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Shanna Nesser

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A Look at the Effectiveness of High School Chemistry Curriculum in Preparing Students for the ACT

by

Shanna Elizabeth Lavergne Nesser

A Dissertation
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the College of Arts and Sciences
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Approved by:

Dr. Rachel Gisewhite, Committee Chair
Dr. Julia Cwikla
Dr. Richard Mohn
Dr. Julie Pigza
Dr. J. Hugh Broome

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ABSTRACT

In the ever-changing world, students are challenged with cultivating the skills and knowledge needed to handle the pace and level of understanding required to excel in their future. The foundation for a student's future begins in their formative years, but high school is a prime environment for nurturing the applied, critical thinking, and problem-solving skills needed to move forward into independent, adult life. Mississippi schools are ranked by an accountability score, which is used to determine fund allocation and the development of improvement plans. This score is compiled by looking at various state-tested courses, *College and Career Readiness Standards* (MS CCRS) scores (including the ACT), and graduation rates. Chemistry is not an accountability subject, but students who take chemistry also take the ACT in the same year. In this case, the ACT serves as a tool for accountability and a tool for predicting college readiness and success (ACT.org, 2016). Given that the skills needed to succeed in chemistry are also needed to succeed on the ACT, it seems prudent to find ways to help students understand the chemistry content while simultaneously strengthening the skills to do well on the ACT Science sub-test.

To address this, a two-tiered study was conducted over five years to determine if integrating an Inquiry-Based (IBL) method, specifically Process Oriented Guided Inquiry Learning (POGIL), would benefit student chemistry success and increase scores on the ACT. The first two years looked at the effects of POGIL integration by comparing 3 assessment scores (Pre-test, Post-test, and ACT science sub-test). Years 3-5 sought to establish a difference between teaching methods by comparing the effects of POGIL integration versus non-POGIL integration The POGIL and non-POGIL classes were taught by two different teachers, and the scores were compared through the 3 same assessments (Pre-test, Post-test, and ACT Science sub-test).

The research significantly impacts student ACT Science scores over a five-year period. The two-tiered study indicated that students were better prepared to be successful on the ACT science test. The change came through using critical thinking in the chemistry classroom in controlled environments and helping students build capacity with those skills.

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DEDICATION

To My Husband, John, thank you for being there as support through this process. Your ability to encourage and push me to keep going knows no equal. I couldn’t have done this without you. I love you!

To my children, Christian and Caroline, you two have kept me smiling when things got tough and have been so understanding throughout this process. Thank you for being wonderful. I love you both!

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GLOSSARY OF TERMS

1. *Chemistry Education* refers to teaching and learning in chemistry (NRC, 2012).
2. *Critical thinking* is a process of thinking that requires skillful analysis of a subject by assessing and making connections between pieces of information (criticalthinking.org, 2020).
3. *Scientific understanding (literacy)* is the understanding of scientific concepts and the processes needed for individual participation in world affairs and being a productive citizen (Lambrozo, 2015; National Academy of Science, 2019).
4. *Problem-solving* can be defined as a process through which an individual forges or constructs an answer while considering various options (Cooper & Stowe, 2018).
5. *IBL (inquiry-based learning)* is a process in the classroom that allows students to mirror scientific processes to construct information and allows the student to develop hypotheses and use problem-solving skills to actively participate in generating new information using with the help of their peers (Keesleman, 2003; Pedaste, Mäeots, Leijen, & Sarapuu, 2012; (Pedaste & Sarapuu, 2006)
6. *Scientific curiosity*- the desire to seek out and obtain scientific information for the sake of learning (Carey, 2017), those who are science-curious find joy in solving problems and learning about the scientific world (Gurteen, 2021)
7. *Processed Oriented Guided Inquiry Learning (POGIL)* is defined as a student-centered, learning strategy where students follow a research-based learning cycle to design, explore and construct content understanding through critical thinking and application of knowledge (POGIL.org, 2022)

8. *Zone of Proximal Development (ZPD)* is an educational construct by Vygotsky, that focuses on a student’s ability to successfully complete tasks compared to the rate of completion by their peers (Walker, 2010; Gauvain, 2020)

LIST OF ABBREVIATIONS

ACT	American College Testing
ANOVA	Analysis of Variance
CBA	Chemical Bond Approach
CHEMs	Chemical Education Materials Study
IBL	Inquiry-Based Learning
MDE	Mississippi Department of Education
MS CCR	Mississippi College and Career Readiness
NCLB	No Child Left Behind
NGSS	Next Generation Science Standards
NRC	National Research Council
NSTA	National Science Teachers Association
PBL	Problem Based Learning
POGIL	Process Oriented Guided Inquiry Learning
SAT	Standard Achievement Test

CHAPTER I – INTRODUCTION

Scientific literacy, quantitative thinking, and analysis are important skills that can be developed during high school chemistry classes. With society becoming more focused on technology and the ease of finding information, students have become more dependent on looking up information and not as focused on investigating, dissecting, understanding, or learning the skills needed to independently make meaningful connections within and across the content. An obstacle I faced as a high school chemistry teacher consistently centered on the question, “How do I teach students to process and analyze information that they can easily search and find using the internet?” Simply memorizing information is not enough. Students will face high-stress situations in the workplace where they will be expected to analyze, strategize, and problem-solve at high capacity. These life and workplace skills for success and adaptability begin in the high school classroom.

Chemistry teachers do not have a state test, nor are the course outcomes directly scored for accountability in Mississippi. However, once in the chemistry classroom, students realize chemistry is not just another science, it is more than atoms and molecules. It is a course demanding critical thinking and processing skills. Unfortunately, many students realize too late they cannot get through the course with straight memorization. According to the Mississippi Department of Education (MDE) science standards, “it is essential to the scientific process, requiring students to quantify, analyze, and present results. Students must be familiar with data analysis, critical thinking, and recording their data; students must organize and analyze it before presenting their findings (2018, p.13).” These critical skills are valuable in science and crucial for preparing students for college careers and to be effective citizens after high school. They are also beneficial skills for excelling in standardized testing like those in the state-tested courses and the American College Testing (ACT) college readiness test.

Students’ reliance on quickly retrieved answers and default to memorization is a function of the national focus on standardized testing. The ultimate goal is to help students overcome the ever-present crutch of technology and develop deep reflective thinking and scientific skills regardless of content matter, and processes, analyze, and problem solve and apply these skills in any situation, whether in the classroom or the job site. I posit that students develop and demonstrate a better understanding and retention of applied scientific skills and can better communicate knowledge gained during guided Inquiry-Based Learning (IBL) activities compared with more traditional chemistry classroom practices.

1.1 Background

1.1.1 Chemistry in the Classroom

The past century has given way for methods and instruction in the classroom to fluctuate due to changing school policies and changes in classroom focus. In Mississippi, Science Standards have changed twice since 2009, with new standards implemented in 2010 and 2018 (MDE, 2019). Students need a well-organized chemistry curriculum to develop intellectual independence and take initiative in their learning regardless of the current science standards. In the past ten years of teaching, I have noticed that students consistently struggle with long-term understanding, applying multiple concepts, and expressing frustration in the classroom due to difficulty in problem-solving and critical thinking. Mississippi standards and students’ hesitant attitudes about the course content, in general, have led to considering what can be done to support student learning for long-term understanding and retention, as well as problem-solving and processing skills that can be beneficial in other high school and college courses. By looking at chemistry curriculum changes over time, I will show a link between historical and current research in chemistry curriculum and the need for a purposeful addition of material/teaching tools, such as the IBL method Process Oriented Guided Inquiry Learning (POGIL) to help students with retention, critical thinking, and problem-solving.

Chemistry education reform can be historically analyzed starting from the early 1900s. Early research shows the need for a well-rounded, inquisitive look into chemistry content to develop a deeper and more complete understanding of chemistry. Through the years, the most effective staple in the chemistry curriculum has been hands-on or active learning. Early chemistry literature posits that lectures were for the recitation of material, demonstrations, material drills, and board work (Bawden et al.,1929). As far back as 1929, literature references the need for “tutorial or autonomous courses” (Havignhurst,1929). An autonomous course encouraged student responsibility in their learning and helped facilitate critical thinking and problem-solving. The students were to take information from previous lectures and apply it through experimentation and research to make predictions about their observations and glean information from data collection and active experiences in the classroom. These early chemistry educators described the role of the teacher as merely a guide (Reed, 1929; Bawden et al., 1929). Bawden et al. (1929) researched an alternate approach to lecture and memorization by studying a supervised study method. These methods included student group work, hands-on and inquiry-based, and teacher facilitation of questioning. Current chemistry education research in IBL and my experience in the classroom suggest students learn best and retain knowledge while actively engaging in classroom discussion and activity. The advancements in chemistry education could profoundly impact student success by using more purposeful activities and testing in the classroom.

According to the MDE Chemistry Curriculum (2018), "the nature of science refers to the foundational concepts that govern the way scientists formulate explanations about the natural world to increase the depth of understanding based on evidence, logic, and innovation (p.74)." Chemistry requires students "design data tables and draw conclusions using mathematical computations and/or graphical analysis. It is recommended that students should actively engage in inquiry activities, laboratory experiences, and scientific research (projects) for a minimum of 30% of class time" (MDE, 2018, p.74). Unfortunately, I have witnessed chemistry students struggle to connect bits of data and draw conclusions. They ask for a step-by-step method that will allow them just to plug in numbers and not process the information, defaulting to lower-order thinking skills. To combat this, the 2018 changes in MS College and Career Readiness Standards (MS CCRS) require students to focus more on the process and not straight science content to promote "student mastery of both disciplinary core ideas (concepts) and application of science and engineering practices (skills) to support student readiness for citizenship, college, and career (MDE, 2018, p. 74)." This document mirrors this sentiment in all areas of science and has imported many of these skills into the chemistry curriculum.

With the shift in focus of the chemistry curriculum over time (this has not really been demonstrated at this point – either add to above paragraph or some here), there is also a need for students to understand the development of chemistry content and a strong link between the classroom and everyday life. Students need to see a purpose in learning chemistry and how it relates to technology, society, and the historical perspective of science, including many philosophical approaches because of the abstract nature of the science students have a difficult time understanding chemical processes (Sjostrom, 2014). Throughout the history of chemistry education, there have been many different attempts to make teaching and learning more efficient and effective for modern students. Further, through the various reform efforts and requirements of daily life, students are faced with a greater need to problem solve and process large amounts of information to draw conclusions. Through the development of chemistry education practices, there is a substantial connection that can be made between classroom instruction and hands-on learning to help students experience what they are learning through kinesthetic activities (Orna, 2015). “The vast majority of chemistry educators believe that hands-on experience is an opportunity for students to deepen their understanding of chemical concepts, as well as an assessment tool for teachers (Orna, 2015, p.12).”

1.1.2 POGIL – Process Oriented Guided Inquiry Learning

One example of a guided inquiry system for teaching Chemistry and Biology was developed by such as POGIL, which allows students to experience challenging content through the strategic use of previous knowledge integrated with exposure to new material (POGIL, 2019). *Processed Oriented Guided Inquiry Learning (POGIL)* is defined as a student-centered learning strategy where students follow a research-based learning cycle to design, explore, and construct content understanding through critical thinking and application of knowledge (POGIL.org, 2022) The foundations of POGIL directly align with the MS CCRS, as they focus on developing content mastery through purposeful questioning and improving learning skills (POGIL, 2019).

1.1.3 Chemistry and the ACT

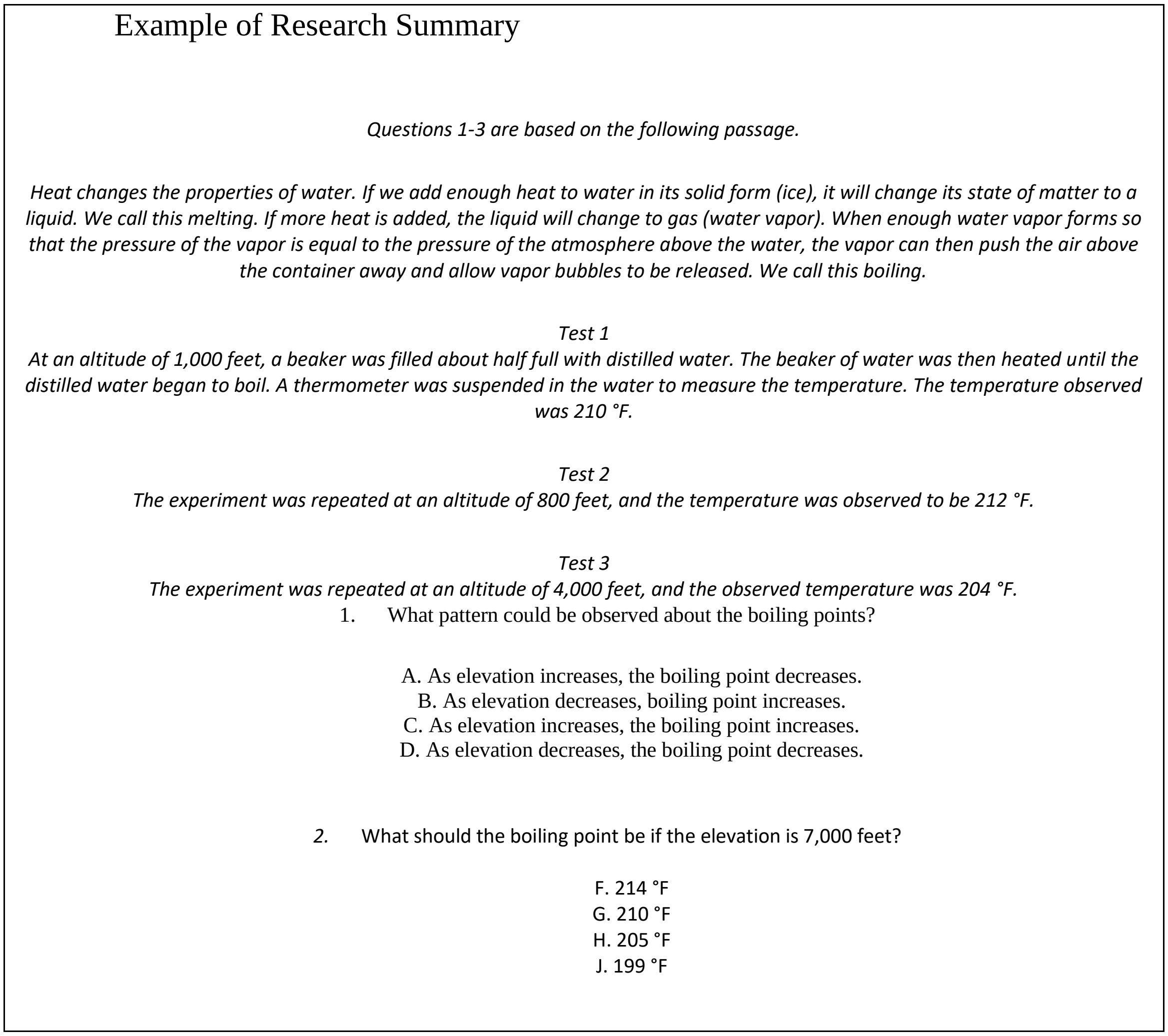
Over the past decade, universities have made ACT scores a major consideration in students' admission as well as placement in college courses. The ACT was created in the 1950s under the name the American College Testing Program (ACT Inc., 2006) as an alternative to the SAT (Standard Achievement Test). As college admissions and enrollment increased, institutions looked to the ACT to help determine admission standards and it provided a new way for the national comparison of applicants (ACT, Inc., 2006). Through the years, ACT has modified its testing strategies and image to better suit the needs of the changing world and has several content components including science and chemistry content items (Princeton Review, 2019).

The ACT set baseline scores for each subsection to help predict a student's probability of success in a college curriculum. Baseline scores were separated into middle-skill majors (business and accounting) and high-skill majors (chemistry, physics, and scientific research) (Steedle et al., 2019). Research conducted by the ACT guided the definition of a base score for each sub-test to predict a 50% chance of a student obtaining a B average in the program. The ACT college readiness score for science is 23 out of a possible 36). This score is indicative of a student who would function as a B student in a college science course.

The ACT science sub-test is a 40-question assessment administered over thirty-five minutes. The test is not based solely on scientific knowledge. Basic science content understanding is necessary, but the science sub-test focuses on understanding and interpreting scientific information. A student is asked to read and analyze data, charts, graphs, and research information to make connections and determine the meaning of the research given (Princeton Review, 2019). The ACT science test assesses information processing, communication of results, critical thinking, and problem-solving. These skills are assessed through three types of passages: data analysis, research studies, and conflicting viewpoints. Data analysis examines a student's ability to interpret data in a graph or chart. It assesses a student's ability to draw conclusions and make predictions based on the data given. The research studies passages measure a student's ability to analyze a series of experiments and predict possible causes and effects. Research summaries (see Figure 1) will also ask a student to decide why something may have gone wrong or what would happen if a particular change was made to the experimental process. Finally, conflicting viewpoints allow the student to compare various perspectives on a scientific topic and compare/contrast the viewpoints to draw conclusions on the issue based on all the perspectives given (Princeton Review, 2019).

Students are expected to have a good foundation in critical thinking and problem-solving skills to respond to these questions correctly, and while there is no explicit mention in the MS CCRS of alignment to the ACT, the connection is clear. According to ACT research in 2019, students in Mississippi had an average science sub-test score of 18.4. This number is well below the college readiness score of 23. This data shows that about 19% of Mississippi graduating seniors were college-ready for science and has remained consistently around 20% over the previous three years (ACT, Inc., 2019).

Figure 1.1 . *ACT Research Summary Example Passage* *(MyCollegeOptions.org, 2021)*



Example of Research Summary

Questions 1-3 are based on the following passage.

Heat changes the properties of water. If we add enough heat to water in its solid form (ice), it will change its state of matter to a liquid. We call this melting. If more heat is added, the liquid will change to gas (water vapor). When enough water vapor forms so that the pressure of the vapor is equal to the pressure of the atmosphere above the water, the vapor can then push the air above the container away and allow vapor bubbles to be released. We call this boiling.

Test 1
At an altitude of 1,000 feet, a beaker was filled about half full with distilled water. The beaker of water was then heated until the distilled water began to boil. A thermometer was suspended in the water to measure the temperature. The temperature observed was 210 °F.

Test 2
The experiment was repeated at an altitude of 800 feet, and the temperature was observed to be 212 °F.

Test 3
The experiment was repeated at an altitude of 4,000 feet, and the observed temperature was 204 °F.

1. What pattern could be observed about the boiling points?

A. As elevation increases, the boiling point decreases.
B. As elevation decreases, boiling point increases.
C. As elevation increases, the boiling point increases.
D. As elevation decreases, the boiling point decreases.

2. What should the boiling point be if the elevation is 7,000 feet?

F. 214 °F
G. 210 °F
H. 205 °F
J. 199 °F

Along with the pressure for students to achieve higher ACT scores, Mississippi has emphasized high school state tests in four core areas: Algebra I, Biology I, English II, and US History. The push for students to excel in state-tested areas has increased the pressure on teachers and administrators to prepare students to achieve high scores to maintain a passing school accountability score. High school accountability brings recognition to the school and drives monetary awards for facilities and teachers' salaries. This shift in priority has diminished the ability of students to learn through inquiry and problem-solving in favor of making sure students learn the objectives measured by the standardized test (ACT, 2014). That amount of material is expansive and both local and state pressures incentivize teachers “teach to the test.” Course curriculum and ever-growing content have pushed to fact-based lectures and shortened the time established for student discovery and application. This has led to more low-level memorization of facts and quick recall for students to handle the amounts of information given.

The ACT science sub-test, however, does not measure specific science content that can be memorized but assess how well students use the content and problem-solve. Because the ACT science sub-test is primarily centered on analysis and critical thinking instead of a science curriculum, students have conflicting messaging. They are expected to memorize and succeed in the high school classroom and state assessment, but to demonstrate potential at the next level, in college must show they are master problem-solvers and critical thinkers.

Because Chemistry is NOT a state-tested subject in Mississippi, we have this opportunity to use this course as a bridge to transform students’ way of being and learning from rote memorization to critical thinking and application. The chemistry curriculum introduces students to new material while requiring them to analyze and interpret information. In the classroom, a student is expected to learn and master skills using critical thinking and problem-solving. Chemistry requires many processes and applications beyond basic understanding. A well-organized chemistry curriculum that requires students to develop intellectual independence, to take the initiative in their learning, facilitates these transferable life skills. This directly aligns with the constructivist learning theory, which serves as the theoretical framework for my dissertation.

1.1.4 Constructivism as a Learning Tenet

Bodner (1986) explains constructivism as a learning theory in which students formulate knowledge and understanding in their minds. This is apparent when teachers ask chemistry students to reflect on their understanding of previous experiences and guide their thought processes to help them to construct new knowledge. Learning is an active process that infuses prior knowledge with new information rather than simply replicating pre-existing experiences (Cooper & Stowe 2018). Active learning is a central tenet of the Constructivist Theory of teaching (Piaget, 1970) because learning is most effective when students actively try to construct knowledge from the learning environment and are allowed to develop new understandings through modification (diSessa, 2014). In chemistry classes, the self-construction of knowledge can be fostered and intentionally designed in the curriculum in many ways through hands-on activities, lectures, and inquiry-based activities.

Science curriculum across the country has shifted to using IBL to incorporate active learning and constructivist tenets (Hofer et al, 2018). IBL aligns with constructivism allowing students to start with a question or problem and think through the answer using other guiding questions, giving them the flexibility to make mistakes and construct their understanding and knowledge. The tenets of constructivism support the underlying foundations for this study and my choice to integrate an IBL method to promote critical thinking and problem-solving schools in my chemistry classes and for the student's future success.

The United States National Research Council (NRC) states that “science as inquiry” is a major factor in students learning science from preschool through the completion of secondary education (National Research Standards, 2000). IBL is centered on a student taking an activity/problem/assignment and using their foundation in the scientific process to make observations and predictions, while collaborating with peers in a teacher-facilitated environment (Weaver, 2008; Herron, 2009, & Smallhorn, 2008). By the required chemistry standards, using POGILs is a way to incorporate activities that build on prior chemistry knowledge and guide students to use new information to develop and create their understanding. Further, POGIL systems are geared for constructive learning and are similar in structure to questions and scenarios assessed on the ACT, which makes them an ideal approach to use in addressing the question of POGIL is beneficial in helping to strengthen skills also needed to be successful on the ACT science sub-test.

1.2 Problem Statement

ACT scores are predictors of college success and I suspected meaningful guided inquiry activities (i.e., POGIL), practice assessments, and purposeful questioning would help students (1) improve their understanding and application of problem-solving and critical thinking skills success in Chemistry and (2) these strategies would also increase ACT science scores as well. The data collected from this study were used to answer the research questions below.

1.3 Research Questions and Hypothesis

To address the issues outlined above, descriptive analyses and significance testing were used to investigate the following:

- Research Questions
    - Does using POGIL in a chemistry class improve student critical thinking and problem-solving skills as assessed by comparative science sub-test ACT data?
    - How do students learning with POGIL in chemistry perform on ACT sub-sections versus peers not learning with POGIL?
- Research Hypothesis
    - There will be a positive difference in student achievement on the ACT science sub-test through the introduction of Inquiry-Based Learning (IBL), specifically Process Oriented Guided Inquiry Learning (POGIL)

1.4 Research Parameters

Student test scores were collected from chemistry classes in a rural Mississippi high school over five academic years (2016-2017 to 2020-2021). Students self-selected chemistry for their classes in their junior year. They were randomly placed in classes from the general education population. The study intended to answer the research questions about the use of IBL, specifically POGIL, as part of the chemistry curriculum to increase student science scores. The study also looked at the test scores between two classroom groups: POGIL-integrated and non-POGIL-integrated.

The data for this study included three assessments given to each student: a practice ACT pre-test, a practice ACT post-test, and the ACT science sub-test. The pre-test and post-test were former ACT science sub-test passages. The pre-test was given during the first week of the semester, and the post-test was given during the last week.

The ACT science sub-test scores were collected from the February school-wide accountability assessment. All assessments were taken in person during a 35-minute testing period.

1.5 Assumptions

In this research study, valid conclusions depend on data collection and analysis. Assumptions for this study include student integrity and effort in assessment completion, and all assessments follow standard testing protocols.

1.6 Outline for Dissertation

The remaining chapters will explore the development of techniques and curriculum in the chemistry classroom, how they align with the skills outlined in the MS CCRS, and how those skills are also needed to successfully pass the ACT science sub-test to determine if making more purposeful changes to chemistry curriculum and instruction can better serve high school chemistry students in their future successes. This outline guided my research and analysis of literature and data collected over five years.

Chapter two will outline historical teaching methods in chemistry dating back to the turn of the 20th century. The purpose of the literature is to show early methods and standards of the chemistry curriculum and how it has changed through educational research and policies to current methods and standards. This literature will establish a timeline through various teaching processes, documenting research that reports that teaching chemistry cannot be successful if attempted using a monochromatic approach. The literature timeline additionally presents information on learning theories in science that shows how constructivist tenets have laid the foundation for better teaching methods in chemistry education. A discussion on constructivism will lead to the analysis of inquiry-based learning and POGIL. These sources are beneficial in creating a link between educational research and the classroom. The literature will be used to show a definitive link between the tenets of POGIL and the skills assessed in the ACT. Conceptually, both ACT and POGIL are highly dependent on critical thinking and problem-solving. For this reason, I used POGIL with the chemistry curriculum to help students refine critical thinking and problem-solving abilities. Because chemistry understanding is highly dependent on critically thinking through chemical processes and formulas, I hypothesized the results from implementing POGIL in the chemistry curriculum would demonstrate clear reasoning for the use of POGIL in chemistry to promote greater success on the ACT.

Chapter 3 will take an analytical look at the research data. Junior ACT science sub-test scores with pre- and post-practice ACT science sub-test scores were analyzed to investigate any differences in testing with new instructional methods in the classroom. By conducting a mixed ANOVA (2016-2017 and 2017-2018) and a One-Way Repeated Measures ANOVA with an independent t-test (simple effects measure) (2018-2019, 2019-2020, and 2020-2021) of both the pre-, post-test, ACT data and by comparing that information to the official ACT science sub-test scores, data was examined to see if there was a statistical difference in years 1 and 2 with students' scores from pre-test to ACT and in years 3 to 5 if there was a statistical difference in pre-test and ACTs between a POGIL-integrated and a non-POGIL classroom. The quantitative methodology and analytical procedures for data analysis are also outlined. Chapter four is the discussion of data findings and results. In the final chapter, a summary of the study, conclusions on the hypothesis, and considerations for potential implications for chemistry teaching and learning and ACT success are based on the data. A list of the components of this study, which could include student demographics and timing is provided. Student data was collected from 2016-2017 through the 2020-2021 school year. Additionally, the implications for future research and testing are discussed. The results of this study can be an integral part of improving science education in Mississippi. By using IBL, POGIL, or others, teachers can help strengthen student understanding of the subject while supporting student growth in college and job-applicable skills.

1.7 Important Terms

The following terms are used in this research study. The meaning and context of the words should be fully understood as it applies to this research.

- *Chemistry Education* refers to student learning and instruction in chemistry (NRC, 2012).
- *Critical thinking* is a process of thinking that requires skillful analysis of a subject by assessing and making connections between pieces of information (criticalthinking.org, 2020).
- *Scientific understanding (literacy)* is understanding science concepts and the processes needed for individual participation in world affairs and being productive citizens (Lambrozo, 2015; National Academy of Science, 2019).
- *Problem-solving* can be defined as a process through which an individual creates or constructs an answer while considering all options (Cooper & Stowe, 2018).

- *IBL (inquiry-based learning)* is a process in the classroom that allows students to mirror scientific processes to construct information. It allows the student to develop hypotheses and use problem-solving skills to actively participate in generating new information with the help of their peers (Keseleman, 2003; Pedaste, Mäeots, Leijen, & Sarapuu, 2012; (Pedaste & Sarapuu, 2006)
- *Scientific curiosity* is the desire to seek out and obtain scientific information for the sake of learning (Carey, 2017); those who are science-curious find joy in solving problems and learning about the scientific world (Gurteen, 2019)
- *Processed Oriented Guided Inquiry Learning (POGIL)* is defined as a student-centered learning strategy where students follow a research-based learning cycle to design, explore, and construct content understanding through critical thinking and application of knowledge (POGIL.org, 2022)
- *Zone of Proximal Development (ZPD)* is an educational construct by Lev Vygotsky that focuses on a student's ability to complete tasks compared to the rate of completion by their peers (Walker, 2010; Gauvain & Munroe, 2020)

CHAPTER II – LITERATURE REVIEW

Over time the ACT has become a staple of college preparedness, and the skills most often tested are critical thinking and problem-solving. These same skills are essential in teaching the sciences and extremely important in chemistry due to the sometimes-abstract nature of this science. As such, intentional instructional processes and procedures can help students learn the state-mandated chemistry curriculum requirements while fostering the skills needed to succeed on the ACT. To understand the need for this type of instructional change, this chapter begins by outlining the historical development of modern chemistry curricula starting from the early 20th century. Constructivist theory and inquiry-based learning processes (IBL), such as Process Oriented Guided Inquiry Learning (POGIL), will be discussed along with their usage in chemistry. This literature review demonstrates how using these instructional strategies in chemistry education can help students be more successful in the ACT science sub-test.

Since the turn of the 20th century, new advancements and improvements in K-12 chemistry education can be accounted for in educational curriculum reform. The change was necessary because early chemistry classrooms were centered around basic chemistry and lacked connecting theories or fluid concepts (Lloyd & Spencer, 1994). Due to a series of discoveries in chemistry, such as atomic theory, acid-base theories, bonding (Sheppard, 2005), and especially the discovery of the neutron by James Chadwick, educators reformatted the high-school chemistry curricula to give students a more robust set of math and science skills (Lloyd, 1992) needed to keep up with the field. Reform efforts over the last century have made the education process more efficient and effective for modern students. These reforms included curricular changes, incorporating new activities and labs, implementing interventions, and adding computer and technology advancements (Cooper, 2015). The changes made in classroom standards and instructional methods throughout the history of chemistry education reform can all be functional parts of a well-rounded and developed chemistry education. Examining these changes over time, however, highlights the skills students need for success in chemistry and the strengths of current methods to hone those skills.

2.1 Overview of Chemical Education Reform Efforts

2.1.1 Teacher Preparation as Impetus for Reform

The nature of early 20th-century educational preparations in the United States did not adequately prepare teachers for chemistry instruction, inhibiting student learning in the chemistry classroom. Teacher preparation classes were geared towards chemistry research and development and not for educational purposes. These classes centered around pre-service teacher exploration and detailed understanding and did not address methods of teaching chemistry. The lack of teacher pedagogical preparation led to issues such as feeling inadequately prepared in effective instructional strategies and curriculum design, college courses centered on research skills that left teachers not thoroughly understanding the subject matter, and scarcity of funding all attributing to low pre-service teacher motivation for learning the subject.

Along with incomplete chemical education, teachers referenced a lack of uniform teaching methods and insufficient grading rubrics as the main problems in chemistry education (Hale, 1929). Teachers of early chemistry education also were ill-prepared to define learning objectives. As time moved forward and through various reforms, objectives have become more defined but lack some clarity. In education, the term *learning objective* can be defined as “a brief statement that describes what students will be expected to learn by the end” of a given period (*Hidden Curriculum,* 2014). Around the turn of the 20th century, until the Soviet Union launched Sputnik into Space in 1957, clearly defined learning objectives and outcomes were absent in the chemistry curriculum. Teachers were forced to make assumptions about what students were to learn, or learning objectives were left to interpretation as teachers' background in chemistry was self-taught and were teaching themselves the chemistry content. Finally, early chemistry research indicated that teachers’ training in research skills over pedagogical content knowledge (PCK) made them unable to consistently link chemistry laboratory experimentation with real coursework topics despite chemistry not being rooted solely in research work but serving a purpose in many other areas (Worstall, 1929).

Chemistry is abstract in nature; teachers are attempting to impart an understanding of a sub-microscopic occurrence while not having the true ability to demonstrate what is happening visually. These early fundamental issues were the foundations for the beginning of reform to refine the chemistry curriculum in the United States. Hale (1929) added that the advancement of school assets, including buildings, equipment, and educators; increasing value placed on college and technology; the birth of chemical publications in America; the development of the American Chemical Society in the US; the importance of research and graduate school; and finally, the battle between classical education and science education were all part of an educational staircase in the quest to properly educate students in the field of chemistry.

2.1.2 Early Chemistry Curriculum Reform

Although there was a push for curriculum reform in the late 19th century due to changing social context, disease, and development of technologies through the Industrial Revolution, there was little success in an actual change in effective curriculum in science education (DeBoer, 2000; National Academies of Science and Engineering, 2019). To understand the need for reformation over time, we can look more closely at the historical development of chemistry education practices, starting with the initial placement of chemistry in the secondary science curriculum around the turn of the 20th century. Sheppard and Robbins (2005) explain that nationwide, the subject of chemistry was placed between biology and physics to have the proper influence on a student's developing science mind. This was an early decision in the formation of the subject of chemistry between the years 1890-1930. Students had been exposed to small amounts of chemistry in biology, which was critical to the development and implementation of chemistry in the secondary classroom because it meant that they should have been better able to handle the theory before moving on to a full chemistry course (Sheppard and Robbins, 2005).

During this time, Reed (1929) explained that there was a "scientific attitude" among chemistry teachers, which led them to focus on three main ideas: "an appreciation of the role of chemistry in modern life," "the fundamental principles necessary for advanced study," and "practical information for everyday living" (p.1036). According to Reed (1929), one approach for chemistry education during the early 1900s was to allow students to receive readings and information before coming to class so that they are already exposed to the subject matter. Students were to read pre-assigned materials before class and then demonstrate mastery and understanding of that material read before class by achieving strong scores on a homework assignment or pre-class assessment. Class time was for hands-on instruction and answering questions. Upon arrival to class, students would then be assessed on the material to gauge mastery and understanding of the given information. Reed stated that all class discussions were anchored in student experience and questions to gauge student understanding before the day's lesson. Student misconceptions were to be addressed with either lab experiments or lectures. Having students learn before coming to a class created a portal for students to get lost in the learning. Specifically, if a student did not have the raw ability to learn from the teacher, they made assumptions about the content, which often led to making incorrect conclusions. Misconceptions were exacerbated with further instruction. Suppose a student was not vocal in their lack of understanding. This might cause misconceptions to take root and cause further difficulties in understanding. This method made it difficult for students to understand chemical phenomena deeply.

Bawden et al. (1929) suggested a slightly more structured approach but very similar in its outcome. This technique was to help students go beyond lecture-based and laboratory-based learning in the chemistry classroom. He saw a need for multiple layered approaches to teaching: students were to get their knowledge from the textbook and classroom experiences (laboratory), and the teacher was a mere facilitator of questions. This was geared to foster critical thinking in the student. Students were responsible for mastery of the subject; however, due to insufficient text materials and problem sets, students ended up with a minimal understanding of the material. After completing the bookwork, students were to conduct a lab experiment to support learning. The laboratory was centered on elementary-type experiments that did not engage deep thinking or inquiry and utilized stepwise (listed) analytical procedures. There was no room for exploration or experimentation. This teaching method should have strengthened students' understanding of abstract concepts. However, due to a lack of cohesion between the lecture and lab, there were often huge gaps that created more misunderstandings. With this method, there was a 22.8% failure rate in the general chemistry course during the mid-1920s (Bawden et al., 1929).

2.1.3 The Implementation of Laboratory Procedure in the Chemistry Classroom

According to the previous section, earlier chemistry instructional methods suggested that learning was student-driven, requiring students to oversee their education. Former methods included additional questions and student preparation before teacher guidance. Kirk (1929) researched an alternate approach to lecture/memorization by studying a supervised study method. The supervised study method required students to put in two more hours of study before the instructor, like a study hall before class (see *Early Chemistry Curriculum Reform*). This allowed lecture and experimentation to be purposefully linked to show a continuation of information, thus leading to a higher retention rate and understanding rate. Flipped methods were structured for students to learn without lectures and were student-driven. Students were introduced to a topic at home and had time to process the information, thus allowing for more collaboration through both lecture and lab. There has been a resurgence of the flipped model through the evolution of science instruction. Kirk (1929) stated that the use of laboratories in chemistry education and the need for diversity in the classroom is essential, especially in various specialty areas, including general, analytical, and organic chemistry. “Laboratory experiences provide opportunities for students to interact directly with the material world” (National Research Council, 2006, p.31). By using lab experiences, students made sense of chemical content because they witnessed the chemical phenomenon as it occurred and brought meaning to learning. This opened time for teacher-guided review to help students focus on concept retention and understanding. The supervised study method averaged about 1% failure in each semester in 1929. The noteworthy decrease in failure rate was attributed to lab-based teaching and was significantly different from recitation methods (Reed, 1929).

Southern (1929) outlined an approach that centered around the question, “Why can’t we [the students] see everything we study about?” There was a gap in understanding documented during this time because students could not physically see and experience the happenings in a chemical process at the microscopic level. This prompted instructors to create a series of projects for the students to help them "see" what they are studying, also referred to as project-based learning (PBL). Research showed that teachers using a PBL process in their classrooms helped students better understand chemical reactions, fueled students' desire to learn chemistry, sparked interest in low-scoring students, and helped build a bridge or appreciation for the subject matter by linking it to everyday examples. However, the overall takeaway from this experimental method was that a student better-understood formulas, compound names, valence electrons, and free radicals (Southern, 1929).

Hjort and Woodward (1932) introduced the process of using micro-methods in the laboratory. Micro-methods are a process of teaching using microscopes and a small number of physical materials for observation-scale investigative learning. This could help to expand upon the use of PBL referenced by Southern (1929) to help foster student understanding of what was happening on the microscopic level in chemical processes. Three distinct advantages were found through this teaching method: it saved time due to shorter activities, reduced material usage, and minimized space needed to complete the activity. Hjort and Woodward concluded that the longer this micro-method approach was used in chemistry education, the more time was saved. They claimed that this efficiency would escalate student understanding in the future.

2.2 Mid- 1900s teaching approaches in Chemistry- The Shift

Due to a series of discoveries in chemistry, such as atomic theory, acid-base theories, bonding (Sheppard, 2005), and especially the discovery of the neutron by Chadwick, there was a reformatting of high-school curricula to give students a more robust set of math and science skills (Lloyd, 1992). The reform was necessary due to the inclusion of a species that was taking up space within the atom but did not affect the charge of the atom. This dramatically shifted the understanding of how the atom functioned and was balanced. Between the 1950s and late 1960s/early 1970s, there was a push in chemistry education to use a uniform and set way of delivering chemistry content to successfully incorporate the new findings of Chadwick and quantum mechanics. There was a need for a more efficient and holistic way to provide chemistry content.

During this time, the United States and Russia were in a scientific evolution toward space exploration and the education of the public. Many programs and projects started to help the US education system become more equal to that of Russia. With the successful launch of Sputnik by the Soviet Union, the United States government put measures in place to help strengthen science education in the US. This consisted of the

National Defense Education Act and the subsequent creation of the National Science Foundation (Hechinger Report, 2011). With the developments in Space exploration, the United States Congress passed the National Defense Education Act (1958) to springboard science education through the National Science Foundation (NSF) (Hercher, 2011). The NSF was designed to support scientific research, teacher training, and curriculum development. The NSF helped to support teacher training and curriculum development in science. The Chemical Bond Approach (CBA) and the Chemical Education Materials Study (CHEMs) were two main programs. They each were developed around the same time and focused on different areas of student growth and development while learning chemistry and preparing a student for the introductory year of chemistry in college. CBA focused on critical thinking through understanding the bonds of atoms, while CHEMs looked at developing understanding and problem-solving through laboratory experiences (Osborn, 1969). These two programs looked to help expand the modern student's view and understanding of current chemistry terminology and growth (Bell, 2015).

With these structured curriculum plans, educators began using the theory-first presentation, where the teacher was responsible for presenting research theory, and then students were released to learn the given content. The concept behind the theory-first presentation was that students were put through a rigorous program of study where they learned the theory behind the concepts before applying them. This sought to cancel the “unlearning” process later. The theory-first method later became the basis for general chemistry textbooks and chemistry course foundations until the next major revision of the curriculum around 1970. With this educational revolution, educators gained many supplementary texts, audio and visual aids, computer-based instruction, and a thoroughly redesigned curriculum (Bereit et al., 1964; Bell, 2015).

The Chemical Systems: Chemical Bond Approach Project (CBA) was a written text designed to introduce chemistry as a modern-day science. CBA broke the subject of chemistry into five parts: how atoms can interact to form compounds, the roles of the subatomic particles, the effects of the kinetic molecular theory, the relationship between the three concepts, and chemical equilibrium. Emphasis on content materials and engaging experiments was placed continuously throughout the book for the students to learn (Bereit et al., 1964). By using recurring themes and content focus, students could make much-needed connections to the experiments skillfully placed with content lessons. Research into the CBA text determined that the CBA course pushed students to link previously learned concepts to analyze and interpret new data, and the CBA course was less focused on memorization of all facts (Marks, 1967).

In 1971, there was a significant shift in science education reform to take students from understanding structures and principles to becoming scientifically literate (NSTA,1971). The National Science Teacher Association (NSTA) stated that scientific literacy was the most important outcome of science education (National Academy of Sciences, Engineering, and Medicine, 2019). With the call to science literacy, an increase in the use of mathematics, and a change in chemistry content complexity, the second major transformation towards a universal curriculum in chemistry education came during the 1970s (Lloyd, 1992; Sheppard, 2005; National Academy of Sciences, 2019).

The main question in this round of curriculum formatting was “whether a chemistry laboratory should be set up to teach instrumentation and procedure or whether it should be set up to have students learn to interpret data and how to ask and answer scientific questions” (Lloyd & Spencer, 1994, p. 206). The laboratory setting can be quite beneficial to a student’s understanding and learning. How the lab is conducted can help reinforce knowledge and lead to deeper understanding. The dilemma of using the laboratory as the foundation of learning was not immediately fixed but required years of curriculum reform to help better serve the lab needs of students, beginning with the creation of the “chemistry triplet” (Johnstone, 1989). Ultimately it was determined that laboratory experiences were necessary and needed to evolve from a traditional solo experience to one that would allow for the integration of laboratory activities (National Research Council, 2006).

2.3 Curriculum and Instruction

2.3.1 Reform in Chemistry Curriculum and Instruction

Due to changes in content, chemistry education methods, and curriculum reform, the teacher has continuously changed the cycle of learning to ensure students can both think through and apply their understanding of a given topic. Discoveries that led to changes in content (e.g., the Atomic Bomb) and the subsequent refinement of previous theories (e.g., atomic theory) have contributed to the ever-evolving teaching methodologies for those interested in chemistry content and learning. Despite the struggle it has caused chemistry teachers in early chemistry education, reform of the curriculum to focus on key concepts is essential to growing student understanding for depth of knowledge in these changing times. Curriculum reform, based on experience and research, should address the following areas: early access to information by students, empowering teachers, making curriculum flexible, timely implementation, and making chemistry accessible and understandable to the many, not just a few (Lloyd & Spencer 1994; Bowen, 1994; Science and Engineering, 2019). The curriculum should incorporate the content's fundamentals and essential teaching methods to foster student understanding. To address all areas of concern, there should be a clear focus on what is required for students to learn so that teachers are not left to make interpretations of important chemistry topics.

Curriculum changes over time have included reform to give students autonomy and ownership in their learning in at least one of the following areas: a core/modular approach, a zero-based curriculum, and a laboratory-based curriculum (Lloyd & Spencer,1994). In core/ modular reform, the curriculum assumes a singular set of chemistry concepts that all students should learn, and the teacher has the freedom to expand on these topics using a modular approach. Zero-based allows teachers to introduce chemistry theory as needed throughout the duration of the course, though no more theory than necessary. The final approach allows for laboratory-based instruction. This approach centers instruction around inquiry through experimentation first, allowing the teacher to expand using chemical theory (Lloyd & Spencer, 1994). According to DeBoer (2000), the laboratory component has remained a key focus of curriculum success. Students develop skills and experiences essential to growing scientific understanding in the laboratory, including deductive reasoning, hands-on experience, and quantitative application of science methods (DeBoer, 1991; National Research Council, 2006). However, using a singular approach, teachers and students are subjected to a one-dimensional interpretation of scientific knowledge.

In the chemistry classroom, students should be given every reasonable opportunity to learn and understand the subject matter. that reform in at least one area of science is beneficial, multiple areas of reform allow the student to truly learn and understand. Students can participate in various activities, including the lab and investigation, to actively build scientific knowledge (National Research Council, 2012; Singh and Kaushik, 2020). To understand the need for reformation over time, we can look more closely at the historical development of chemistry education practices, starting with the initial placement of chemistry in the secondary science curriculum around the turn of the 20th century. Sheppard and Robbins (2005) explain that chemistry was placed between biology and physics to have the proper influence on a student's developing science mind. This was an early decision in the formation of the subject of chemistry between the years 1890-1930. Students had been exposed to small amounts of chemistry in biology, which was critical to the development and implementation of chemistry in the secondary classroom because it meant that they should have been better able to handle the theory before moving on to a full chemistry course (Sheppard and Robbins, 2005). During this time, Reed (1929) explained that there was a "scientific attitude" among chemistry teachers, which led them to focus on three main ideas: "an appreciation of the role of chemistry in modern life," "the fundamental principles necessary for advanced study," and "practical information for everyday living" (p.1036).

According to Reed (1929), one approach for chemistry education during the early 1900s was to allow students to receive readings and information before coming to class so that they are already exposed to the subject matter. Students were to read pre-assigned materials before class and then demonstrate mastery and understanding of that material read before class by achieving strong scores on a homework assignment or pre-class assessment. Class time was for hands-on instruction and answering questions. Upon arrival to class, students would then be assessed on the material to gauge mastery and understanding of the given information. Reed stated that all class discussions were anchored in student experience and questions to gauge mastery and understanding of the given information. Reed stated that all class discussions were anchored in student experience and questions to gauge student understanding before the day's lesson. Student misconceptions were to be addressed with either lab experiments or lectures. Having students learn before coming to a class created a portal for students to get lost in the learning. Specifically, if a student did not have the raw ability to learn from the teacher, they made assumptions about the content, which often led to making incorrect conclusions.

Misconceptions were exacerbated with further instruction. Suppose a student was not vocal in their lack of understanding. This might cause misconceptions to take root and cause further difficulties in understanding. This method made it difficult for students to understand chemical phenomena deeply. Bawden et al. (1929) suggested a slightly more structured approach but very similar in its outcome. This technique was to help students go beyond lecture-based and laboratory-based learning in the chemistry classroom. He saw a need for multiple layered approaches to teaching: students were to get their knowledge from the textbook and classroom experiences (laboratory), and the teacher was a mere facilitator of questions. This was geared to foster critical thinking in the student. Students were responsible for mastery of the subject; however, due to insufficient text materials and problem sets, students ended up with a minimal understanding of the material. After completing the bookwork, students were to conduct a lab experiment to support learning. The laboratory was centered on elementary-type experiments that did not engage deep thinking or inquiry and utilized stepwise (listed) analytical procedures. There was no room for exploration or experimentation. This teaching method should have strengthened students' understanding of abstract concepts. However, due to a lack of cohesion between the lecture and lab, there were often huge gaps that created more misunderstandings. With this method, there was a 22.8% failure rate in the general chemistry course during the mid-1920s (Bawden et al., 1929).

An effective example of this is POGIL activities, which allow students to learn a topic using a modular-based design, where information is chunked and slowly introduced through critical thinking and analysis. As students would progress through the activity, teachers assess student understanding at prescribed checkpoints. reform of the curriculum aids student learning, changing how the material is presented can be mutually beneficial for students and teachers and continues to drive curriculum changes. An effective example of this is POGIL activities, which allow students to learn a topic using a modular-based design, where information is chunked and slowly introduced through critical thinking and analysis. As students make progress through the activity, teachers assess student understanding at prescribed checkpoints. While reform of the curriculum aids student learning, changing how the material is presented can be mutually beneficial for students and teachers and continues to drive curriculum changes.

In 1991, Alex Johnstone suggested that chemistry should be learned as a multilevel construct requiring students to think about chemistry on different conceptual levels: the macro, sub-micro, and symbolics (see Figure 2).

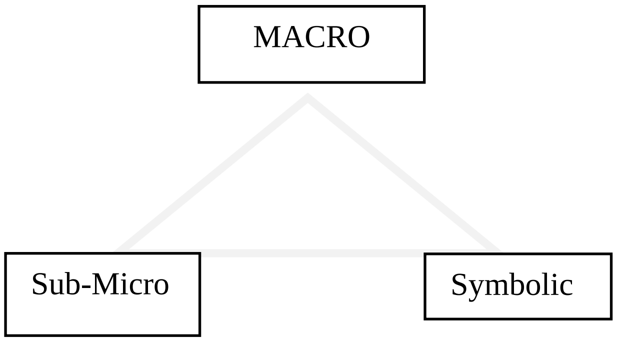


Figure 2.1 *Three levels of Chemistry thought (adapted from Johnstone, 1991, p.78 & Taber, 2013, p.157)*

The three levels of the chemistry triangle represented the physical descriptors of chemistry (macro), the individual components of chemistry such as atoms and compounds (sub-micro), and the models and representations (symbolics) (Johnstone, 1991; Johnstone, 2000). The chemistry triangle, or the "chemistry triplet," has become a pinnacle of chemistry and science education as it seeks to use theory and research to drive understanding (Talanquer, 2011; Taber, 2013). The development of the chemistry triplet could be viewed as a major turning point in how chemistry is taught in the classroom. It defines the complexities of chemical nature and began the conversation of needing multi-dimensional teaching described previously.

With the introduction of the chemistry triplet, chemistry education became more student-centered incorporating inquiry- and thought-based learning. The triplet focused on learning the three dimensions where students can make meaning of the physical, the abstract, and the symbolic aspects of the chemical world. These methods focused on deeper understanding from the students and more concise and accurate teaching from the educators. The triplet helped to back Bowen’s (1994) call for a learning environment centered on student-engaged learning where the teacher takes on the facilitator role. In Bowen’s study, student groups were working on solving a content problem; the teacher walked around listening to their reasoning and approach to creating an understanding of the problem. The teacher then interjected probing questions to get students to develop meaning from their learning. The purpose of the study activity was to engage educators and see if they were listening to their learners. Bowen referred to this example of IBL as a think-aloud method, which considers multiple variables such as identification of students, student cognitive levels, delivery of instruction, and interviews with the students (1994). The study concluded that by allowing students to talk through a given topic, the teacher was more likely to understand where misconceptions were happening and allowed students to share their understanding of a topic with their peers. Results like these attributed to IBL becoming a staple in science education towards the end of the 20th century.

Transitioning from a purely research-based chemistry classroom to the current mixed teaching models of today has been a long and arduous task—one that has had roadblocks due to need, culture, and societal expectations. To fully understand the undertaking in chemistry education reform, it is relevant to discuss the historical aspects of education focus and the need to nationalize standards and expectations in the classroom. By developing methods needed to fully teach all areas of chemistry, chemistry education has found a place in the world of academia. Chemistry education is no longer

100% research-focused; it is now essential for students to learn to apply knowledge and truly interact with the chemical world around them.

2.3.2 Late 1900s teaching approaches in Chemistry

During the 1980s and after the publication of *A Nation at Risk Report* (1983), science education evolved to reflect broad standards within the science curriculum (National Research Council, 1996). With this shift in the emphasis on content knowledge and scientific literacy, there was a transition in chemistry education from pure content facts to incorporating the historical aspects of the discovery and development of chemical processes and theory (Kamsar, 1987; National Academy of Sciences, 2019). Kamsar introduced the idea of teaching chemistry history and science objectives. By teaching these historical reference points, students could better link science to human experience, thus opening a connection for the student between the two. By linking the different science disciplines and history through the evolution of science education, it created common educational goals and a clearer path for educators to proceed (Kasmar, 1987; National Research Council, 2006).

For this to happen, Hodson (2008) stated that an individual needs to develop “an understanding of the nature and methods of science, an appreciation of its history and development, and an awareness of the often-complex interactions among science, technology, society, and environment” (p.23). The appreciation of history within the subject area allowed for linking different science disciplines and a better flow of understanding (Sjostrom, 2014). Curricula changes were brought about to give chemistry a more interdisciplinary feel where students could connect to different disciplines. The changes focused on three main areas of chemistry: material science, biochemistry, and environmental science. For example, materials science should cover all areas under metals, ceramics, and polymers. The biochemistry section of the course should link the basic life science processes to chemistry to show the need for both sciences to be utilized for complete understanding (Owens, 1995).

Sumter and Owens (2011) argued for the need for a common language that allows students to incorporate chemistry effectively into other disciplines. The methods they sought to implement were geared to introduce a medically relevant and concept-based approach to the second semester of general chemistry. Their approach sought to incorporate biology and chemistry content by merging the fundamentals of chemistry, medical approaches, and neuroscience to make lectures more efficient and effective. Using scientific knowledge from each area would help build a bridge between biology and chemistry, allowing students to better understand how the disciplines work together (Sumter & Owens, 2011). Because the two subjects were taught as separate sciences, there was no continuum in science literacy which left holes when adding concepts. Students couldn’t see the relationship in real life. Standard evolution sought to have students build a viable scientific argument using evidence gathered and applied logic to present a well-rounded scientific observation with explanations (National Research Council, 1996).

2.3.3 Modern Teaching Methods in the Chemistry Classroom

Since the early 2000s, there has been a shift in the teacher's role in the science classroom (National Academy of Sciences, 2019) to address questions related to how students best learn and what this means for student work. The National Academy of Sciences states that students need to “make sense of phenomena through exploration, reflection, and discussion” (2019, p.2). This concept is not too foreign from early chemistry teaching methods, but what has changed since early methods? How did we come full circle in our education methods? What makes this time different? To address those questions, there have been two significant curriculum changes in science: *No Child Left Behind* in 2010 and the Next Generation Science Standards (NGSS) incorporation in 2018. Rather than use the NGSS, the Mississippi Department of Education (MDE) published the Mississippi Career and College Readiness Standards (MS CCRS) in 2018. Creating a well-rounded, complete list of topics and standards is a daunting and nearly impossible task. For example, according to the MS CCRS Chemistry Standards, students need to be able to “analyze the periodic table to identify quantum numbers (e.g., valence shell electrons, energy level, orbitals, sublevels, and oxidation numbers) (MDE, 2018, p.75). For students to be able to meet this standard, they must have a background in electron configuration and periodic table layout. However, these topics are not explicitly addressed in the standards. As a result, addressing the standards to be taught requires teacher interpretation and building bridges of understanding for their students.

The organization of the standards has led to an instructional process that can vary from teacher to teacher and classroom to classroom, but the result is the same: the standards must be met. This can lead to teachers rushing through standards and leaving students who have not grasped the material behind. Currently, high-school chemistry is broken into various categories that attempt to give a well-rounded insight into the subject. Modern chemistry focuses on chemical mixtures, the development of chemistry, and chemistry in life. However, a modern lecture-based curriculum needs to shift to a more fluid, less structured “lecture” presentation to support the growth of technology in the ever-changing world. It allows for adaptations for students with short attention spans and the need to transition to different activities throughout the lesson. Teachers can take the theoretical framework and develop a method for scientific inquiry using a chemistry context. Students need a framework that allows for the complete absorption of the material, and the way scientific knowledge is constructed, validated, and communicated is the difference between a student's understanding and misunderstanding. This difference weighs heavily on communication in the classroom. Engaging in scientific conversation gives students access to a multifaceted atmosphere that allows them to fully digest and understand the full complexities of the presented information (Driver et al., 1994).

The rapid increase in chemistry understanding and the vast increase of technologies have created a bridge in teaching methods in the modern chemistry classroom. This approach is a combination of context-based and inquiry. This more rounded approach leaves room for narrative teaching (lectures), demonstrations, lab experiments, question-and-answer sessions, and projects (Yuksel, 2013).

Context-based chemistry is becoming more and more foundational to a successful chemistry course. A context-based chemistry course aims to help students better understand by building upon their levels of understanding (Bennett & Lubben, 2006). The process begins with a great deal of teacher professional development that allows teachers to investigate and experiment with the most effective way to deliver information for successful student learning (Stolk, 2011). Three questions need to be addressed when planning for context-driven course work: What is the role of the theory being used, who is known for having developed the concept, and what evidence was being used (Bennett & Lubben, 2006)?

Scientific inquiry has become one of the main focuses of successful science education and is an important sub-focus and an essential part of context-based teaching. Inquiry-based learning has become integral to science education in the last 30 years (Hofer, et. al.; 2018). Through IBL, students interact with real-world experiences. This allows teachers to facilitate student concept connection (Carey, 1986; Glaser, 1984; National Academy of Sciences, 2019) with prior knowledge can help students merge concrete and abstract thought to foster new ideas and understanding that will lead to multifaceted learning through inquiry processes (Gobert and Buckley, 2000; National Academy of Sciences, 2019).

To understand the content fully, students need to think through processes and engage in learning. Effective teaching is done efficiently by utilizing student knowledge with the following categories: deep subject knowledge, practical and useful equipment, the continuous focus on accuracy and reliability, and how the concepts go together (Van Rens, Pilot, & van der Schee, 2010; & Crawford, 2007). Teachers must be able to bring scientific inquiry into the classroom to help students build a bridge between content knowledge and their everyday world. Students must see a link between real life and textbooks to make relevant connections. If they only see atoms and round globes and do not have a correlation between their drinking water or their medications and their body, then they do not truly understand what they need to learn.

Students need to have everyday representations of the exact concepts they are being taught in the classroom. By having a tangible example of their studies, students can better link the concept to relative ideas (Driver, Asoko, Leach, Mortimer, & Scott, 1994). Lab activities are increasingly designed to allow students to gain skills, master concepts, and understand the nature of science in each task (Eubanks, 2015). For labs to be effective, they must be implemented correctly. They cannot just be an activity or a filler given in place of instruction; they must have purpose and meaning (Drury, 2018). Laboratory experiences must be integrated to “allow students to interact directly with the material world (or data drawn from the material world), using the tools, data collection techniques, models, and theories of science” (National Research Council, 2006, p.31). Teachers, however, cannot rely solely on hands-on laboratory activities. Experiences should include the opportunity to investigate possible solutions and outcomes for true student understanding (National Academy of Sciences, 2019).

Creating an environment that fosters investigation and inquiry can be tricky. Training deficits can hinder effective science inquiry in the classroom in terms of scientific foundation. This leads to a discussion of how the teachers articulate their understanding of science and what effect the teacher's personal views have on their students. Hofer attributes a lack of student knowledge and understanding and minimal materials and organizational support to teachers' inability to implement inquiry in the classroom. Factors influencing students' ability to succeed in an inquiry-based environment (Crawford, 2007). A critical consideration for determining a proper teaching approach to scientific inquiry is the students’ predetermined beliefs about science (misconceptions) and the actual dissemination of scientific knowledge in the classroom (Crawford, 2007). Teachers have had to methods outside of lectures to help further drive understanding in the classroom. Professional learning opportunities are integral to teacher efficacy and practice for being the vessel for inquiry within the science classroom (National Academy of Sciences, 2019).

Many attempts to reform science education assumed that all students and educators were starting from the same level of ability and access to resources (Science and Engineering, 2019). Ultimately, to be most effective for optimal student learning, changes in science education had to include cultural influences, lack of equality in funding, and gaps in content knowledge (National Research Council, 2002, 2012; Science and Engineering, 2019). Further, before a student can be exposed to the deeper facets of chemistry, the teacher needs to be aware of any preconceived notions. When preconceived notions and misconceptions are redirected to learning using accurate representations, inquiry techniques can be helpful. Scientific inquiry activities open the door for students to work in teams to ask questions of their peers and actively engage in meaningful conversation to glean knowledge through the application (Mehltretter Drury, 2018). There are some limitations, however, which include a lack of clarity in the assignment, low student buy-in, and voids in understanding due to misinformation.

2.4 Complications in Chemistry Education Reform

In chemistry, content is broken into three focus areas of understanding, they are macroscopic (things that we can see with the naked eye), sub-microscopic (something that cannot be seen with a microscope), and symbolic (things that are representative of scientific nature) (Johnstone, 1991; Eilks, Witteck, & Pietzner, 2012). These three areas in chemistry education must be mastered for the individual student's success. With a better understanding of the three areas of chemistry knowledge, teachers can use IBL to help students make connections within the three aspects. Hmelo-Silver et al. (2007) state that IBL is effective as long as the material is presented with support from a facilitator and under the condition that errors are part of the inquiry process. They stated that three concepts make IBL effective: important elements, level of open-endedness, and the interaction of the teacher facilitator (2007). By combining an IBL practice such as POGIL, which incorporates the effective components of learning with the three tiers of chemistry understanding, students have the potential to absorb and understand chemistry content more completely.

An underlying problem for students in chemistry education is when a student cannot see the scientific occurrence in real-time, although the wonders and depths of chemistry can be fully explained and explored at the submicroscopic level. Chemistry at the sub-microscopic level discusses topics that cannot be seen by the eye or even by regular microscopes. This makes chemistry an abstract subject area and harder for students to understand the topics more deeply.

Students cannot fully grasp the levels of complexity in what they cannot see in chemistry. Educators must take on the responsibility to help train them to better “see” the interactions that occur (Suits & Sanger, 2013). Direct visualization of the concept is impossible; pictures, videos, or other visual representations must be created often to foster understanding. Visual representations often involve discrete particles, individual atoms, and molecular structures. Student engagement with visual aids is due largely to their effectiveness in stimulating interest and understanding. Poorly constructed representations can hurt student growth and understanding (Eilks et al., 2012). Through time educators have developed visual representations to help explain what cannot be easily observed by the naked eye. These effective visuals also help the student to be able to observe occurrences at the molecular level (Jones & Kelly, 2015). This leads to a focus on a common approach to modern chemistry curricula, bringing in the added importance of animations, simulations, and visualizations in the classroom (Ashe, & Yaron, 2013). These tools are essential for the abstract understanding of students by allowing them to see individual molecular behaviors at a sub-microscopic level. Simulations can also be effectively used to boost student understanding. The complications come with balancing the three facets of chemistry so students can make sense of their learning and how it relates to their lives. Too much stimulus can leave the student in over their heads with dense materials and terminology, whereas under-activity can leave the student with many gaps in understanding and knowledge.

By combining molecular-level visuals, interactive chemistry simulations, and chemical processes and functions, the student can acquire a more well-rounded and in-depth understanding of the abstract nature of chemistry (Suits & Sanger, 2013). This supports an increased need for multi-media instruction both in and out of the classroom. Computer and technological advancements over time have been better adapted to give students a clearer understanding of the phenomenon, and they can provide a more accurate representation of the process. Conceptual understanding in the classroom has also been adapted to help support the visual and technological representations in chemistry (Jones & Kelly, 2015).

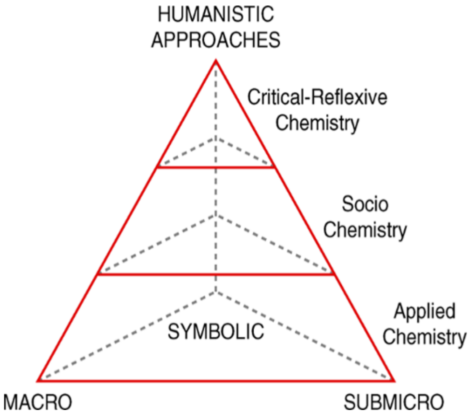
Visual representation of chemistry content is essential to further students' understanding in the classroom. New methods for designing effective and efficient visuals are needed to maximize student retention and understanding. The construction and use of appropriate visual aids will allow students to interpret the graphics and lead to a deeper understanding (Kelly, 2013). Computer and laboratory simulations are considered to positively reinforce chemistry content (Schwartz, Milne, Homer, & Plass, 2013). When choosing or developing appropriate visual aids or simulations for students, multiple factors need to be addressed to help students fully digest and incorporate the learning styles and needs of the student (Kelly, 2013). The way material is presented in chemistry must address the visual and microscopic levels. These factors include levels of understanding: behaviorist (the behavior of matter), cognitivist, schemata development (development of the information), and situated learning designs (Ashe & Yaron, 2013; Gregorius, 2013).

With the different chemistry levels needing to be addressed, models and diagrams are often introduced into the classroom. The context through which the model is introduced is just as important. The model must be relevant to the learning target and easily deciphered for the student. Through models, students can make a connection between what is seen macroscopically and what is happening microscopically.

Chemistry education is an expansive area of study; therefore, every aspect cannot be covered. This expanse can have models and activities that lack the total picture of the phenomenon that is being presented. With the change in focus in the chemistry curriculum and the need for visual representation, students must be able to link the development of chemistry content. There needs to be a strong link between chemistry teaching and everyday life. The student should be able to make the connection between chemistry technology, society, and the historical perspective of science, including many philosophical approaches (Sjostrom, 2014). Multiple layers of complexity in a chemistry lesson create a logistical nightmare for the teacher to develop lessons that meet learning objectives, visual understandings, and technological requirements. By building on the chemistry triplet, the curriculum can be expanded to look at multiple areas within the macro, sub-micro, and symbolic approaches.

Research points to students needing the link between chemistry and the contributors to the development of science to fully engage a student and allow for maximum understanding and retention. This approach to chemistry education is referred to as the humanistic approach (former symbolics) (Sjostrom, J., 2014.) Sjostrom also incorporates various levels of chemistry information in a triangular prism fashion. Chemistry education is a tiering process that allows teachers and students to incorporate visual aids, technology, history, and an in-depth understanding of all aspects of the chemistry curriculum (see Figure 2.2).

Figure 2.2 *Chemistry Triangle of Instruction* *(Sjostrom, 2014.)*



Using Sjostrom’s triangle can help to layer student understanding by anchoring learning into the three points and the three tiers of chemistry. In this representation, the triangle anchors the three major areas of understanding: the macro, sub-micro, and humanistic approach (relating chemistry to everyday life). Macro and Submicro are placed at the bottom of the triangle as the foundation for chemistry. In contrast, the humanistic element is placed at the top of the triangle to show true chemistry mastery. There are three levels of understanding within the three tiers: the applied (most basic), socio-scientific, and critical reflexive (most complex).

Socio-scientific issues are useful in helping to incorporate real-world issues into the chemistry curriculum in the current day and age (Sjostrom, 2014). Information used in lessons, the effects of socio-scientific subjects in the classroom, and participants' active engagement can help improve teaching effectiveness on style. Information can be used to drive content knowledge toward a deeper understanding by inquiry and design (Stolz, Witteck, Marks, & Eilks, 2013; Hofer et al., 2018). The critical-reflexive stage of understanding allows students to critically analyze situations using data, models, and formulas to get a multi-dimensional understanding of the coursework. This is the most difficult level to achieve due to a lack of critical thinking and problem-solving skills. The lack of skill makes it difficult for a student to achieve the level of understanding needed to grasp the abstract nature of chemistry. Students are being asked to explain and understand interactions between particles that they can’t physically see, but they are expected to describe how they function, move, and interact in the students’ world.

Along with the needs of the chemistry triangle of information, students are being faced with a greater need to problem-solve and process large amounts of information. This brings to the field the use of inquiry with a purpose, or IBL (National Research Council, 2000). Using guided inquiry activities like POGIL allows students to experience content through knowledge. IBL is not a new concept in the field of education. It has had its place in literature since the 1960s, starting with Dewey’s pragmatism (Hofer et al., 2018). IBL is a necessary educational tool that can help transform understanding of concepts to a deeper level. Inquiry learning is an academic construct that has rooted itself through the teachings of Piaget and has become a stronghold in science education within the past two decades (Hofer, 2018). According to Piaget's theories, "knowledge is constructed as the learner strives to organize his or her experiences in terms of preexisting mental structures or schemes" (Bowden, 1986). According to the National Science Education Standards (NSES), inquiry can be defined as “activities of students in which they develop knowledge and understanding of scientific ideas, as well as an understanding of how scientists study the natural world” (NRC, 2000, p.23). By using guided inquiry activities, students can better make “accommodations” for their learning. In other words, they can better fit existing material into a new frame of thought by using inquiry-based learning (Duckworth, 1972).

2.5 Mississippi Curriculum, Theory, and Teaching with Inquiry

2.5.1 Chemistry Curriculum in Mississippi

Before moving forward, it is important to understand the influences of the Mississippi State Educational Standards on science education. During the Cold War, the launch of Sputnik, and the creation of the NDEA, the United States government began supporting the needs of schools from primary education through college to help funnel money and education into all areas of student learning, specifically in the areas of math, science, and language (US Department of Education, 2021). Through subsequent Educational Movements and the No Child Left Behind Act (2001), states were required by the Department of Education to provide equal and fair education to all students ensuring they succeeded (Lee, 2021). As a response, states were charged with creating testable checkpoints to ensure all students were learning and the schools were held accountable.

The Mississippi Science framework, first introduced in 2008 (MDE, 2010), can be used to guide teachers in bringing multiple dimensions of learning and analysis into the classroom. A committee writes the standards of science teachers assembled by MDE to set minimum requirements for education, allowing teachers to expand lessons for student retention and understanding. The chemistry standards begin with an introduction on how to interpret chemistry, the content of the state frameworks, and a guide to how teachers should use the frameworks. The frameworks were revised in 2010 and again in 2018. The Mississippi Science Framework is written to include three content strands, including Earth and Space Science, Physical Science, and Life Science, for grades K through 8. Beyond this level, when students reach upper-level science coursework in high school, the standards are written to encompass a specific course and the criteria for that course. Along with the content, criteria are guidelines for implementing Science and Engineering skills and practices. Science as Inquiry is a theme that has a strong presence throughout the Mississippi Science Standards from kindergarten to 12th grade. Mississippi also recognizes the need for investigation and critical thinking in the chemistry curriculum, as it states, *"It is recommended that students should actively engage in inquiry activities, laboratory experiences, and scientific research (projects) for a minimum of 30% of class time"* (Mississippi CCRS, 2018, p.74). The guidelines are essential for teacher accountability and student growth through learning.

Specifically, the Mississippi chemistry framework focuses on chemistry being an opportunity to develop an understanding of matter and to be able to fully communicate that understanding through coursework. This includes chemical structure, properties (chemical and physical), and chemical change. Using the chemistry curriculum based on these standards, students can process and develop their content knowledge into more complex and in-depth concepts (Mississippi Science Framework: Chemistry, 2010; MDE, 2018).

Although it is important to have guidelines for what needs to be covered in a class and what a student should leave knowing, it is also important that what is being taught is delivered to students effectively. Teachers need guidance for disseminating content to students. Standards do not cover educational processes, but the direction and educational theory can help manifest the best practices for student learning and understanding, starting with constructivist theory.

2.5.2 Constructivist Theory

Multiple educational reforms and rulings, including *No Child Left Behind, A Nation at Risk* (National Commission of Excellence, 1983), and the *National Science Education Standards* (National Research Council, 1996), had different directives on science education. Still, they all put a strong focus on content knowledge and critical thinking skills that were essential to developing a scientifically literate student. Key factors in students’ success are connecting with new information and drawing from previous experience. This need stems from scientific curiosity. Students want to know how things work. They want to understand daily occurrences, and through inquiry, students can take hold of their learning and begin understanding at a deeper level.

Constructivism as practice begins from the need for the individual to ask questions and find meaning. Constructivists place the focus on student learning through engagement, questioning, active learning, and connections. By applying constructivism tenets to learning in science, especially chemistry, teachers can better support students' analytical thinking. According to the National Academy of Sciences (2019), students need to “use evidence, apply logic, and construct scientific arguments and explanations for observations made during investigations” (p.28). According to the founding fathers, John Dewey, Jean Piaget, and Jerome Bruner, constructivism is founded on these tenets.

Rooted in constructivism, IBL was first mentioned in the literature in the 1960s, starting with Dewey’s pragmatism (Hofer et al., 2018). John Dewey stated that education should not be rote memorization or repetition; instead, students should be actively engaged in their learning through collaboration and real-life problems (DeVries, 1974). Piaget supported active learning, where a learner could create and refine their constructed knowledge (Piaget, 1970). In creating their learning experiences through discovery rather than memorization, students establish some ownership over their learning experience (Piaget, 1972). Bruner added that the teacher is responsible for engaging the learner in active conversation, allowing the student to build on prior learning experiences (Bruner, 1990). Bruner attributed successful constructive learning to the student being willing and able to learn through scaffolding information while also allowing the student to construct reasoning and meaning behind their experience (Bruner, 1996).

A constructivist teacher should present a learning experience with content for a student to help connect the knowledge that builds upon earlier experiences and encourages the student to help them construct their conclusions (Novak and Gowin, 1984; Clements & Battista, 1991). Connecting concepts can help transform and enrich learners as they interact with their surroundings, react to human needs, and make decisions using their experiences (Novak and Gowin, 1984; National Academy of Sciences, 2019). The chemistry content can be more thoroughly explored in the student learning experience, and a shift in teaching chemistry from heavy content to a constructivist-based inclusion of systematic problem-solving can make a difference in student understanding (Sjostrom, 2014). This shift can potentially take students' surface-level understanding to a deeper appreciation of the molecular world around them.

Constructivist teaching methods can be used in multiple ways in the classroom as individual and small group approaches. According to Yager (1991), learning is more focused on the student and less on the teacher in a small group setting. Constructivism is founded on the process of learning through the formulation of ideas and finding a way to explain what is going on rather than just finding the correct answer. Constructive learning is also influenced by the classroom culture allowing students to discuss findings and thoughts and get immediate feedback (Yager, 1991).

This is reflected in the teachings of Vygotsky, where there is a vested relationship between an individual’s social and physical world (National Academy of Sciences, 2019). The *zone of proximal development* highlights the difference between a student's performance level and what can be achieved when the student has guidance from a teacher or other students (Scribner & Cole, 1978, National Academy of Sciences, 2019). Together, these theories can potentially support complete student understanding and growth in the classroom.

Through the zone of proximal development (scaffolding), instructional resources can help reduce content complexity by providing hints and connecting material to enhance the learning experience (Wright et al., 2009; Tabak, 2004). By allowing students to make connections through problem-solving and critical thinking, they should be better able to retain and make deeper meaning of the materials they are learning. This can be done through properly used and placed inquiry opportunities in the classroom.

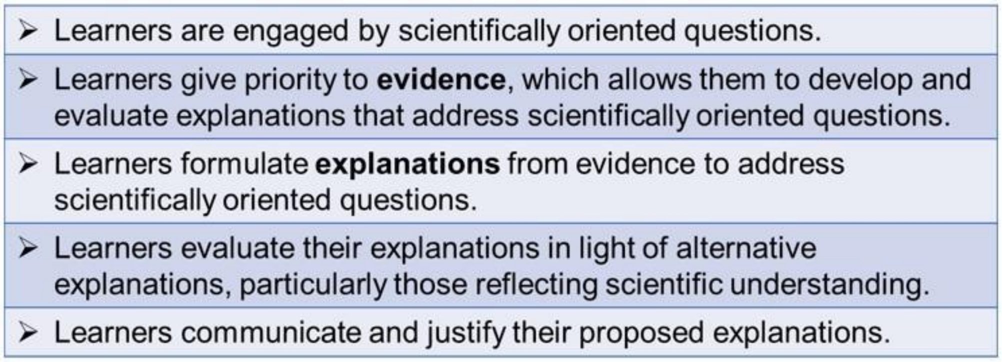
2.5.3 Inquiry-Based Learning

In keeping with the constructivist theory and student involvement in the learning process, there has been a shift in the science curriculum to include inquiry-based learning (IBL). According to Lazonder and Harmsen (2016), research has shown that active involvement by a student in their education is essential for a successful learning atmosphere. IBL is more effective in getting students involved and in the teaching of content than other methods because it allows students to process the information independently instead of through direct instruction. Inquiry-based learning allows students to lead instruction in the classroom in an individual or small group setting (Bohlen et al, 2021). In this way, IBL also provides a social environment for students to be more vested in their learning and understanding.

IBL is a constructivist method of teaching that allows the classroom to be student-centered and the teacher to act as a facilitator in the confines of that room. As a facilitator, the teacher is responsible for guided learning and not dictated learning (Herron, 2009; Smallhorn et al., 2015). The United States National Research Council (NRC) states that “science as inquiry” is a major component of student learning from preschool through the completion of secondary education (National Research Standards, 2000). IBL is centered around a student taking an activity/problem/assignment and using their foundation in the scientific process to make observations and predictions while collaborating with peers in a teacher-facilitated environment (Weaver, Russell & Wink, 2008; Herron, 2009, & Smallhorn, et al., 2008). IBL can manifest itself in many ways:

common practices include guided inquiry, discovery learning, problem-based learning, or open learning (Blanchard et al., 2010; Hmelo-Silver, Duncan, Chinn, 2007). IBL methods are useful in taking students from the mundane and putting them in an environment that actively involves them in the discovery and learning process (Weaver, Russell, & Wink, 2008). Being actively engaged in the classroom is a new essential for effective learning in the classroom (Moog et al., 2015). The National Research Council listed key factors (Table 1, below) in an inquiry-based classroom. These features help educators to alter IBL to fit the needs of their learners.

Table 2.1 *Essential Features of Classroom Inquiry* *(NRC, 2000, p.25)*



➢ Learners are engaged by scientifically oriented questions.

➢ Learners give priority to **evidence**, which allows them to develop and evaluate explanations that address scientifically oriented questions.

➢ Learners formulate **explanations** from evidence to address scientifically oriented questions.

➢ Learners evaluate their explanations in light of alternative explanations, particularly those reflecting scientific understanding.

➢ Learners communicate and justify their proposed explanations.

It is important to consider an environment that would promote cognitive engagement and can help students to push themselves to formulate substantial ideas. When students are engaged, they can develop a deeper understanding, strengthen their skills, and have a greater interest in what they are learning (Schneider et al., 2016). Choosing the appropriate IBL method is important in maximizing student engagement, motivation, autonomy, and retention (Cook and Artino, 2016). To determine the most appropriate IBL method one must consider the critical aspects of IBL, the caliber of the open-ended question, and the interactions of the teacher (Hmelo-Silver et al., 2007) The conditions in which IBL is presented can help determine the chosen method's effectiveness.

Project-based learning is a type of IBL popular among teachers to help students explore a phenomenon. Project-based learning can increase student choice of topics by allowing them to actively research a topic of interest (National Academy of Sciences, 2019). The project can be centered around a question or a phenomenon where students can explore and ask questions (Krajcik and Shin, 2014). Project-based learning can be a challenge for students who are not particularly invested in the subject and can often leave them lost and more confused.

Another form of IBL, guided inquiry, has the benefits of project-based learning with the added appeal of a support system and the most autonomy in student learning while also having a safety net to explore possible explanations. Activities that are designed for guided-inquiry learning have ways to facilitate retention and recall of learning content as well as to spark interest in the learner (Häussler and Hoffman, 2002). IBL manifests itself in inquiry lab activities, POGILs, and testing in the chemistry classroom. Students are given multiple opportunities to grow their inquiry skills and implement what they have learned.

“Many of the science curriculum reform efforts of the late twentieth century, particularly those in chemistry, were crucial in providing a context for the development of POGIL” (adapted from Moog and Spencer, 2008, p.8). POGIL is a research-based method in IBL that uses current instructional philosophy and methodology in student learning (Moog and Spencer, 2008). The POGIL process has two main goals: 1) content mastery through student content construction and 2) improving critical learning skills to develop the whole learner (Moog and Spencer, 2008; Moog, 2015). During a POGIL activity, students are actively participating in discovering meaning in chemistry content while developing essential learning skills, such as problem-solving and critical thinking (POGIL.org, 2019). “Students engage in POGIL activities through self-managed teams, where each student is responsible for contributing to the material. Moog and Spencer state that the instructional focus should be on the students' activity rather than the instructor's presentation” (2008, p.2). The best way to help students gain knowledge is to understand what is going on in their minds through active engagement in the development of understanding with their peers and check their understanding with the instructor to show what they have learned (Johnstone, 1997; Elmore, 1990). This makes using POGIL a vital asset in helping to guide students in their quest for content understanding.

POGIL was chosen as the IBL method for this study because it allows for the social environment needed for effective student collaborations and learning. POGIL itself is geared towards curriculum enhancement. “The POGIL activities guide students through an exploration to construct an understanding of the content while developing higher-level thinking skills” (Drury, 2018). A POGIL approach focuses on the development of critical thinking skills that can help achieve this goal, including whatever other goals the instructor intends for the lesson that day. “Thus, the POGIL philosophy is that the development of process skills (information processing, critical thinking, communication, assessment, etc.) is a focus of the classroom implementation; improving these skills will not only complement and enhance the mastery of course content for the student but will also help achieve the overall goals of the institution (Moog et al., 2006).”

The use of POGIL can help to increase student performance in critical thinking and retention substantially. POGIL activities start with generally accepted information and allow students to work in teams, develop understanding, and critically think through aspects of a given lesson (POGIL.org, 2019). According to Moog, et al, (2015), various studies have shown that the inclusion of POGIL in the classroom has diminished student attrition, and students have scored about the same or higher on content assessments. One study from Franklin and Marshall College showed an attrition decrease from 22% to 10%, and students receiving passing grades of at least a B increased to 62% from 54% (Farrell, Moog, and Spencer, 1999). In 2016, a study by Feng et al. found that students involved in guided inquiry activities showed a greater increase in procedural thinking skills. When the inquiry activity was more structured, students increased their content knowledge (Tate et al., 2016).

The most vital component of the POGIL activity is the ability of teachers to give immediate feedback on student work. Constructive learning is influenced by the social environment and social interactions, thus allowing a student to discuss findings and thoughts and get immediate feedback. Effective learning happens when students receive informative and timely feedback during the lesson (Hattie and Timperley, 2007; Healy and Sinclair,1996; Karpicke and Roediger, 2008). Students can better answer questions, grasp concepts, and apply context to connect material and experience phenomena with consistent and timely feedback.

Though POGIL is being presented as a chemistry teaching process, it impacts the whole student as they move to the next chapter in their lives. As students prepare for the next steps, the skills nurtured through POGIL can be a significant aid in helping them end up in the college or job they seek. The more frequently students are supported in growing essential skills, the stronger these skills become and become evident in a student's behaviors. If POGIL is used in different science subjects, it can help build a culture of IBL and skill development. “The standard mission of undergraduate education at the vast majority of institutions in the United States is to produce independent life-long learners who will lead meaningful lives and be contributors to society” (Moog and Spencer, 2008, p.6). One of the leading indicators of students’ college success is their scores on the American College Test (ACT). Students can begin taking the ACT as early as 8th grade, but in Mississippi are required to take the ACT during their junior year for school accountability. Although students take the test for school district accountability, students can also use their ACT scores for college entrance and placement.

2.5.4 ACT

The ACT was created in the 1950s under the name the American College Testing Program (ACT Inc., 2006) as an alternative to the SAT (Standard Achievement Test). As college admissions and enrollment increased, higher education institutions looked to the ACT to help determine admission standards and institution success rates (ACT, Inc., 2006). Through the years, the ACT has modified its testing strategies and image to better suit the needs of the changing world (Princeton Review, 2019). In 1996, the company changed its name from the American College Testing Program to ACT (Act, Inc., 2006). The ACT is divided into four academic sections: reading, English, math, and science. A student may take an extended version that includes a writing section, though the writing section is not required for all institutions.

The ACT came to the forefront of student preparedness in 1997 when the ACT company released its list of College Readiness Standards (ACT, 2004; ACT, 2007). By the turn of the century, there was evidence that students could pass tests and meet graduation requirements without being college-ready (Mattern et al, 2014). Since the enactment of No Child Left Behind in 2002 (NCLB, 2002), there has been a focus on testing students for common core benchmarks to show school accountability (ACT, 2014a). Teacher accountability became more and more prevalent with *NCLB* and shifted the teaching focus to academic subjects, leaving little time for skills and competencies needed in college and beyond (ACT, 2014b). Because of accountability, there is less focus on the student-centered model of the classroom, thus, minimizing the focus on the skills and competencies needed for success (Conley, 2013). To incorporate all the areas of science that students need to be successful, learning must be tiered in complexity and multidimensional (Mattern et al., 2104). College and career readiness can be built into the classrooms where benchmark mastery is not tested, such as high school chemistry.

Students take the ACT to measure their college and career readiness. The measure of how ready a student is for college is based on academic growth and essential skills such as critical thinking and problem-solving. By meeting college and career readiness, high school student shows that they can be successful beyond the 12th grade, with 50% of students succeeding in attaining at least a B average in an entry-level college course (ACT, 2004; Allen & Sconing, 2005; Allen, 2013).

The ACT is geared toward a student-centered approach. It accounts for learning in four domains: core academic skills, cross-cutting capabilities, behavioral skills, and education and career navigation skills (ACT, 2014a). Core academic skills, cross-cutting capabilities, and behavioral skills can be addressed in the chemistry classroom—core academic skills centers around content knowledge. Cross-cutting capabilities deal with critical thinking and collaboration through problem-solving. Behavioral skills can be used in small group activities to work effectively with peers, adapt to situations, and manage stress (ACT, 2014a). All three domains can be embedded in the chemistry curriculum by using POGIL.

2.6 Conclusion

Through the progression of this literature review, a roadmap has been created outlining the historical development of chemistry education and how it has become more effective over time. Over the past 150-plus years, there has been an astronomical shift from “learn through reading and asking questions” to student-centered learning that brings in multiple dimensions —moving from student learning with little teacher lecture to using IBL, specifically POGIL, to create student efficacy and a deeper understanding of the abstractness of chemistry. By using both educational theory and more pointed strategies, such as POGIL (critical thinking and scientific inquiry), it was shown that using the chemistry curriculum to help teach the whole student through the development and mastery of these skills and using these processes is aligned with the same skills and techniques necessary for being successful on the ACT science test. These skills are not only relevant to the successful completion of the test but are considered highly effective skills once a student reaches college and beyond.

In Chapter 3, the methods outlined and discussed the collection of test data and the analytical processes that were chosen to analyze test data. Data collection was conducted over five years, from 2016-2017 through 2020-2021. Through data collection in pre-test and post-test ACT Science tests in both a POGIL and non-POGIL learning environment, as well as ACT Science test official scores, the impact of using POGIL on students' ACT science test scores is investigated. The impact of IBL when nurturing critical thinking and analysis, on chemistry performance in the classroom and on the ACT science test is discussed.

CHAPTER III – RESEARCH METHODS AND DESIGN

3.1 Introduction

Teaching is challenging, especially when creating a well-rounded, critically analytical, problem-solving, and developmental environment. When working with students, multiple learning styles must be addressed along with the variation in the course studied (e.g., Chemistry and AP Chemistry). To address multiple needs, many variables must be considered to aid students in their quest for content knowledge and to foster the skills needed to be successful. The learning environment must not only challenge and nurture the requirements in the now but also adequately prepares for the possibilities of the future.

The previous chapter outlined the historical approaches to chemistry education and showed the path of educational reform in chemistry education from the late 19th century to the current day. Creating an effective working curriculum with achievable standards led to the use of Inquiry-Based Learning (IBL) to help foster a classroom based on critical analysis and problem-solving. The specific example of IBL used in this research is Process Oriented Guided Inquiry Learning (POGIL). POGIL was chosen because it allows for student-centered multi-dimensional learning, provides immediate teacher feedback, and helps students strengthen their critical thinking and analysis skills. Importantly, the skills learned and honed through POGIL are transferable skills that can be applied on a quantifiable standardized test, such as the ACT Science test, to show the capabilities of a successful college student. In other words, research suggests that successful college students can analyze and critically solve problems using skills fostered and nurtured through their high-school years (ACT, 2015). Additionally, these skills will better prepare students to function in a group setting where communication and collaboration are expected, such as in a college classroom or an employment setting.

No Child Left Behind (NCLB) emphasized content mastery, so much so that schools began to focus on achieving accountability benchmarks. As a result, common science skills were not integrated as often, if ever, in the chemistry classroom. Despite this focus on content mastery, academically strong students still struggle to succeed in college due to a lack of such important skills as critical thinking and problem-solving in the classroom (Allen, 2013). Outside organizations such as the ACT set parameters that determine college and career readiness to guide students on the skills and knowledge needed to prepare for the academic rigors of college (ACT, 2015). Using skills-based teaching methods (IBL and POGIL), teachers can build and nurture these critical skills while teaching the chemistry content to help students meet the Mississippi College and Career Readiness Standards (MS CCRS) and be more successful in the next steps in their lives beyond high school.

In this chapter, the methods, and procedures used to collect, analyze, and interpret data about this research are outlined. The research aimed to explore the effects of the development and implementation of purposeful curriculum and instructional techniques in the classroom in concordance with the MS CCRS, POGIL, and the ACT science sub-test. Specifically, these changes were designed to help effectively develop skills in critical thinking and scientific analysis through the content application. The data was collected over five years, from the 2016-2017 school year to the 2020-2021 school year and will be used to test the research hypothesis using the following procedures and methods.

3.2 Problem Statement

The purpose of this study was to find ways to positively impact student success on the ACT science sub-test by starting with skill foundations in the classroom, as the ACT is a known indicator of student success in college (Allen & Sconing 2005; Allen, 2013). To support student skill building in the classroom, new teaching methods were implemented to enhance the current teaching of content in the chemistry classroom. This started with implementing IBL using POGIL to nurture student efficacy and critical thinking through their chemistry class. The content was taught using guided inquiry-based activities and assessed through a pre-and post-test practice ACT science sub-test.

3.3 Purpose of the Study

This study aims to show a link between purposeful inquiry-based lessons, practice and learning through doing, a central tenet of constructivist theory, and student preparation for lifelong learning and better success on the ACT science sub-test. In analyzing pre-test and post-test data, looking at classroom instructional strategies, and analyzing ACT science sub-scores over five years, this work will provide insight into the selected teaching method used to help increase science sub-test ACT scores through the chemistry curricula. The examined teaching methods including IBL and POGIL were used to teach the whole student content knowledge as the primary goal but integrating problem-solving and critical thinking as the underlying tenets of learning.

Before this study, it was unknown to what extent, if any, using POGIL in the chemistry classroom impacted overall student success on the ACT science test. Through ANOVA and t-test analysis to compare student scores, I compared a POGIL-driven chemistry classroom and a control classroom where students did not have significant access to IBL and POGIL in their learning.

3.4 Methodology & Design

The research in this study was completed as an experimental, quantitative measures analysis looking at five years of collected test data. A quantitative methods approach was chosen due to the nature of the data collected. Numerical data were collected as test sub-scores to determine student growth in a high-school chemistry course because of the instructional changes made through the integration of IBL's POGIL. Data were collected over five academic years, from 2016-2017 to 2020-2021. The data collected included twice a semester diagnostic ("pre-," and "post-," respectively) ACT science sub-test scores and yearly ACT science sub-test scores of the same students. Each of the three iterations of the ACT science sub-test given (pre-, post-, and ACT) contained 40 questions and was given over 35 minutes. These official ACT science sub-test scores were obtained from the school administration of the ACT in February of the student's junior year.

The data sets from the 2016-2017 and 2017-2018 school years were collected solely from a POGIL-integrated classroom to determine if there was a statistical difference in students' pre-, post-, and ACT scores. The final sets of data, school years 2018-2019 through 2020-2021, were collected in a POGIL-integrated classroom and a non-POGIL classroom. The purpose of using two classrooms was to establish a difference (if any) between the teaching approaches and materials used to teach chemistry and support ACT preparation to find correlations between the instructional methods and student growth in the two classrooms over the three years. Test data were not analyzed during each step, all test data was analyzed as a conclusion to the research process.

After collecting data, two different statistical analyses were run to test the hypothesis: a one-way repeated measures ANOVA for years 1 and 2 and an independent samples t-test was used to measure statistical findings for years 3-5. Two different tests were chosen to address the differences in the importance of data. Each set of data was collected to test various aspects of the research hypothesis.

A one-way repeated measures ANOVA was conducted on the first two years of data for the POGIL-integrated classroom [pre-, post-, and ACTs] to compare the same participants using independent observations. This analysis was conducted to test the strength of the data versus a simple paired samples t-test. ANOVA was chosen due to its flexibility with using multisets or variable data. ANOVA can be used under conditions with blocking of data, repeated comparisons in data, or when looking at different factors in variables considered (Smalheiser, 2017). It is a robust method for comparison when studying large groups of individuals (Sinharay, 2010), particularly because it can be used to determine if there is a statistical difference in the various sets of data and can help determine the effect size of that difference.

The independent variables t-test was conducted to determine the difference in student scores in the integrated POGIL classroom and the non-POGIL classroom over three years. The independent variable t-test was used to compare pre-, post-, and ACT scores in each classroom between 2018-2019 and 2020-2021. This test was chosen because there were two groups for comparison: the POGIL-integrated group and the non-POGIL group. This comparison is known as the between-participant design (Fields, 2009).

All statistical analysis was conducted using IBM SPSS with data imported from Microsoft Excel. Excel data contained pre-, post-, and ACT science sub-test data for all five years. There were no missing data points. For the final three years, data was split into non-POGIL (C=0) and POGIL-integrated (P=1).

3.5 Sample Population

There were two stages of data collection. In 2016-2017 and 2017-2018, data samples were taken for a high school chemistry class, at least three classes per year, with 15-20 students per class. This first data collection stage focused on students being taught in a POGIL-integrated environment. The second stage of data was taken during the 2018-2019 through 2020-2021 school years. This stage of data was taken in two different teachers' classrooms. One teacher taught using IBL (POGIL), and the other taught using traditional content lectures, labs, and assessments. The second, "traditional" classroom did not use inquiry methods and was used as the control variable in the research. The total sample population included classes over five years with 15-20 students per class period taught each year, for a total of 513 students over five years. Students were in their junior year in high school. Students were placed in classes randomly by counselors. Students pre-selected the course as part of their requirements for graduation. They were not pre-selected based on ability or pre-assessed ACT scores. All students were general education track students. Since students were randomly assigned, they can be considered representative of the student body population. The school was geographically located in south-central MS, with an average population of 1200 students. Student demographics reveal approximately a 50/50 male-to-female ratio, 28% minority representation, and 100% of students are economically disadvantaged (NCES, 2022). Student demographics were not analyzed per class but are assumed representative of the school population. The lab-to-class ratio was 1:11, this opened the door for looking at lab-type lessons without taking up lab space. POGIL was an opportunity to increase exposure to inquiry and critical thinking while exposing students to lab-type activities. The teacher-researcher taught the POGIL-integrated chemistry classes, and another chemistry teacher taught the non-inquiry-based chemistry classes.

Data was collected using the pre-and post-test scores in each course and the yearly ACT science sub-test administered each February. Student scores were individually documented. Students completed a 35-minute timed practice ACT science baseline test at the beginning (pre-) and end (post-) of each course. Scores from each assessment were recorded and analyzed to test for overall score changes. These scores were compared to the state-administered ACT science sub-test given in February of the given year. Student scores were also compared in the POGIL-integrated classroom and the non-POGIL classroom.

3.6 Data Questions

Data points for each of the following research questions were collected over five years. Data for each year was collected in three intervals: pre-test, post-test, and ACT.

1) Does using POGIL in a chemistry class help improve student skills in critical thinking and problem-solving when looking at comparative science sub-test ACT data?

    a. Data in the form of numerical test scores were collected from pre-baseline tests and end-of-course subtest scores to determine student growth and were compared to the February science ACT scores. These data were collected in a POGIL-integrated classroom over two years. These data are necessary to determine if POGIL (the IBL instructional technique) in the classroom effectively increased student abilities in critical thinking and analysis, skills necessary to succeed as a chemistry student, and on the ACT science sub-test. Score changes were analyzed to see if there was a significant change between pre-and post-test numbers. The analysis tested the significance of student pre-, post-, and ACT changes in the POGIL-inclusive classroom.

2) How do students learning with POGIL in chemistry perform on ACT sub-sections versus peers not learning with POGIL?

    b. The comparable value was determined by looking at the overall change in scores for students who had access to POGIL in the classroom versus those who did not. The purpose was to determine if a change had occurred, either positive or negative, and how significant the impact was.

        i. Data included pre-and post-test data for the POGIL- integrated and non-POGIL classrooms over three years. Data were compared directly to see any correlation between students in POGIL- integrated versus non-POGIL classrooms. There was an added variable of the ACT science sub-test scores for students in both classroom dynamics from the February of each given school year. By comparing in-class testing to standardized test scores (ACT science sub-test), the analysis was validated due to the use of the same students in the same conditions for all three test scores.

3.7 Research Parameters and Limitations

Data collection was conducted for the entire five years of this study using the same pre-and post-test practice ACT science sub-test. Testing and data collection were consistent in both the POGIL-integrated and non-POGIL classrooms. The teachers in each classroom remained the same over the research period. Student ACT data came from the February ACT science sub-test following the end of the chemistry course. Since the ACT was taken through high school, the ACT each year consisted of the same passages. All assessments, pre-, post-, and ACT, were 40 questions completed over 35 minutes. Students were given one chance to complete the passages and get a score.

3.8 Summary

Using POGIL to enhance student learning experiences in the classroom, measured the connection between IBL and student success on the ACT. Using a two-tiered data analysis approach, the impact of POGIL was investigated to determine the effect it has on student achievement in the POGIL-integrated classroom versus student achievement in the non-POGIL classroom. SPSS was used to analyze any relationships and correlations in the next chapter.

CHAPTER IV – ANALYSIS and RESULTS

The primary purpose of this research study was to determine if integrating an IBL method, such as POGIL, would be effective in helping students to build the critical thinking and problem-solving skills needed to be successful on the ACT science sub-test. The secondary research purpose was to see the significance of the effect (if any) that POGIL had on student success over students taught in the control classroom. The results of this research were used to determine the significance of using POGIL by MS CCR standards for chemistry, affecting student scores on the ACT science test.

4.1 Findings

A quantitative analysis was conducted using IBM SPSS. There was a total of 513 student scores across five years used to test the strength in significance of each research question. Data were collected in two different classrooms, with student test scores collected in three separate intervals (pre-, post-, and ACTs). Student data were analyzed to test the research hypothesis using IBM SPSS.

Students were placed in chemistry class periods that fit their schedule by school counselors over five years. The students were all on the general education track and not placed due to race, academic ability, gender, or any other categorical difference. Students were in classes ranging from 15 students to 24 students. A certified chemistry educator taught the control classroom (non-POGIL integrated) for a period of three years (2018-2021), and they did not use POGIL as part of the general chemistry curriculum. The teacher-researcher is a certified chemistry educator who taught the independent group classroom (POGIL integrated) for a period of five years (2016-2021). Both classrooms were taught using the MS CCR Science Standards. The teachers in the POGIL-integrated and non-POGIL classrooms were the same throughout the research.

4.2 Results for Research Questions and Hypothesis

Before the analysis of the research hypothesis could move forward, the two research questions needed to be individually tested. This furthered the research into the two-tiered data analysis. Research Question 1 was tested using a One-way Repeated Measures ANOVA. Research Question 2 was tested using a Mixed ANOVA, followed by independent samples t-test in place of simple effects due to SPSS limitations. Tests were run with a Bonferroni corrected alpha to determine if there was a difference between the pre-, post-, and ACT score data. POGIL-integrated and non-POGIL-integrated were both considered at this point. The following information was collected using IBM SPSS.

Research Question 1: Does using IBL-based methods, such as POGIL, positively impact student ACT science scores?

Data collected from the 2016-2017 and 2017-2018 school years were analyzed to test this research question. The POGIL-integrated classroom data was utilized to look at any impact of inquiry-based teaching techniques on student test data. Using the One-Way Repeated Measures ANOVA, the following means were collected.

Table 4.1 *Means from 2016-2017 and 2017-2018 School Years*

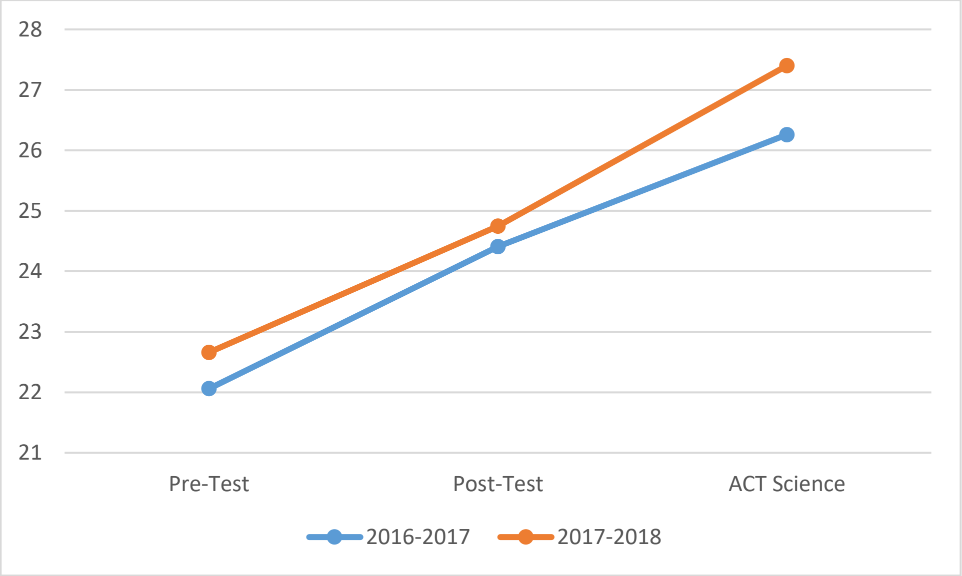
	Test	Mean	Std. Deviation	N
2016 -2017	Pre-Test	22.06	3.777	68
	Post-Test	24.41	3.727	68
	ACT Science	26.26	3.823	68
	Pre- Test	22.66	4.827	68

Table 4.1 Continued

2017- 2018	Post-Test	24.75	4.970	68
	ACT Science	27.40	4.522	68

The One-Way Repeated Measures ANOVA was conducted to compare the effect of using IBL-based methods such as POGIL in the chemistry classroom at $p < .05$ for the three test intervals (pre-, post-, and ACT) within-subjects effects were [F (2,143) = 54.486, $p < .001$] for the 2016-2017 school year and [F (2,143) = 72.816, $p < .001$] for the 2017-2018 school year. The statistical means for each year were plotted to show the correlation between the pre-, post-, and ACTs.

Figure 4.1 *Statistical Means for the 2016-2017 and 2017-2018 School Years*



After conducting the One-Way Repeated Measures ANOVA for years 1 and 2, a Two Three-way Mixed ANOVA was conducted to test data from years 3-5. Results for the omnibus test indicated the need for further analysis using an independent samples t-test to analyze test data from 2018-2021. This analysis was conducted to evaluate the statistical means of two groups of participants in each of the three studied years. Student data were collected at the same time intervals in both research groups.

Research Question 2: Is the difference, over three years, in test scores of students in a POGIL-integrated classroom statistically significant to scores received by students in a non-POGIL classroom?

Data collected from the 2018-2019, 2019-2020, and 2020-2021 school years were analyzed to test this research question. For each year, test scores for the non-POGIL group, C, were compared to the POGIL integrated group, P, to test the assumption that using IBL methods, such as POGIL, with the general chemistry curriculum made an impact on overall student success in the ACT science test.

The Mixed ANOVA was conducted to analyze the effect between the non-POGIL classroom and the POGIL-integrated classroom on student test scores (pre-, post-, and ACT) [F (2,136) = 44.403, $p < .001$]. To further analyze the measure of the simple effects, an independent t-test was used to test the comparisons *per condition* (Fields, 2009). Using the independent t-test, the following means were collected.

Table 4.2 *Means from the 2018-2019 School Year*

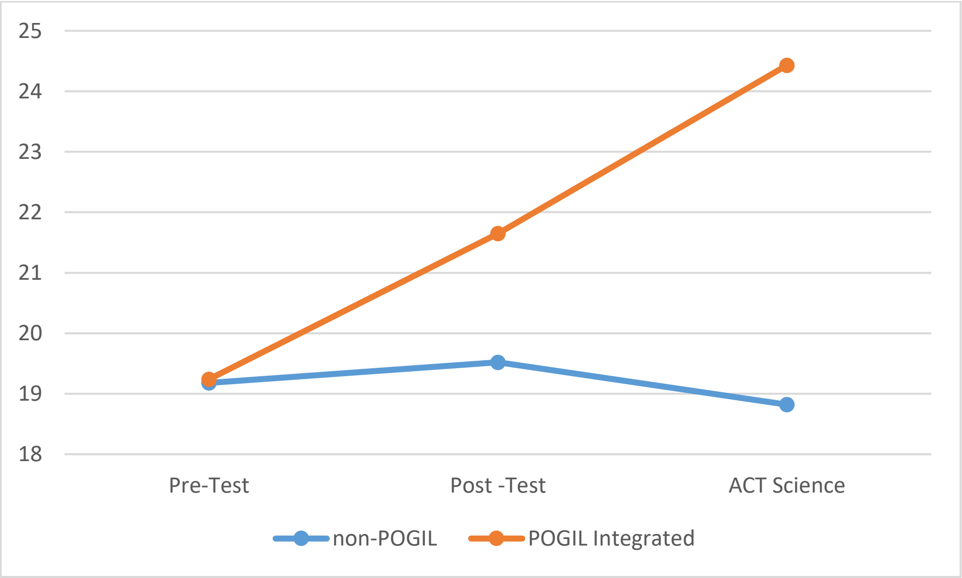
Test	Classroom (C or P)	Mean	Std. Deviation	N
Pre-Test	C	19.18	3.860	62
	P	19.24	4.438	74
Post-Test	C	19.52	3.7332	62
	P	21.65	3.981	74

Table 4.2 Continued

ACT Science	C	18.82	3.757.	62
	P	24.43	4.506	74

Using the independent t-test for C, pre-test (M= 19.18, SE= .490), post-test (M=19.52, SE=.474), and ACT (M=18.82, SE= .477) and for P, pre-test (M=19.18, SE= .516), post-test (M=21.65, SE= .463), and ACT (M=24.43, SE=.524). Levene's Test for Equality of Variances showed *t (*134) = .322 (pre-), .583 (post-), and .381 (ACT) this gave values for equal variances assumed using the Bonferroni adjustment with three tests (.05/3), $p < 0.0167$. The two-sided significance for 2018-2019 showed *t* (134) = .091, *p*=.927 (pre-), *t* (134) = 3.20, *p*= .002 (post-) and, *t* (134) = 7.792, *p*<.001 (ACT Science).

Figure 4.2 *Means for the 2018-2019 School Year*



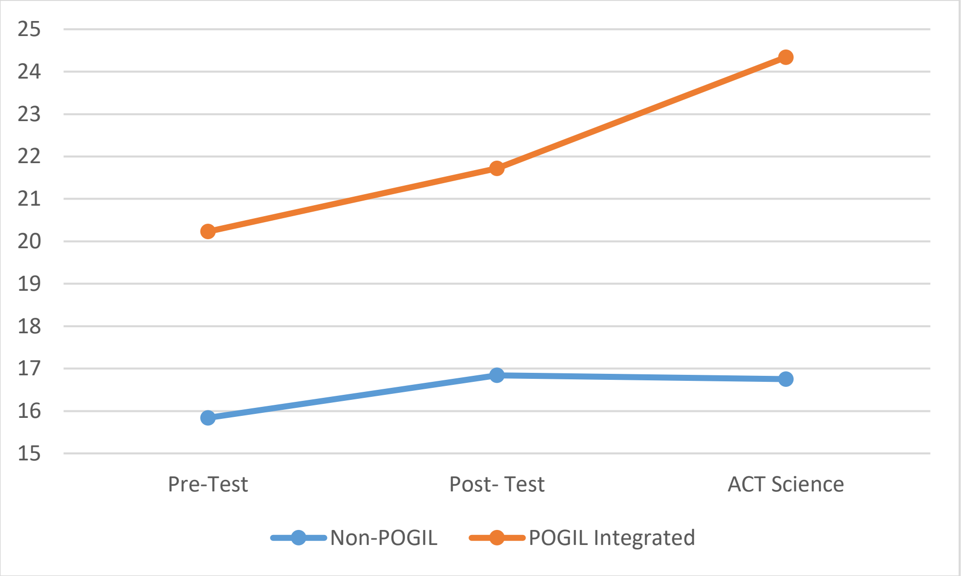
The Mixed ANOVA was also conducted for the 2019-2020 school year. The statistical data used to analyze the effect between the non-POGIL classroom and the POGIL-integrated classroom on student test scores (pre-, post-, and ACT) showed the following F statistic [F (2,123) = 19.454, p <.001]. An independent t-test was used to test the significance of each factor to further analyze the measure of the simple effects. Using the independent t-test, the following means were collected.

Table 4.3 *Means for the 2019-2020 School Year*

Test	Classroom (C or P)	Mean	Std.Deviation	N
Pre-Test	C	15.84	4.417	61
	P	20.23	4.727	64
Post-Test	C	16.84	4.030	61
	P	21.72	4.603	64
ACT Science	C	16.75	4.463	61
	P	24.34	4.571	64

Using the independent t-test for C, pre-test (M= 15.84, SE= .565), post-test (M=16.84, SE=.516), and ACT (M=16.75, SE= .571) and for P, pre-test (M=20.23, SE= .591), post-test (M=21.72, SE= .575), and ACT (M=24.34, SE=.571). Levene's Test for Equality of Variances showed t *(*123) = .368 (pre-), .195(post-), and .600 (ACT) this gave values for Equal variances assumed using the Bonferroni adjustment with three tests (.05/3), p < 0.0167. The two-sided significance for 2019-2020 showed t (123) = 5.369, p<.001 (pre-), t (123) = 6.30, p< .001 (post-) and, t (123) = 9.39, p<.001 (ACT Science).

Figure 4.3 *Means for the 2019-2020 School Year*



Finally, for the 2020-2021 school year, the Mixed ANOVA conducted resulted in [F (2,114) = 22.023, p <.001] when comparing the effect between the non-POGIL classroom and the POGIL-integrated classroom on student test scores (pre-, post-, and ACT). To fully analyze the measure of the simple effects, an independent t-test was used to test the significance of each factor. Using the independent t-test, the following means were collected.

Table 4.4 *Means for the 2020-2021 School Year*

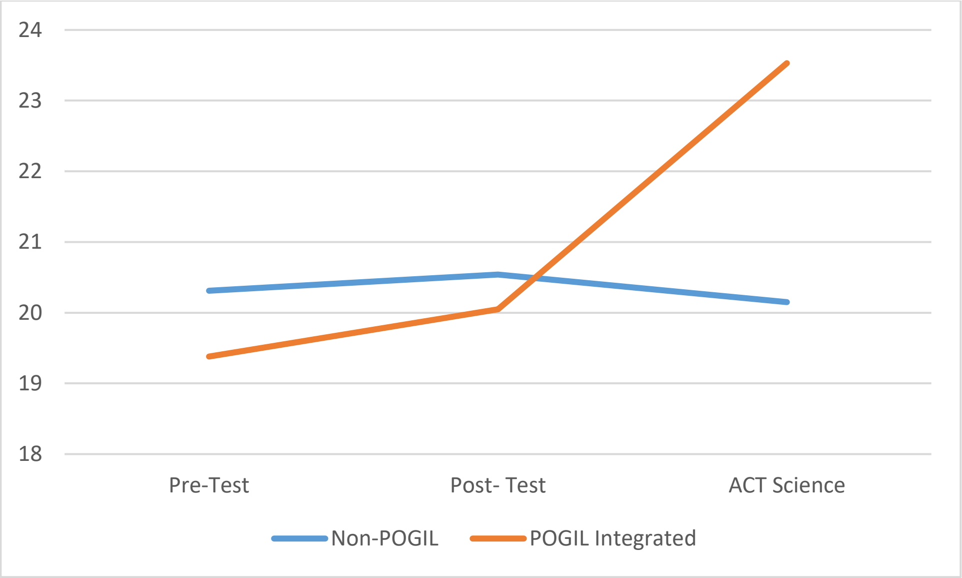
Test	Classroom (C or P)	Mean	Std. Deviation	N
Pre-Test	C	20.31	4.479	52
	P	19.38	4.943	64
Post-Test	C	20.54	4.832	52
	P	20.05	4.675	64

Table 4.4 Continued

ACT Science	C	20.15	4.412	52
	P	23.53	4.075	64

Using the independent t-test for C, pre-test (M= 20.31, SE= .621), post-test (M=20.54, SE=.670), and ACT (M=20.15, SE= .612) and for P, pre-test (M=19.38, SE=.618), post-test (M=20.05, SE= .584), and ACT (M=23.53, SE=.509). Levene's Test for Equality of Variances showed *t (*114) = .304 (pre-), .866 (post-), and .833 (ACT) this gave values for Equal variances assumed using the Bonferroni adjustment with three tests (.05/3), *p* < 0.0167. The two-sided significance for 2020-2021 showed *t* (114) = -1.054, *p*= .294 (pre-), *t* (114) = -.555, *p*= .581 (post-) and, *t* (114) = 4.278, *p*<.001 (ACT Science).

Figure 4.4 *Means for the 2020-2021 School Year*



4.3 Summary

Descriptive statistics and F values were needed to answer Research Question 1. Group statistics, equality of variance, and two-sided significance values were needed to support Research Question 2. All statistical data were analyzed to support the research hypothesis. The sample data was collected from 513 high school chemistry students over a period of 5 years. Research Question 1 was supported using a comparison of pre-test, post-test, and ACT science test scores over two years. The F statistic was important to help analyze the effect of IBL (POGIL) in the high school chemistry classroom. The second research question was tested using Levene’s test for Equality of variance and two-sided significance values to determine which factor had the greatest significance between-subject factors. Because there were strong p-values in both levels of analysis, the hypothesis was supported.

In the next chapter, the importance of statistical analysis is discussed while supporting the research hypothesis. The limitations of the study, possible variations in the data, and the implications of IBL for future use in classroom instruction are addressed along with opportunities for future research.

CHAPTER V – DISCUSSION

Using the Mississippi College and Career Readiness Standards (MS CCRS) chemistry curriculum as a foundation, quantitative research was conducted to determine the effect of inquiry-based learning on student ACT science sub-test scores. Data was collected over five academic years and consisted of student practice ACT pre-test and post-test scores and official scores from the ACT science sub-test taken in February of the participating students' junior year. After taking the pre-test in years 1 and 2 of the study (phase one), students were taught the chemistry content aligned with the Mississippi College and Career Readiness Standards (MS CRSS) for chemistry using the Inquiry-Based Learning (IBL) method Process Oriented Guided Inquiry Learning (POGIL) to help build content understanding, analysis skills, and critical thinking capacity. POGIL activities were given throughout the course, and all students completed the activities. Before the end of the course, students completed the post-test to ascertain growth in the assessment. The ACT was administered within two months of students completing the course, and those scores were recorded.

The second phase of the study was conducted in years 3 through 5. For this phase of the research, data were collected from students taught by two different chemistry teachers. One teacher did not include POGIL in teaching the chemistry curriculum (non-POGIL integrated classroom), and the other teacher integrated POGIL throughout the course each year for three years. Data were collected at three intervals per course: pre-test, post-test, and ACT scores. All scores were recorded and analyzed to test the research hypothesis. This chapter includes the final analysis of the research conducted for this dissertation. It also includes a summary of the research, a detailed analysis of the data results, limitations of the research study, policy implications, and future research possibilities.

5.1 Description of Study Data

Research data were collected over five years for a total of 513 students. Each year there were three test scores collected for analysis. The first and second scores were pre-benchmark (pre-test) and post-benchmark (post-test) assessment scores. The benchmark assessments were former ACT science sub-tests. Students were given 35 minutes to answer 40 questions. Scores from each assessment were recorded. The pre-benchmark assessment was administered in the first week of classes, and the post-benchmark assessment was given during the last week. The final test score and data points for each student were collected from the student's February ACT science sub-test score. The ACT science sub-test was given under ACT regulations and conditions.

Data was collected in a POGIL- integrated classroom for years 1 and 2; students all took the same pre-benchmark and post-benchmark assessments. Students also took the same February ACT, as it was administered schoolwide on the same day under the same conditions. During the academic year, the three data points per student were used to determine a change in students' scores overall. In phase one (years 1 and 2), student scores were compared from one teacher's classroom. I was the teacher-researcher during this phase. The students in each chemistry class were taught under the same conditions and practices. POGIL was integrated throughout the semester to enhance the chemistry curriculum and build students' critical thinking and analysis capacity.

5.2 Analysis of Research Hypothesis and Questions

Research Question1: Does using POGIL in a chemistry class help improve student skills in critical thinking and problem-solving when looking at comparative science sub-test ACT data?

The data used to test this research question was collected in the first two years of the study. Test data from the academic years 2016-2017 and 2017-2018 were analyzed using descriptive statistics and a One-Way Repeated Measures ANOVA. For the 2016-2017 school, there were 68 participants, each of whom contributed three test scores: pre-, post-, and ACTs. The descriptive statistics show that the mean score increased by at least 1.75 points between each assessment. The effect of using POGIL in the chemistry classroom for within-subjects indicates that the test score analysis results were not by chance. Descriptive statistics also reveal a significant implication that POGIL being integrated into the chemistry classroom has an impact on student ACT scores.

Like test data from 2016-2017, test scores from the academic year 2017-2018 were analyzed using descriptive statistics and the One-Way Repeated Measures ANOVA. A total of 68 students contributed three scores (pre-, post-, and ACT) for analysis. Descriptive statistical analysis determined a mean difference increased from 1.91-to-2.65-points from the pre-test to the post-test and post-test to ACT science, respectively. Results further indicate that POGIL had a significant effect on student test scores.

For both years 2016-2017 and 2017-2018, the magnitude of the F statistic and the p-value do not allow for rejection of the null hypothesis that POGIL integration in the chemistry classroom influences student ACT science scores. It is unclear if the increase in student test scores is solely influenced by using POGIL, as it could also be attributed to growth through maturity, effective teaching, or other factors. This leads to the second phase of the research study: comparing test scores from a POGIL-integrated classroom versus a non-POGIL-integrated classroom.

Research Question 2: How do students learning with POGIL in chemistry perform on ACT sub-sections versus peers not learning with POGIL?

Data collected in years 3 through 5 were analyzed using a Mixed ANOVA and were supported using the independent samples t-test with equal variances assumed using the Bonferroni adjustment for three tests. The independent t-test was used in place of the measure of the Simple effect due to software limitations in SPSS. Test groups were broken into group C (the non-POGIL chemistry classroom) and group P (the POGIL-integrated classroom. The following information breaks down each research year's statistical analysis starting with the 2018-2019 school year.

In 2018-2019, of 136 students, 62 were in group C, and 74 were in group P. The Mixed ANOVA results indicate a significant effect between the non-POGIL classroom and the POGIL-integrated classroom on student test scores (pre-, post-, and ACTs). Levene’s Test for Equality of Variances shows a non-significant result in the homogeneity of variance. Thus, looking at data values for equal variances was assumed using the Bonferroni adjustment with three tests. The difference in test means for groups C and P is significantly different when comparing the post-test means and ACT science means. Pre-test mean differences are not considered significant. A possible explanation for insignificance would be that students’ ability and distribution between the two classes are similar at the beginning of the course. It would therefore be important in future studies to examine student ability levels at the beginning of the course, as it helps to strengthen the significance of test score increases in the POGIL-integrated classroom.

In 2019-2020, there were 125 students, with 61 in group C and 64 in group P. The Mixed ANOVA results indicate a significant effect between the non-POGIL classroom and the POGIL-integrated classroom on student test scores (pre-, post-, and ACTs). Using the independent t-test, Levene's Test for Equality of Variances showed that the results for all three test comparisons supported homogeneity of variance within test scores, and the difference was not by chance. Using values for Equal variances assumed, including a Bonferroni adjustment for three tests, and all tests had a significant difference in scores from the non-POGIL integrated and the POGIL-Integrated classroom. The mean difference supports the null hypothesis that POGIL used in conjunction with the chemistry curriculum significantly affected student score increases. Students were randomly placed into classrooms taught using the same two distinct procedures as the previous year. Likely due to random placing, students in the P group started the year with a greater mean score on the pre-test than did students in group C. The increase in test scores over the three assessments continued to show a significant difference between the two classrooms.

In the final year of the study, 2020-2021, of 116 students, 52 were in group C and 64 in group P. The Mixed ANOVA indicated a significant effect between the non-POGIL classroom (C) and the POGIL-integrated classroom (P) on student test scores, resulting in the need to run the independent samples t-test. Using the independent t-test, Levene's Test for Equality of Variances supported the assumption of homogeneity of variances. Using equal variances assumed with the Bonferroni adjustment, both the pre-test and the post-test comparisons were insignificant and failed the assumption. Students during the 2020-2021 school year were experiencing the effects of a COVID setting. Students were in and out of school with quarantine requirements, alternate school schedules, and for many, a lack of internet availability during school closures. Under quarantine, students could be sent home for up to seven days upon COVID exposure. Throughout the school year, school schedules changed due to the number of positive cases in the school at a given time. During that time, the school went to a hybrid schedule, where students were only physically present in class every other school day. The student population did not have equal access to internet services in their home as the school was in a rural area. These are all potential reasons for not having a significant difference between pre-test and post-test scores in both classrooms.

In phase two, the ACT science test scores comparison indicated that students in the POGIL-integrated classroom scored significantly higher than those in the non-POGIL-integrated classroom. The score increases from the post-test to the ACT science test were significantly greater compared to differences in both pre-and post-test comparisons. Despite COVID-related issues in the final year of the study, these results ultimately still support the second research question.

Over the three years, 2018-2021, pre-test scores for both participating classrooms were overall not significantly different. This can be explained by the random placement of students with distributed ability levels. This is important to show that students started the chemistry course with similar abilities, and all had the potential to grow. Year 3 (2020-2021) was the only year where post-test scores between the two groups were not significantly different. This is likely a result of students in both groups facing academic hardships due to COVID absences and the inability to keep students' lessons completely equal in rigor and context when some students were in class, and some were receiving lessons at home. It is impossible to mirror POGIL processes when a student is not physically present in the classroom. All students felt COVID academic hardships to some degree. Finally, all three years of phase two of the research study showed a significant difference in ACT science sub-test scores. Both groups increased from pre-test to ACT science sub-test over all three years, but the POGIL-integrated group had a significantly higher increase. This indicates that POGIL contributed to helping students score better on the ACT.

Research Hypothesis: There will be a positive difference in student achievement on the ACT science sub-test through the introduction of Inquiry-Based Learning (IBL), specifically Process Oriented Guided Inquiry Learning (POGIL).

After analyzing data from Research Questions 1 and 2, the statistical analysis supports the null hypothesis that integrating POGIL into the chemistry curriculum can help students succeed on the ACT science test. Research Question 1 was supported with significant F-statistics for both years (2016-2017 and 2017-2018). Although there was a significant increase in ACT science sub-test scores, further analysis in years 3 to 5 was necessary to test the significance of scores from the POGIL-integrated curriculum versus the non-POGIL-integrated classroom.

Data collected to test Research Question 2 showed a significant effect of the F-statistic from the Mixed ANOVA. Although there was evidence to support a significant effect, it was not known through the Mixed ANOVA which assessment (pre-, post-, ACT) had the greatest effect each year. The independent samples t-test was therefore used to analyze between test measures and ascertain the magnitude of the IBL introduction into the participating classrooms. For the 2019-2020 and 2020-2021 school years, there were significant effects in the POGIL-integrated classroom, indicating that the introduction of IBL into the chemistry classroom contributed to higher post-test scores in the POGIL-integrated classroom. This result was not replicated for the 2020-2021 school year. Most importantly, all three research years significantly increased the ACT science sub-test scores for the POGIL-integrated classroom over the non-POGIL-integrated classroom.

During the five years of the research study, student ACT science sub-test scores were significantly greater than the pre-test assessment. When students' scores in the POGIL-integrated classroom were compared to student scores in the non-POGIL-integrated classroom, there is statistical evidence to support the null hypothesis that there would be a positive difference in student achievement on the ACT science sub-test through the introduction of Inquiry-Based Learning (IBL), specifically Process Oriented Guided Inquiry Learning (POGIL). Because the ACT science test is based on *"students' ability to interpret, analyze, evaluate, reason, and problem solve" (*ACT Certified Educator Guide, 2020, p.7), the successful integration of IBL, specifically POGIL, is an ideal way to promote content understanding and to help students strengthen their scientific analysis and critical thinking.

5.3 Implications of the Study

The results of this study could significantly impact the planning and curriculum support for chemistry in the state of Mississippi. Mississippi is continuously ranked low for public education and finding new ways to improve education in MS could significantly affect the future of students and the state. How the curriculum is presented is essential to student success within the abstract nature of chemistry. Purposeful planning and integration of POGIL in chemistry classrooms across the state could help boost student understanding of chemistry content knowledge. It could also provide teachers a way to make minor adjustments to their teaching, and yet produce significant gains. The processes used and learned in POGIL classrooms are essential scientific and everyday skills to help build foundational student academic success. However, while students' critical thinking and problem-solving skills are essential to understanding content, they are also indicators of success in future assessments and life positions.

Secondly, results from this research study could be used in a policy, where leaders could use this evidence to push for curriculum improvements and teachers' professional support and development. Because of accountability in the state, the policy focuses on, and the government subsequently distributes most resources to, the tested areas in science. Because the ACT is a small part of school accountability, the results of this study can be used to advocate for the curriculum in non-tested sciences areas to be evaluated, adjusted, and given funding and resources for the integration of opportunities that grow student analysis and critical thinking skills. Integration of POGIL or other IBL processes would benefit all students because of the nature of their design and their focus on honing critical thinking and problem-solving skills.

5.4 Limitations of the Study

Limitations of the study include data sampling in school, student effort in academic areas, one type of IBL method used, teacher influence, and testing conditions. Data sampling is a limitation because the study was conducted in a single high school in south-central Mississippi. Students were from the same geographical residency and had been taught identical policies and procedures. Therefore, the results of this study may not be representative of student populations in other geographic areas. Student effort could be questioned, especially with pre-and post-test data. Students did not receive a grade or additional incentives for completing the pre-and post-test, as they were used as baseline scores for the chemistry course. As a result, students may have rushed through or did not give adequate time per question when completing these assessments due to a lack of greater motivation. This could affect the accuracy of individual scores. Using a single IBL method could have impacted the overall student effect in building and using critical thinking and analysis skills.

Teacher influence can be seen as another motivator or non-motivator to how a student performs. Teacher-student classroom rapport is critical when trying to support students to give their best. Any disruption to the teacher-student rapport could affect student effort on the classroom-based assessments. Student-teacher interactions can vary from teacher to teacher and student to student. The POGIL- integrated classroom was a procedural motivating environment, where students were emersed in learning processes and devoted to students being successful. Testing procedures in the POGIL-integrated classroom were geared to foster continued critical thinking through test questions. Also, the testing room, environment, and procedures could not be guaranteed uniform in the non-POGIL integrated classroom and the ACT rooms. Distractions, the temperature of the room, and proctors could affect student focus during testing. These variables could have a small effect on student test scores.

5.5 Recommendations for Future Research

Future studies might include using other science courses, and other types of IBL, collecting more frequent test data, and examining the long-term effects of the study of a random sampling of students who were a part of the original study. This research could expand into any of the four areas of the ACT science test: biology, physics, chemistry, earth, and space science. These courses have been taught before or during a student’s junior year. Expanding the study to include biology, generally taken in students’ sophomore year of high school, would allow for long-term research on the effects of IBL in classes. POGIL activities have been written for biology and are gaining ground in the other two subject areas. Expanding POGIL into different classes could help promote an atmosphere of success and push students to want to achieve higher.

The ACT testing company has presented research indicating that critical thinking and analysis skills are essential to success beyond high school (ACT, 2015). Because of the nature and goals of these types of instructional methods, the more frequently high school students are exposed to IBL and POGIL-type activities, the more practice they will have in working through problems before entering adult life beyond the walls of a structured high school. Another way to expand the research is by comparing student success on the ACT Math sub-test with the success on the ACT Science sub-test. Also to isolate chemistry test questions from the ACT Science sub-test and compare the success of the chemistry-specific questions to the rest of the science test. These potential future research opportunities are abundant at the high school level, but it would also be beneficial to extend this work to look include data from students who have graduated and moved into college or a job setting to track the job performance of students with specific training using IBL.

The use of data and findings can be used to help make a significant impact on science education in Mississippi. If teachers blend IBL (POGIL or others) into the science classroom, students would be able to continuously grow critical thinking and analysis skills which could have a positive impact on student's future.

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