to participate in a research study. In order to participate you must be currently enrolled in CHM 253 or CHM 257 in the Department of Chemistry and Biochemistry. Taking part in this research project is voluntary. The consent for this research will be good for the spring semester (starting January 2023) and fall semester (starting August 2023) of CHM 253 and CHM 257 and will end in December of 2023.

Key information regarding this study:

The purpose of this research is to differentiate the impact of expository laboratory experiences and guided inquiry laboratory experiences on college students' perceptions of their knowledge and understanding, communication skills, and confidence levels related to organic chemistry. If you choose to participate you will be asked to complete surveys and answer questions regarding your own self-reflection as part of this course as well as complete all assignments related to the course. This will take approximately 15 minutes for the survey and each prompt. Total involvement is not expected to exceed normal laboratory class hours. Risks or discomforts from this research include the slight discomfort that might come from thinking about your learning. The study will not benefit you directly, but could be used to help future students. Taking part in this research project is voluntary and will have no impact on your course grade. You don't have to participate and can stop at any time. Please take the time to read this entire form and ask questions before deciding to participate in this research project. Your instructor will not have information on who consents to participate in this research study until after grades for the class are posted.

What is purpose of the study?

The purpose of this research is to differentiate the impact of expository laboratory experiences and guided inquiry laboratory experiences on college students' perceptions of their knowledge and understanding, communication skills, and confidence levels related to organic chemistry.

What will happen if you take part in this study?

If you agree to take part in this study, you will be asked to occasionally complete surveys and perform self-reflection as part of this course. You will also be asked for permission to use your de-identified written reports and oral presentations as examples. Total involvement is not expected to exceed regular laboratory class hours. The survey will ask questions about the type of material covered within the course, your self-assessment of your current understanding of topics within this course, and how lab experiences impacted your knowledge and skills in chemistry and biochemistry.

What are the risks of participating in the study?

Risks are considered minimal and include the slight discomfort that can come from thinking about your learning. One possible risk you might experience from this study is a breach of confidentiality. We will take steps to protect privacy and minimize this risk.

What are the benefits of participating in the study?

You probably will not benefit from this study, but the information may strengthen Chemistry and Biochemistry courses for future students.

Are there any incentives for participating in the study?

There are no incentives offered for participating.

How will your information be protected?

We plan to publish the results of this study. To protect your privacy, we will not include any information that can directly identify you. Your name will be stored separately from the data collected for this study.

After the study, what will happen to the data collected?

We will keep your research data to use for future research. Your name and other information that can directly identify you will be deleted from the information collected as part of the project. We may share your research data with other faculty, administrators, and researchers without asking for your consent again, but it will not contain information that could directly identify you.

What are the costs?

There are no costs for participation in this study.

Your participation in the study is voluntary

Taking part in this study is voluntary. You may choose not to take part or may leave the study at any time. You do not need to answer any question you do not want to answer. You will be asked if you wish to be in this study each semester that we collect survey information.

Who should I call with questions or problems study?

If you have any questions about this study, please contact the researcher in charge of this study. Shawn Montag; smontag@[redacted].edu

Who should I contact with questions about my rights as a research participant?
If you have questions about your rights as a research participant, or wish to obtain information, ask questions, or discuss any concerns about this study with someone other than the researcher(s), please contact the following:
Committee on the Use of Human Subjects in Research (CUHSR)
[redacted] University
[redacted]

Your informed consent
You are voluntarily making a decision to participate in this study. Your signature means
that you have read and understood the information presented and have decided to participate. Your signature also means that the information on this consent form has been fully explained to you and all your questions have been answered to your satisfaction. If you think of any additional questions during the study, you should contact the researcher(s).

I agree to participate in this study I will not participate in this study

I am at least 18 years old Yes No (Circle one)

____ ____________

Name of Participant Date

Appendix B

Recruitment Script

You are invited to participate in a research project on the use of guided inquiry research experiences as they relate to student engagement, perceptions, and learning in science courses. This study is part of the assessment program of the Department of Chemistry and Biochemistry at Bradley University. The purpose of this study is to differentiate the impact of expository laboratory experiences and guided inquiry laboratory experiences on college students' perceptions of their knowledge and understanding, communication skills, and confidence levels related to organic chemistry.

Involvement in this project will not require extra class work on your part. The professor is requesting permission to use writing prompts that you produce in class and surveys that are conducted in class as data in their study. Further details are included in the distributed letter of informed consent. Participation in this study is completely voluntary and it will not impact your experience in this class. No course instructor will know who consented to participate until after semester grades are final. The only foreseeable risk is the discomfort you might feel knowing that your work is being used in a research study. We will keep your information confidential and your name will never be associated with the study.

I will be happy to answer questions you may have about the study.

Thank you for your consideration.

Appendix C

CUR Transformations Project: Research Driven Experiences in the Chemistry and Biochemistry Curriculum

Department of Chemistry [redacted] Curriculum Pre-Survey

Your name: ________________________________ Student ID # ____________________

(Reminder: To protect your privacy, we will not include any information that can directly identify you. Your name will be stored separately from the data collected for this study.)

In this chemistry laboratory course, I expect...		**completely disagree**	**disagree somewhat**	**neutral**	**agree somewhat**	**competely agree**
A	to learn how to implement safe laboratory practices					
B	to collaborate effectively with classmates to solve problems					
C	to recognize the importance of finding ways to reduce waste, conserve energy, and discover replacements for hazardous substances					
D	to effectively present the details of my lab work in writing					
E	to make mistakes and try again.					
F	to feel unsure about the purpose of the procedures.					
G	to experience moments of insight.					
H	to be excited to do chemistry.					
I	to consider whether my data makes sense.					
J	to effectively present the details of my lab work orally					
K	to communicate effectively with my classmates about the methods, data, etc.					

L	to be confident about my ability to design and carry out experiments					
M	to read and understand the primary literature.					
N	to learn critical thinking skills.					
O	identify and use the primary literature to interpret and solve scientific problems					
P	to be nervous when handling chemicals.					
Q	to be confused about what my data mean.					
R	to be confused about how to use the instruments					
S	to be confident when using equipment.					
T	to use my observations to understand the behavior of atoms and molecules					
U	We use this statement to discard the survey of people who are not reading the items. Please select “disagree somewhat” for this item.					
V	to be nervous about making mistakes.					
W	to use chemical concepts I know from other courses.					
X	to be interested in learning how to use the instruments					
Y	to be frustrated most of the time.					
Z	to worry about getting good data.					

AA	to record the details of my work thoroughly, accurately, and in an organized fashion					
AB	to recognize the difference between collaboration and cheating/scientific misconduct					
AC	to utilize the principles of green chemistry					
AD	to interpret my data beyond only doing calculations.					
AE	to learn problem solving skills.					
AF	to learn about what distinguishes ethical laboratory behaviors from unethical ones					
AG	to feel intimidated.					
AH	to make some of the decisions about how to carry out the experiment					
AI	to learn chemistry that will be useful in my life.					
AJ	to think about what the molecules are doing.					

Appendix D

CUR Transformations Project: Research Driven Experiences in the Chemistry and Biochemistry Curriculum

Department of Chemistry [redacted] Curriculum Post-Survey

Your name: ________________________________ Student ID # ____________________

(Reminder: To protect your privacy, we will not include any information that can directly identify you. Your name will be stored separately from the data collected for this study.)

In this chemistry laboratory course, I…		completely disagree	disagree somewhat	neutral	agree somewhat	competely agree
A	learned how to implement safe laboratory practices					
B	collaborated effectively with classmates to solve problems					
C	recognized the importance of finding ways to reduce waste, conserve energy, and discover replacements for hazardous substances					
D	effectively presented the details of my lab work in writing					
E	made mistakes and tried again.					
F	felt unsure about the purpose of the procedures.					
G	experienced moments of insight.					
H	was excited to do chemistry.					
I	considered whether my data made sense.					
J	effectively presented the details of my lab work orally					

K	communicated effectively with my classmates about the methods, data, etc.					
L	was confident in my ability to design and carry out experiments					
M	read and understood the primary literature					
N	learned critical thinking skills.					
O	identified and used the primary literature to interpret and solve scientific problems					
P	was nervous when handling chemicals.					
Q	was confused about what my data meant.					
R	was confused about how to use the instruments					
S	was confident when using equipment.					
T	used my observations to understand the behavior of atoms and molecules					
U	We use this statement to discard the survey of people who are not reading the items. Please select “disagree somewhat” for this item.					
V	was nervous about making mistakes.					
W	used chemical concepts I know from other courses.					
X	was interested in learning how to use the instruments.					
Y	was frustrated most of the time.					

Z	worried about getting good data.					
AA	recorded the details of my work thoroughly, accurately, and in an organized fashion					
AB	recognized the difference between collaboration and cheating/scientific misconduct					
AC	utilized the principles of green chemistry					
AD	interpreted my data beyond only doing calculations.					
AE	learned problem solving skills.					
AF	learned about what distinguishes ethical laboratory behaviors from unethical ones					
AG	felt intimidated.					
AH	made some of the decisions about how to carry out the experiment					
AI	learned chemistry that will be useful in my life.					
AJ	thought about what the molecules are doing.					

Appendix E

Oral Presentation Rubric

			Introduce		Reinforce		Proficient	Unable to evaluate
category	**subcategory**	**0**	**1**	**2**	**3**	**4**	**5**	**-**
Content	**Content presented at level appropriate for audience and adheres to length guideline**	Most content is presented at a level above or below what is appropriate for audience or presentation is substantially shorter or longer than expected ☐	Some content is presented at an audience-appropriate level and presentation length is close to meeting the guideline ☐	☐	Most content is presented at an audience-appropriate level and presentation length is close to meeting the guideline ☐	☐	Content is presented at a level appropriate for audience and presentation adheres to length guideline ☐	☐
	Significance of work and context (relevant previous studies) are adequately described	Neither significance of work nor context are described to a significant extent ☐	Significance of work or context are not mentioned or are unclear or inadequate ☐	☐	Significance of work and context are described but clarity and thoroughness could be improved ☐	☐	Significance of work and context are clearly and thoroughly described ☐	☐
	Methods/procedure is adequately described	Lack of methods/procedure substantially limits audience ability to understand data, conclusions, etc. ☐	Methods/procedure is described but several key details are missing or lots of superfluous details are included ☐	☐	Methods/procedure is described but one or two details are missing or superfluous details are included ☐	☐	Methods/procedure is adequately described ☐	☐
	Results and conclusions are adequately described	Most results/conclusions are absent or are	Most results/conclusions are included but in		Most results/conclusions are included but in		Results/conclusions are clearly and thoroughly described and	

		inadequate to the extent that they substantially limit audience understanding ☐	many cases are unclear, not thoroughly described, or not supported by the data ☐	☐	a few cases are unclear, not thoroughly described, or are not supported by the data ☐	☐	supported by the data ☐	☐
Organization	**Sequence of ideas supports audience understanding**	Sequence of ideas is illogical or interferes with audience understanding ☐	Sequence of ideas supports audience understanding somewhat but is illogical in some instances ☐	☐	Sequence of ideas mostly supports audience understanding ☐	☐	Sequence of ideas effectively supports audience understanding ☐	☐
	Relationship between data and experimental questions is clear	Relationship between data and experimental questions is not addressed ☐	Relationship between data and experimental questions is addressed but unclear ☐	☐	Relationship between data and experimental questions is mostly clear ☐	☐	Relationship between data and experimental questions is clear ☐	☐
Visual aids	**Slide design supports audience comprehension** (e.g. slide numbers, adequate white space, no distracting designs, legible text, line spacing, key words/ phrases instead of complete sentences)	Slide design interferes with audience comprehension ☐	Some aspects of slide design support audience comprehension but others interfere with it ☐	☐	Most aspects of slide design support audience comprehension with a few exceptions ☐	☐	Slide design is highly effective at supporting audience comprehension ☐	☐
	Illustrations (graphs, diagrams, molecular structures) support audience understanding (size, labeling,	Illustrations interfere with audience comprehension ☐	Some illustrations support audience understanding but others are ineffective	☐	Illustrations mostly support audience understanding with a few exceptions	☐	Illustrations are highly effective at supporting audience understanding	☐

	appropriateness)		☐		☐		☐	
	Appropriate references are included	References are not included ☐	Some references are absent or incorrect, misplaced or illegible ☐	☐	References are included but are misplaced or illegible ☐	☐	References are included where they are appropriate ☐	☐
Presentation	**Delivery** (Eye contact, pace, volume, effective use of pointer, and correct use of terminology)	Delivery is not effective at promoting audience engagement and understanding ☐	Delivery is only somewhat effective at promoting audience engagement and understanding ☐	☐	Delivery is mostly effective at promoting audience engagement and understanding ☐	☐	Delivery is highly effective at promoting audience engagement and understanding ☐	☐
	Explains data presented (e.g. noting type of data being reported, define graph axes, describe/compare trends in qualitative or quantitative data, including statistical significance if relevant)	Does not describe data ☐	Describes data minimally ☐	☐	Describes most data clearly ☐	☐	Describes data clearly ☐	☐

Appendix F

Written Communication Learning Outcome Curricular Assessment

			Introduce		Reinforce		Proficient	Unable to Evaluate
category	subcategory	0	1	2	3	4	5	-
Content	**INTRODUCTION: Significance, context (relevant previous studies), and objective are adequately described**	Significance, context, and objective are not described to a significant extent ☐	Significance, context, or objective is missing or very unclear ☐		Significance, context and objective are described but clarity and thoroughness could be improved ☐		Significance, context, and objective are clearly and thoroughly described ☐	☐
	METHODS: Experimental methods/procedures/details are adequately and accurately described	Lack of methods substantially limits audience ability to understand data, conclusions, etc. ☐	Methods are described but several key details are missing or many superfluous details are included ☐		Methods are mostly adequate and accurate but one or two details are missing or superfluous details are included ☐		Methods are adequately and accurately described ☐	☐
	ILLUSTRATIONS: Tables, graphs, diagrams, molecular structures support clarity. Illustrations are well-designed, appropriately labeled, captioned, and referred to within the text.	Illustrations are missing or interfere with audience comprehension ☐	Some illustrations support audience understanding but others are ineffective ☐		Illustrations mostly support audience understanding with a few exceptions ☐		Illustrations are highly effective at supporting audience understanding ☐	☐
	RESULTS/ CONCLUSIONS: Results and conclusions are adequately described. Results are interpreted in the context of objective and significance, where appropriate.	Most results/ conclusions are absent or are inadequate ☐	A substantial fraction of the results/ conclusions are unclear, not thoroughly described, or not supported by the data ☐		Most results/ conclusions are included but in a few cases are unclear, not thoroughly described, or are not supported by the data ☐		Results/conclusions are clearly and thoroughly described and supported by the data and interpreted in the context of the objective ☐	☐
	REFERENCES: Appropriate references are included and follow the required format	References are not included ☐	Some references are absent, incorrect, misplaced or improperly formatted ☐		References are included but a few are misplaced or improperly formatted ☐		References are included where they are appropriate and follow the required format ☐	☐
Writing/Style	**Mechanics (grammar, punctuation, spelling)** **Syntax (sentence structure, conciseness, clarity, logical**	☐ Unreadable due to mechanics and syntax	☐ Many problems with mechanics and syntax		☐ Several mechanics or syntax issues but mostly		☐ Few or no mechanics or syntax issues; excellent	

	organization of paragraphs /transitions)	problems	interfere with clarity		clear		clarity	
	Content and style follow requirements and are appropriate for defined audience. Correct use of scientific and technical terms.	Content and style do not follow requirements and are inappropriate for the audience; scientific and technical terms are often used incorrectly. ☐	Content and style mostly follow requirements and are more or less appropriate for the audience; some scientific and technical terms are used incorrectly. ☐		Content and style-follow requirements and are mostly appropriate for the audience; scientific and technical terms are mostly used correctly. ☐		Content and style are appropriate for the audience and scientific and technical terms are used correctly. ☐	
	Able to write an improved draft based on peer/instructor feedback		Takes very few suggestions to improve writing, errors still in final draft		Adopts some suggestions, ignores others		Accepts corrections that improve work (or no suggestions given due to high quality)	☐

Appendix G

Pre-/Post-Survey Questions side by side comparison

	In this chemistry laboratory course, I expect...	In this chemistry laboratory course, I…
A	to learn how to implement safe laboratory practices	learned how to implement safe laboratory practices
B	to collaborate effectively with classmates to solve problems	collaborated effectively with classmates to solve problems
C	to recognize the importance of finding ways to reduce waste, conserve energy, and discover replacements for hazardous substances	recognized the importance of finding ways to reduce waste, conserve energy, and discover replacements for hazardous substances
D	to effectively present the details of my lab work in writing	effectively presented the details of my lab work in writing
E	to make mistakes and try again.	made mistakes and tried again.
F	to feel unsure about the purpose of the procedures.	felt unsure about the purpose of the procedures.
G	to experience moments of insight.	experienced moments of insight.
H	to be excited to do chemistry.	was excited to do chemistry.
I	to consider whether my data makes sense.	considered whether my data made sense.
J	to effectively present the details of my lab work orally	effectively presented the details of my lab work orally
K	to communicate effectively with my classmates about the methods, data, etc.	communicated effectively with my classmates about the methods, data, etc.
L	to be confident about my ability to design and carry out experiments	was confident in my ability to design and carry out experiments
M	to read and understand the primary literature.	read and understood the primary literature
N	to learn critical thinking skills.	learned critical thinking skills.

O	identify and use the primary literature to interpret and solve scientific problems	identified and used the primary literature to interpret and solve scientific problems
P	to be nervous when handling chemicals.	was nervous when handling chemicals.
Q	to be confused about what my data mean.	was confused about what my data meant.
R	to be confused about how to use the instruments	was confused about how to use the instruments
S	to be confident when using equipment.	was confident when using equipment.
T	to use my observations to understand the behavior of atoms and molecules	used my observations to understand the behavior of atoms and molecules
U	We use this statement to discard the survey of people who are not reading the items. Please select “disagree somewhat” for this item.	We use this statement to discard the survey of people who are not reading the items. Please select “disagree somewhat” for this item.
V	to be nervous about making mistakes.	was nervous about making mistakes.
W	to use chemical concepts I know from other courses.	used chemical concepts I know from other courses.
X	to be interested in learning how to use the instruments	was interested in learning how to use the instruments.
Y	to be frustrated most of the time.	was frustrated most of the time.
Z	to worry about getting good data.	worried about getting good data.
AA	to record the details of my work thoroughly, accurately, and in an organized fashion	recorded the details of my work thoroughly, accurately, and in an organized fashion
AB	to recognize the difference between collaboration and cheating/scientific misconduct	recognized the difference between collaboration and cheating/scientific misconduct
AC	to utilize the principles of green chemistry	utilized the principles of green chemistry

AD	to interpret my data beyond only doing calculations.	interpreted my data beyond only doing calculations.
AE	to learn problem solving skills.	learned problem solving skills.
AF	to learn about what distinguishes ethical laboratory behaviors from unethical ones	learned about what distinguishes ethical laboratory behaviors from unethical ones
AG	to feel intimidated.	felt intimidated.
AH	to make some of the decisions about how to carry out the experiment	made some of the decisions about how to carry out the experiment
AI	to learn chemistry that will be useful in my life.	learned chemistry that will be useful in my life.
AJ	to think about what the molecules are doing.	thought about what the molecules are doing.