

BEYOND THE LAB MANUAL: STUDENT-LED EXPERIMENTAL DESIGN TO BOOST  
CONTENT RETENTION AND CAREER READINESS IN HIGH SCHOOL BIOLOGY

by

Madelyn Rose Bodisch

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## DEDICATION

This work is dedicated to my son, Shiloh, and any future children our family is blessed with. My role as teacher is most impactful when it comes to rearing them. May they grow to be curious, compassionate and critical thinkers. May their father and I know when to let them figure things out on their own, when to rely on each other, and when we are to step in to provide a helping hand along their journeys.

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I would be remiss to not also acknowledge my husband for his support in the dishes done, toys picked up, chicken eggs gathered, and so much more. He would do it all even if I wasn't pursuing this program, but I am able to do so more excellently because of the way he serves our family.

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## ABSTRACT

This action research sought to understand how incorporating student-led experimental design through a constructivist framework would impact learning in a high school biology classroom. Specifically, the impacts on content retention and career readiness skills of teamwork and problem solving were analyzed. Throughout the treatment period, students engaged with genetics content in a constructivist manner as suggested by Kolb's 1984 theory and the Framework for K-12 Science Education (National Research Council, 2012). As a part of this learning process, students designed an experiment surrounding the genetic traits of corn seedlings. Pre- and post-content tests, surveys, interviews, and an observation rubric were used as data collection instruments. Data were analyzed both quantitatively and qualitatively to understand the impact of the treatment on content retention and career readiness skills. Results suggested little impact on content retention and problem-solving skills but a positive impact on students' teamwork skills. These results led the researcher to conclude that while there was no noticeable change in students' problem-solving skills, the treatment period was valuable for student learning and the practice of leadership skills.

## CHAPTER ONE

## INTRODUCTION AND BACKGROUND

Context of the Study

In an educational landscape often molded by end of the year testing regulations, a new shift is underway in science education with the advent of the Next Generation Science Standards (NGSS) published by the National Research Council. These standards, published in 2013, aim to provide research-backed science education standards that incorporate three dimensions of learning in contrast to typical standards that solely focus on content knowledge. These dimensions include content knowledge, called disciplinary core ideas (DCI), as well as science and engineering practices (SEP) and crosscutting concepts (CCC). In the commonwealth of Pennsylvania, this shift is being reflected with the creation of the Science, Technology, Engineering, and Environmental Literacy (STEELS) standards and a new standardized biology test rolled out in the Spring of 2026. This change brought forth by STEELS is far reaching. It not only demands a change in standardized testing, but also in teaching methodology to fully achieve instruction in all three dimensions outlined in the standards.

One school affected is Dallastown Area High School. This high school is a large middle-class suburban school that is part of the Dallastown Area School District in south-central York County, Pennsylvania. In 2025, the district's website stated that it supported 6,416 students. The high school serviced approximately 2,000 of these (About us). Of these 2,000 students, each one will take a set of Keystone Exams in Biology, Literature, and Algebra. Dallastown Area School District has a reputation of performing well on these Pennsylvania state standardized exams. For

example, in 2024, 67.3% of students scored a proficient or above on the Biology Keystone exam while the state average was 50.5% proficient or above (Assessment Reporting). This reputation means that pressure is high to maintain above-average results amidst the shift in testing.

In this well-reputed school district, the median household income is \$57,071 (Dallastown, Pennsylvania). The district is made up of several towns, boroughs, and townships with career options ranging from agriculture to manufacturing and service industries. The district is located one hour north of Baltimore, Maryland, so many residents seek employment in this metropolitan area. Recently, the development of new townhomes and apartments in the area has welcomed several new residents who may come from lower socio-economic backgrounds. One statistic that is reflective of this change is that the number of students who qualified for free and reduced lunch jumped from 35% in the 2021-2022 school year to 41.3% in the 2023-2024 school year (Annual reports). As these students have not been a part of Dallastown programming for their younger learning years, it is difficult to appropriately know where they are on their educational journey when they reach the high school classroom. Dallastown Area School District aims for cohesive instruction across K-12 where knowledge and skills can build on themselves. To provide equitable instruction for students who may not have been within the district this entire time, or those who may have had various changes in their learning throughout this time period, the need for scaffolding instruction is present.

These demographic changes, along with the shift in science standards towards those that include three dimensions of learning, make this current moment the optimal time for trying out methods of science instruction that are new to the teachers in the district. In a landscape where success on standardized tests is normative, teachers must try new things to leverage their

students' aspirational capital so that they continue to see this expected success amongst cultural and testing transitions. As a biology teacher at Dallastown Area High School, I have been working to implement the needed transition by beginning to utilize more open inquiry teaching. Specifically, I have been focusing on making this change regarding the laboratory experience in hopes of increasing students' content retention and career readiness skills.

Before moving in this direction, I identified that while the traditional cookbook style laboratory experiences were somewhat effective at increasing content retention, they did not provide students with the career-like skills required by STEELS standards. When discussing a cookbook lab, I mean those that provide students with step-by-step instructions to perform a procedure and then ask students to draw conclusions and answer analysis questions. Labs in this format often serve a great purpose of meeting the disciplinary core idea or crosscutting concept component of the three dimensions of STEELS. However, as I began to assess my students in the style of STEELS questions which incorporate science and engineering practices, I noticed that cookbook labs are limited in the way in which they enable students to practice these. For example, one science and engineering practice is to "plan and perform experiments". I began to question how students could grow in this skill if they were never doing this but rather, I was providing them with every single step to follow.

When I made this observation, I jumped right in to a lab where I gave students a blank sheet of paper and told them to design an experiment regarding the properties of water. This initial move into the open inquiry world of student-led experimental design was chaotic. I quickly learned that many students had very little experience with this self-directed type of learning up until this point in their education. Amidst the initial chaos, I was able to see that this

type of learning would be valuable. However, I needed to give my students the correct steps to get there. This prompted me to research and discover what these steps should be. These instructional tensions led me to the development of the following focus question.

### Focus Question

The purpose of this action research project was to improve upon my methodology in teaching through the lens of student-led experimental design. My focus question was, How does incorporating student-led experimental design through a constructivist framework impact learning in a high school biology classroom?

My sub-questions include the following:

1. What is the impact of student-led experimental design on content retention?
2. What is the impact of student-led experimental design on career readiness skills of teamwork and problem solving?

## CHAPTER TWO

### CONCEPTUAL FRAMEWORK

As I set out to explore what student-led experimental design would best look like in my high school biology classroom at Dallastown Area High School, I first turned to the established literature on the topic. I quickly discovered that while NGSS and STEELS have caused ideas about inquiry and experimentation to become popular in 2026, research has long established that these are important teaching tools. This conceptual framework forms the basis for my action research project as it explores the history of constructivism in science education, how this can be related to NGSS, methods for teaching experimental design, and the established impact of all these things on content retention and career readiness skills.

#### Experiential Learning Theory and Science Education

In 1984, David Kolb released a framework for experiential learning. Built upon constructivist theories that knowledge builds upon itself, this framework focuses on four stages of learning to make sense of the world through experience. These stages are concrete experience, reflective observation, abstract conceptualization, and active experimentation. The names Kolb gave to these learning stages are descriptive of the events that happen within them. In the concrete experience stage, learners must interact with the world in an experiential way which they then look back on in the reflective observation stage. From here, learners attempt to make sense of the experience in the abstract conceptualization stage before moving on to expand their learning into other concepts in the active experimentation stage. Kolb theorized that through these stages learners could have an integrative and holistic learning experience that combines

hands-on experience with the types of practice that are necessary for acquisition (Kolb, 1984). A recent study built upon this framework showed that through teaching according to Kolb's framework in comparison to traditional teaching practices there was an increase in critical thinking skills among third year college students (Yefang et al., 2024).

Grounded in constructivism, the Framework for K-12 Science Education put forth by the National Research Council recognizes that such a logical progression is necessary for scientific learning. The framework aims to provide a well-designed “map of routes” for students to reach mastery of content that can extend over multiple years. This framework is the basis for the Next Generation Science Standards (NGSS) on which Pennsylvania's Science, Technology, Engineering and Environmental Literacy (STEELS) standards are closely aligned (National Research Council, 2012). A key element of these standards is the integration of three dimensions of learning—crosscutting concepts, disciplinary core ideas, and science and engineering practices. The integration of teaching disciplinary core ideas at the same time as science and engineering practices is one that research shows to create permanent science learning (Alkan, 2016).

One could surmise that the Framework for K-12 Science Education and Kolb's experiential learning theory share commonalities. Both advocate for holistic learning experiences. Kolb does this generally by providing a progression of types of experiences students should have in a learning cycle. The Framework for K-12 Science Education does this more specifically over the years of a student's education through the three dimensions. The researcher developed a conceptual framework which shows how one could interpolate Kolb's theory with the Framework for K-12 Science Education in order to make sense of teaching the three

dimensions together in light of constructivism (Figure 1).

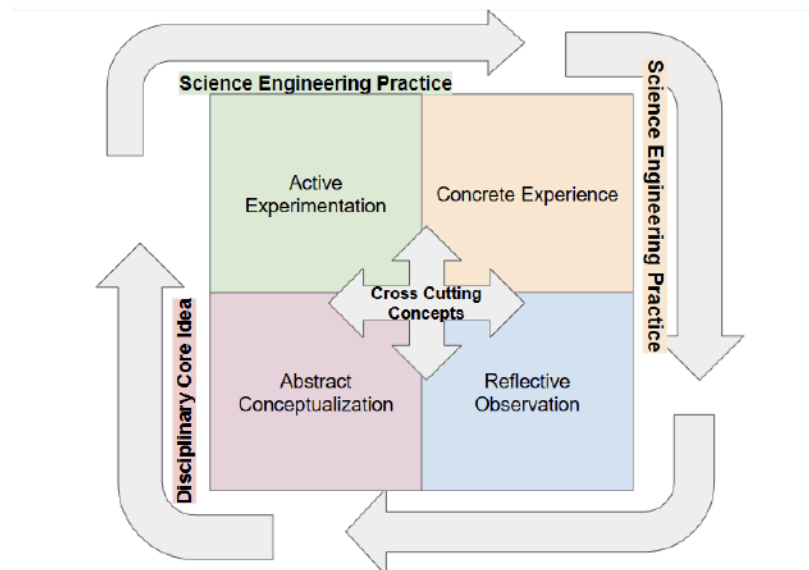


Figure 1. Kolb's experiential learning theory overlaid with the three dimensions of learning from the Framework for K-12 Science Education

As science students learn through Kolb's concrete experience phase and then try out an experiment on their own in the active experimentation phase, they should be engaging in the framework's science and engineering practices. Then, when students make connections during Kolb's abstract conceptualization phase, they should be mastering the framework's disciplinary core ideas. Cross cutting concepts integrate each portion of Kolb's cycle. Kolb's experiential learning theory provides educators with steps to integrate the three dimensions of the National Research Council's framework. Thus, an understanding of Kolb's theory interpolated with NGGS should give educators the skills to help students master both scientific content and scientific skills.

### Steps to Teaching Experimental Design

According to Kolb's theory and the Framework for K-12 Science Education's map of science learning, students could benefit from explicit step-by-step instruction on scientific processes and procedures. Research shows that while an inquiry classroom is key to long-term student learning, it is harmful for students to be given inquiry paths in a disorganized classroom, especially in contexts where content knowledge is limited—like that of a high school classroom. In the same way, cookbook style laboratory experiences are not ideal. An effective science teacher should be actively working to move students from this closed or guided inquiry to open inquiry in an organized, controlled manner to better enable true learning to occur (Szalay et al., 2024). In a 2020 study, van Brederode et al. showed that giving students more guidance during laboratory exercises at the beginning of the year and then removing this guidance led to better learning outcomes in comparison to a previous year's classroom of traditional learning objectives. This is known as scaffolding. The word scaffolding is typically associated with construction to describe how workers use support structures that get removed as the building takes shape. In the same way, a constructivist learning theory like that of Kolb posits that it makes sense to give students supports that are taken away as they build their understanding and skills.

Much research has been done on specific strategies to scaffold teaching experimental design. In 2024, a four-year approach to teaching junior high students experimental design, largely through worksheet exercises, found minimal increase in students' long-term ability to design their own effective experiments. The same study also showed minimal increase in content retention (Szalay et al., 2024). In comparison, a study by King et al. (2024) found that when

students in an undergraduate toxicology course were presented with experimental pathway choices, they had improved learning outcomes, improved experimental design skills, and all students perceived the activity positively. Students themselves stated that the option to choose their experimental pathway increased their critical thinking skills. Similarly, an inquiry teaching model called “GIReSiMCo” focusing on guided inquiry, reading, sharing, mind mapping and communication found success in moving students toward guided inquiry. Researchers credited this model’s success to the fact that all students participated in each step-by-step portion of the process (Senisum et al., 2022).

Overall, these studies give a practical view of what the interpolation of Kolb’s theory and the three dimensions of learning can look like in a classroom. They lead the researcher to the conclusion that students need to be taught experimental design in a step-by-step fashion in order to avoid chaos in the classroom. However, the best way to do this is not through individual worksheets, even if these worksheets are given over multiple years. This research reveals that there is a fine balance as an educator moves students from concrete experiences to active experimentation; students need to be given the steps to master content and processes as well as the freedom to direct their own learning.

### Experimental Design and Content Retention

The freedom to direct one’s own learning in a high school science classroom can traditionally be found most clearly in the laboratory experience. Laboratory experiences have long been known to be a key element in teaching the sciences for the benefit of preparing students for skills that are needed in the sciences. These experiences also increase content retention. In a 1980 study, Schneider & Renner showed this fact very clearly as students exposed

to a concrete teaching method as opposed to a formal teaching method showed higher content scores. In this study, a concrete teaching method referred to a method in which students were interacting with something in the physical world. This was opposed to the formal teaching method where students were sitting and listening to lecture material. An explanation for the higher content retention from the concrete experience can be found in Kolb's experiential learning theory. Students must build their mental structure upon first interacting with these experiences. Therefore, in the same way the foundation of a building must be built before the walls go up, it is a necessity to allow students to have these experiences early in the learning process. If in the sciences most concrete experiences are laboratory experiences, then it would make sense that the foundation of these experiences is designing the experiment itself.

In research completed by King et al. in 2024 on student-led experimental design, students chose a maximum of four out of six different experiments and the order in which to perform them with the aim of understanding the protective mechanisms of a particular living agent being studied. The ability to choose their own pathway allowed students to demonstrate an understanding at the beginning of the experiment that guided them to even more solid content retention as they made mistakes and had successes throughout the process. The interaction with this material as early as choosing which experiments to participate in increased student opportunity to reflect and analyze throughout the process, reflecting Kolb's theory of building content retention off of concrete experiences. King et al. showed that this model of learning led to greater content understanding than in previous years where a specific laboratory pathway was given to students. Similarly, the GIRESiMCo model revealed that having students plan and perform an experiment prior to reading about the content showed higher assessment scores

compared to guided inquiry methods that reversed this process (Senisum et al., 2022). The results of studies done by Senisum et al., Szalay et al., and King et al. all clearly support Kolb's experiential learning theory in the science classroom as a means of building content retention. When students are given proper steps to experience the scientific concepts on their own, scientific understanding deepens.

### Experimental Design and Career Readiness

Along with enabling mastery of scientific content, another major goal of the implementation of Pennsylvania's STEELS standards is to increase Pennsylvania's "economic vitality and civic strength" (What does PAsmart mean to you?). The state recognizes that with an increase in available technology, science learning must emphasize not only content retention, but also skills to apply this content. Recent studies have shown that in major Pennsylvania cities like Pittsburgh, the need for science and technology careers is outpacing the national average of 16 percent by being as high as 18 percent of all jobs that are based on science and technology (Zaber et al., 2023). Additionally, with the advent of the STEELS standards, the state recognizes that science, technology, engineering, and math (STEM) skills are useful in many occupations not formally thought of as STEM careers. Examples of these include carpentry, auto mechanic, dental hygienist, or electrician (What does PAsmart mean to you?).

The science and engineering practices put forth in the NGSS/ STEELS framework are aimed at helping students achieve a level of career readiness that can apply to many different fields needed in the state. Planning and preparing an experiment can achieve this end by preparing students to be collaborators and team players. In the GIRESiMCo model, researchers placed the "S" stage of "sharing" behind that of the planning and conducting of the investigation

to emphasize to students the importance of collaboration throughout the whole of the scientific process (Senisum et al., 2022). This collaboration importance was also conveyed in the student-led inquiry activity conducted by King et al. in 2024 as students worked in pairs for all portions of the lab including choosing which experiments they would run and assessment for content knowledge. Both studies showed effective learning through student led experimental design that was aided by the emphasis on collaboration.

The skill of collaboration is one that is necessary to proper experimental design and will benefit students as they prepare for any career or further science endeavor after high school. The practice of collaboration can be enhanced by proper ordering of an inquiry classroom following Kolb's constructivist theory. Educators must take steps to allow students to experience true student-led experimental design in order for their students to reap the content retention and career preparation benefits that the Framework for K-12 Science Education, STEELS standards, and Kolb's experiential learning theory posit must exist.

### Conclusion

The purpose of including each piece of aforementioned research is to show how Kolb's experiential learning theory and the Framework for K- 12 Science education can work together to provide a constructivist framework for today's science teachers to teach student-led experimental design. Putting these pieces together should allow educators to do this in a manner that increases content retention and career readiness skills. Research on scaffolding inquiry and experimental design demonstrates that students benefit from structured steps as they move from guided to open inquiry. This structure allows students to move through concrete experience and reflection steps as they learn the disciplinary core ideas put forth by the Framework.

Simultaneous to this, they are able to develop career readiness skills like teamwork and problem solving by implementing the science and engineering practices put forth in STEELS. These aligned theoretical strands form the conceptual basis for the student-led experimental design intervention examined in this study.

## CHAPTER THREE

## METHODOLOGY

To improve my personal teaching methodology surrounding student-led experimental design, I designed a treatment period based upon the background of Kolb's constructivism and the NGSS standards. The treatment period was designed to move through the steps that align these two concepts. Data collection methods were centered around content retention and career readiness skills of teamwork and problem solving. This treatment period and subsequent data collection allowed me to analyze the effectiveness of student-led experimental design on content retention, teamwork, and problem-solving skills in high school biology students.

Demographics

This research took place in three different biology class periods at Dallastown Area High School in Dallastown, Pennsylvania. Dallastown Area High School services approximately 2,000 students (About us). The total number of students who participated in the study ( $N=19$ ). While these students were spread across three different class periods, all treatment methods were applied in the same manner and they are treated as one group. Dallastown Area High School approaches leveling of biology classrooms with three options: Foundations, College and Career Ready, or Honors biology. The biology classroom that this study took place in was considered a College and Career Ready classroom. This designation indicates that nearly any student should be able to find success in the classroom and there are a diverse range of learning styles and abilities present in the classroom. The course is designated as College and Career Ready to imply that students will get all the information and skills that they need for either path—college or

career. Because of this designation, this was an optimal course to examine this concept of student-led experimental design as students in this course could be bound for a variety of fields where the skills offered by this type of learning could be beneficial.

Of the students who participated in this research, 13% had IEPs for specific learning disabilities and 13% had 504 service agreements. Of the three class periods this research was conducted within, one class period benefits from the incorporation of a co-teacher. The purpose of this co-teacher is to have a special education teacher in the classroom to support all students so that students with learning needs can find success in a diverse classroom environment.

The research methodology for this project received an exemption by Montana State University's Institutional Review Board, and compliance for work with human subjects was maintained (Appendix A).

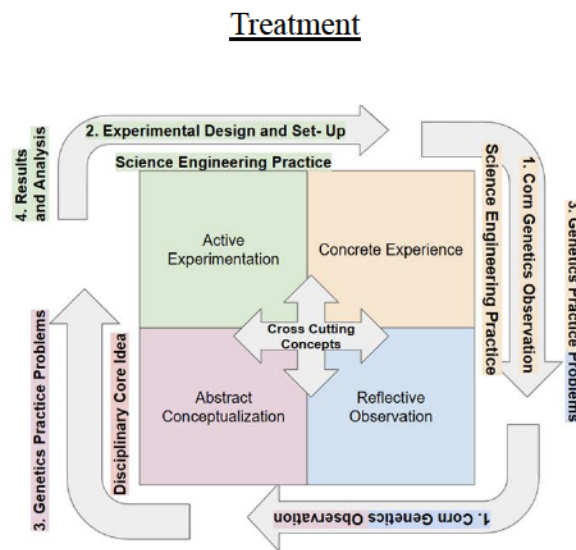


Figure 2. Kolb's experiential learning theory overlaid with the three dimensions of learning from the Framework for K-12 Science Education. *Note.* The treatment process for this action research is presented on this diagram with steps in numerical order to visually represent how they were guided by this framework.

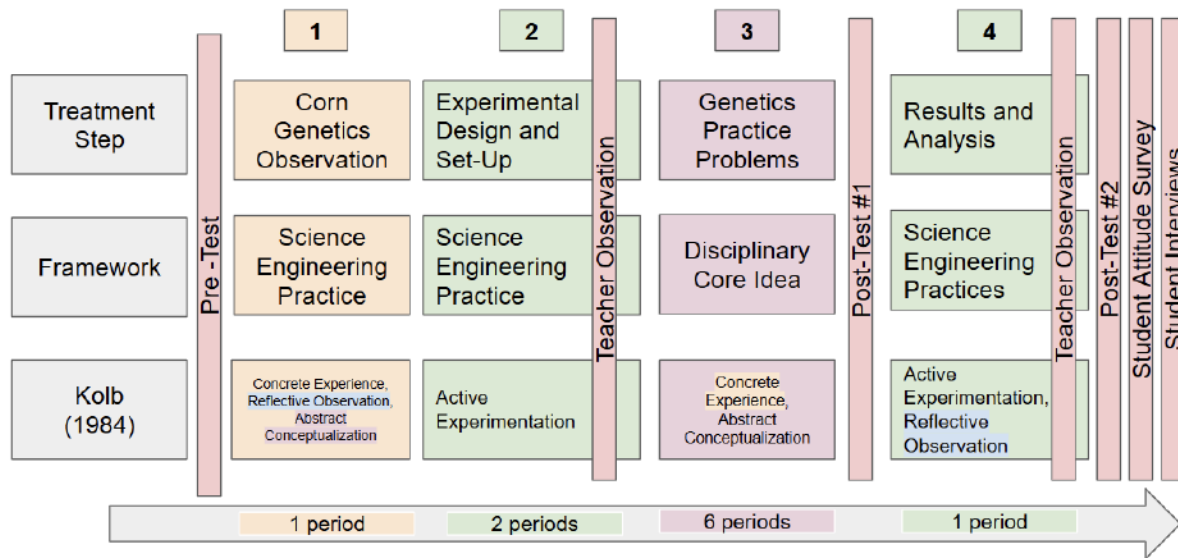


Figure 3. A chart style view of the treatment alignment with the Framework and Kolb. This chart also includes data collection tools in red and a timeline of the treatment along the bottom.

The treatment for this research was designed to follow Kolb's experiential learning theory as well as the Framework for K-12 Science Education (Figure 2). This treatment took place at the beginning of a learning unit on Genetics and lasted for the entirety of the unit. The time period was approximately 3 weeks or 10 school days in February of 2026. The learning unit began with students completing the pre-test for genetics content understanding. The pre-test allowed the researcher to establish a baseline of understanding.

From here, students completed the Corn Genetics Observation Activity (Appendix B). The Corn Genetics Observation Activity was step one of the treatment (Figure 3). Step one of the treatment intended to give students the background they needed to design their own experimental crosses of corn seeds by fulfilling multiple parts of Kolb's learning theory. Primarily, the role of concrete experience was fulfilled as students held physical corn cobs with different ratios of kernels and counted them. The Corn Genetics Activity then moved toward

Kolb's reflective observation as students analyzed and made sense of the results. Finally, the activity ended with the opportunity for students to ask any questions that they have remaining about corn genetics. This questioning was a form of Kolb's abstract conceptualization that was necessary before students moved on to the active experimentation phase of the treatment.

Out of the Corn Genetics Observation Activity, students were presented with the opportunity to enter Kolb's active experimentation stage and employ the science and engineering practice of planning and performing an experiment during step two of the treatment (Figure 3). In step two of the treatment, students were asked to design an experiment regarding the inheritance pattern corn seedlings. To do this, they were presented with a problem, list of supplies, and an experimental planning template (Appendix C). The experimental planning template was familiar to students as they had been using it to various degrees throughout the school year in biology. However, this was the first laboratory experience where the boxes in the template were completely blank. In previous experiences, the instructor had placed scaffolding inside these boxes such as sentence starters, that lead students in the proper direction.

To begin step two of the treatment, students were placed in randomized groups of two using a random name selector. With their group of two, one instructional period (66 minutes) was allotted to planning their experiment. Students were able to talk through the experiment with their peers and were allowed to use their personal devices to research any background information necessary for the experiment. During the class period, the researcher actively circulated the classroom to assist in prompting students towards proper experimental design methods. This prompting involved asking questions such as "why does this make it a good

experiment?” or “how can we ensure that we are only changing one variable?” Throughout this time, the instructor maintained a role of support to ensure that this experiment was student led.

As part of this support role, the instructor also served to approve student experimental designs. Student experimental designs were approved when the instructor placed a “stamp” on the student papers. Requirements for approval included feasibility during the given time period, correct identification of independent, dependent and constant variables, and inclusion of a control group. Given that these were the requirements, a variety of experimental design procedures were accepted. A second consecutive class period was allotted for students to set-up their experiment. During both of these class periods, the researcher was also actively completing the teacher observation rubric. These two class periods together represented step two of the treatment. They exposed students to the science and engineering practice of planning and performing an experiment and to Kolb’s phase of active experimentation (Figure 3).

After the students set-up their experimental designs, the learning sequence shifted to concrete experience and abstract conceptualization for six days. These six days were considered step three of the treatment (Figure 3). During this time, students completed a few select assignments from the traditional learning unit on genetics. These included Punnett Square practice problems and creating fake monsters showing different patterns of inheritance. All assignments completed in this portion of the treatment involved solving genetics practice problems to determine a genotype and phenotype ratio as the answer. In this manner, each assignment was relevant to the experimental design as the problem students were solving in their experiments necessitated the use of genotype and phenotype ratios. The secondary purpose of

these six days was to allow time for the necessary experimental processes of seed germination to take place.

After these six days had passed and step three of the treatment was completed, post-test number one was administered to students. The purpose of this post-test was to measure student growth during the concrete experience learning opportunities that had taken place during step three of the treatment. Since the recording and analysis of the experimental results had not yet occurred, placing a post-test at this time allowed for a comparison of the content retention gained from the different parts of the learning cycle.

Following the Genetics Practice Problems in step three, it was time for students to jump back into active experimentation with step four of the treatment period (Figure 3). This step involved students looking at their and their classmates' germinated seedling, recording results, and completing the analysis of their experimental design set-ups. Students were allotted one, 66 minute learning period to do this. Students recorded data on the tables that they had designed during the experimental set-up day. Then, they created graphs of this data and answered the extension questions that had been posed by the instructor. The extension questions in the lab packet were open ended to allow for varying lab set ups. These extension questions served to fulfill Kolb's reflective observation phase of the learning cycle.

During step four of the treatment, the researcher completed another round of teacher observation rubrics. The next class period, post-test number two was administered to measure the content retention that had taken place because of the student led experimental design. After this, the student attitude survey was administered to students. Once the treatment period was concluded, the researcher allotted two days to complete designated student interviews.

### Data Collection and Analysis Strategies

To successfully measure the effectiveness of teaching student-led experimental design in this constructivist manner, I chose to use mixed-methods approach to analyze both quantitative and qualitative data collected before, during, and after the treatment period (Mertler, 2020). These methods allowed me to successfully analyze the effect of these teaching methods on content retention and career readiness skills of teamwork and problem solving. Multiple data sources were used to triangulate the effects of student-led experimental design on content retention and career readiness skills (Table 1).

Table 1. Data Triangulation Matrix

|                                    | Focus Question: How does incorporating student-led experimental design through a constructivist framework impact learning in a high school biology classroom? |                                    |                                           |
|------------------------------------|---------------------------------------------------------------------------------------------------------------------------------------------------------------|------------------------------------|-------------------------------------------|
| <b>Data Collection Instruments</b> | Content Retention                                                                                                                                             | Career Readiness Skill of Teamwork | Career Readiness Skill of Problem-Solving |
| Pre and Post- Tests                | X                                                                                                                                                             |                                    |                                           |
| Likert- Style Survey               | X                                                                                                                                                             | X                                  | X                                         |
| Student Interviews                 | X                                                                                                                                                             | X                                  | X                                         |
| Teacher Observations               |                                                                                                                                                               | X                                  | X                                         |

#### Pre-tests and Post-tests

I administered three tests to specifically measure the content retention aspect of my action research project. The tests were multiple choice and centered around level one of Bloom's taxonomy of understanding of the content taught. The questions only asked students to

“remember” to best assess the content retention aspect of my focus question (Anderson & Krathwohl, 2001). The tests were aligned with the disciplinary core ideas presented in the genetics unit of the Pennsylvania Science Technology Engineering and Environmental Literacy (STEELS) standards. The content validity and reliability of the tests were ensured by standard use across the high school’s various biology classes after undergoing approval by all biology teachers. One test was given prior to the learning unit. This test is referred to as the pre-test. The pre-test revealed students’ baseline knowledge score. The same test, with different variables, was given at the end of a six-day period of concrete experience while waiting to complete the final portion of the corn genetics experimental design lab. Different variables were used between the pre-test and each subsequent post-test to ensure that students did not simply memorize the answers across the different administrations. This test is referred to as post-test number one. The data from post-test number one served as the control. The unique design of this learning unit to go from concrete experience to active experimentation and back to concrete experience before finishing the active experimentation allowed a unique chance to compare which experiences had the most impact on students’ content retention (Figure 2).

Finally, after students gathered data and analyzed results for their corn genetics lab, a third version of this test was given. There was no added review or instruction on the material between the second and third test other than the data collection, analysis and extension. The scores on these three tests were analyzed using paired t-tests. The paired t-tests allowed me to see if there was a significant difference between both test scores (Appendix D). Specifically, paired t-tests were used to distinguish the significance in change between the pre-test and post-test

number one, post-test number one and post-test number two, and the pre-test and post-test number two.

### Likert-style Survey

I conducted a survey with a four-point scale that assessed students' impressions of the learning process. This was a researcher developed survey. Questions varied from information about how confident students felt with the material (measuring the content retention aspect) to how students felt about the teamwork aspect of each laboratory experience and the problem-solving aspect of each laboratory experience (measuring the career readiness aspect). Survey results were analyzed using mean comparisons to look for increases in perceived confidence, collaboration, and problem solving (Appendix E).

### Student Interviews

After both laboratory experiences, I interviewed students with questions regarding their experience in the laboratory. Questions focused on student perceptions of their learning, their engagement with the content, their engagement with problem-solving and teamwork, and their overall enjoyment of the experience. Students were selected using an electronic random name selector. When inputting names into this selection technology, I assured that half of the students selected had current grades in the top 50% of their class, and half of the students selected had current grades in the bottom 50% of their class to provide equal representation and varying perspectives. Based on this methodology and scheduling availability, nine students were able to be interviewed. I analyzed the responses to these interviews using thematic analysis regarding content retention, teamwork skills, and problem-solving skills (Appendix F).

### Teacher Observation

The researcher created a standardized rubric that was used to make observations during student work time. The rubric consisted of a list of observable behaviors that I was able to easily walk around the room and check off. To establish validity and increase consistency of observational data, my co-teacher was also tracking this data during the class period that she was a part of. Analysis of student learning is a normative role in the classroom for her. These rubrics were compared across laboratory experiences to see how often we saw career building skills of teamwork and problem solving or witnessed conversations surrounding the learning goals occurring (Appendix G).

## CHAPTER FOUR

## DATA ANALYSIS: CLAIMS AND EVIDENCE

The purpose of this action research was to investigate how incorporating student-led experimental design through a constructivist framework would impact learning in a high school biology classroom. My focus question was, how does incorporating student-led experimental design through a constructivist framework impact learning in a high school biology classroom? Specifically, this action research was designed to evaluate the effectiveness of the intervention on content retention and career readiness skills of teamwork and problem solving. The tools used to measure this effectiveness included pre- and post-tests, a Likert style survey, student interviews, and a teacher observation rubric. These instruments provided a triangulated view of each focus question.

Content Retention

As students moved throughout the learning process in the genetics unit, growth in content retention was seen most clearly in relationship to the abstract conceptualization activities rather than the student-led experimental design. The growth in content retention can be seen in the change of test scores from the pre-test to post-test #1 and post- test #2. The average test score on the pre-test was 43.3% with a standard deviation of 18.47%. For post-test #1 the average test score was 76.32% with a standard deviation of 23.56% ( $N=19$ ). Paired t-tests revealed that the difference in test scores between the pre-test and post-test #1 was statistically significant ( $p<0.05$ ). Post-test #2 was given after the conclusion of the entire treatment period. The average on this test score was 80% with a standard deviation of 18.35% (Figure 4). The difference in test

scores between post-test #1 and post-test #2 was not statistically significant ( $p>0.05$ ). Although the increase in test scores was not significant between post-test#1 and post-test #2 there was a statistically significant change between the initial pre-test and post-test #2 ( $p<0.05$ ).



Figure 4. Student average test scores on pre-test (administered before treatment), post-test #1 (administered after step 3 of treatment), and post-test #2 (administered at the conclusion of treatment) with standard deviation ( $N=19$ ).

Student self-perception supports the claim that abstract conceptualization was the phase of the learning cycle that had the most effect on content retention. The Likert survey revealed a mean score of 3.1 for the two statements relevant to this claim. These two statements were: “The genetics corn activity and laboratory experience was more valuable to my understanding of Mendelian genetics concepts than worksheets regarding these concepts”, and “My understanding of Mendelian Genetics grew because of my experiences in the corn genetics pre-activity and laboratory experience”. The score slightly above 3 indicates that on average the students who completed the survey “somewhat agree” with these statements with a slight lean towards a 4 which would indicate complete agreement (Figure 5).

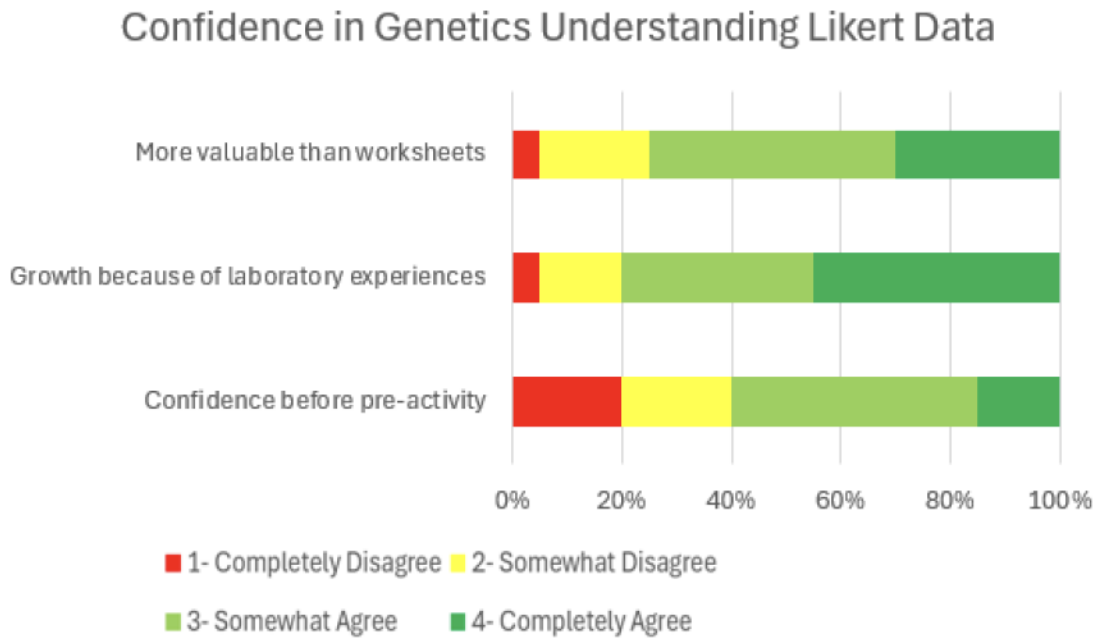


Figure 5. Results from Likert survey questions regarding confidence in Genetics understanding ( $N=19$ ).

Throughout student interviews, a similar theme continued to emerge that students perceived the laboratory experience as helpful, but they viewed the abstract conceptualization activities like a Quizlet flashcard set and practice problems as more helpful. Table 2 shows how often students mentioned each learning tool in interviews about effectively understanding genetics content. While completing practice problems themselves was the most common theme with 39% of interviewed students mentioning this, completion of the corn genetics lab was mentioned 17% of the time in response to this.

Table 2. Percentage of students who mentioned each learning tool when asked about content retention during student interviews ( $n=9$ )

| Learning Tool                        | Corn Genetics Lab | Quizlet | Practice Problems | Notes | Bell-Ringers | Asking Teacher |
|--------------------------------------|-------------------|---------|-------------------|-------|--------------|----------------|
| Percentage of Interviewee References | 17%               | 22%     | 39%               | 11%   | 5.5%         | 5.5%           |

In conclusion, the comparison of test results through paired t-tests along with the Likert survey results and student interview thematic analysis suggest that abstract conceptualization activities may have played a larger role in initial content gains. This interpretation is made cautiously as the phases of the learning cycle overlapped throughout the treatment period.

### Teamwork

Data suggest that the career readiness skill of teamwork increased with the treatment of student-led experimental design and implementation of partner work. Likert style questions revolving around teamwork showed an average score of 3.3. This average indicates that students somewhat agree- completely agree with these statements (Figure 6).

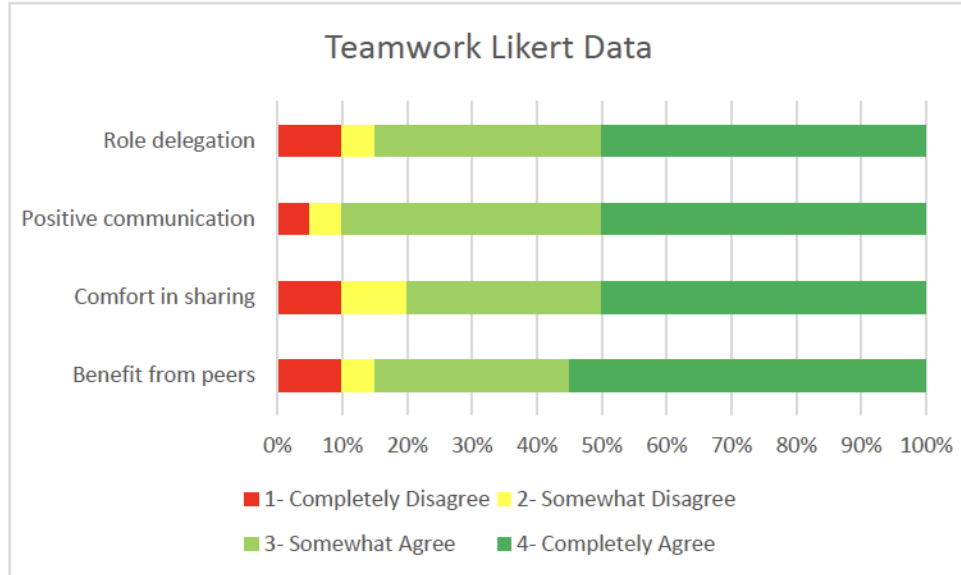


Figure 6. Results from Likert survey questions regarding confidence in Genetics understanding ( $N=19$ ).

Two student interview questions were on the topic of teamwork. The results of these questions also support the claim that the skill of teamwork increased within the treatment of the student-led experimental design. One question that was asked of all interviewees was if they enjoyed their experience working with a group on the Corn Genetics Lab. Of the students interviewed, 78% responded positively stating that they did enjoy working with a group on the corn genetics lab. The other 22% of students who answered the teamwork question unfavorably made qualifying statements saying that it would be “helpful if you have the right person with you” and another stating that “it depends on who is in your group”. Of these students with a neutral or negative view of group work, 100% also indicated that they were “helpers” when asked about their role within the group. Opposite of this, of the 78% of students who responded with a positive view of the group work, only 29% viewed themselves as helpers while the majority (71%) viewed themselves as leaders (Table 3).

Table 3. Thematic analysis of teamwork interview questions grouped according to positive or neutral/negative perception with sub-groups of leader or helper ( $n=9$ ).

| Students with Positive View of Group Work |                           | Students with Neutral or Negative View of Group Work |                           |
|-------------------------------------------|---------------------------|------------------------------------------------------|---------------------------|
| 78%                                       |                           | 22%                                                  |                           |
| Self-Perception of Helper                 | Self-Perception of Leader | Self-Perception of Helper                            | Self-Perception of Leader |
| 29%                                       | 71%                       | 100%                                                 | 0%                        |

As the teacher worked to observe student behaviors in six different categories, the final data revealed that role management was the lowest behavior observed via tallies. The highest observable behavior for teamwork skills was collaboration in procedure design. One such moment when collaboration was observed involved students debating the amount of soil they needed for planting their corn seeds. One student said, “should we just go with 10 grams”, to which his partner replied, “do we even need to measure it?”. Conversations like this were counted in the data recorded for collaboration which amounted to 24.1% of total observable behaviors (Figure 7).

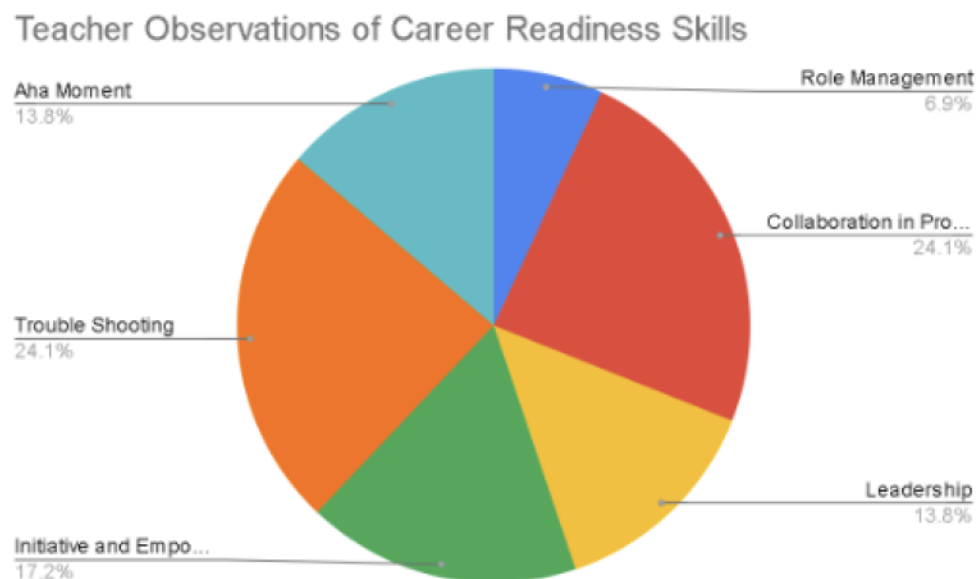


Figure 7. A pie chart showing the ratio of each observable career readiness skill behavior.

Overall, these data support the claim that student- led experimental design had a positive impact on the career readiness skill of teamwork. These findings also suggest that student-led experimental design may create opportunities for leadership development as a component of teamwork.

### Problem Solving

The impact of the treatment on the career readiness skill of problem solving was difficult to measure as many students were unable to identify a problem that they had to solve throughout the Corn Genetics Lab. Thus, there was limited evidence of problem solving to record. The average survey score for questions revolving around the skill of problem solving was 3. This indicates that, on average, students “somewhat” agreed with the assertions that the corn genetics lab increased their problem-solving skills (Figure 8).

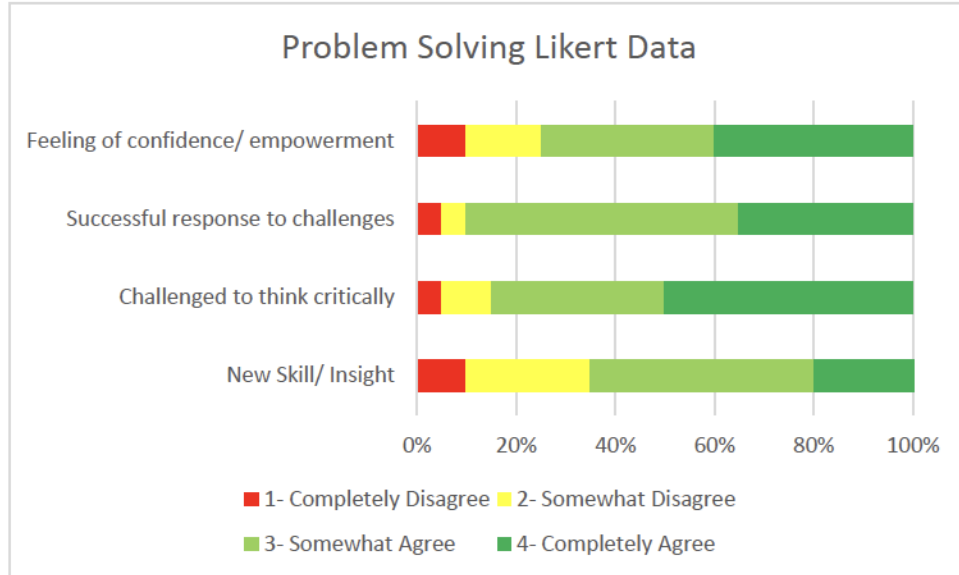


Figure 8. Student responses to survey questions surrounding the career skill of problem-solving.

Additional data to support this claim can be found in thematic analysis of the student interview questions about problem solving. Of the students interviewed, 78% were unable to identify any problems or difficulties that they encountered in the lab. Since they were unable to identify any difficulties, they were unable to provide feedback about what it looked like to overcome setbacks. Several students echoed the sentiment of one student who said, “It was all pretty straightforward”. Of the 22% of students who identified difficulties, one student stated that the most difficult portion of the experience involved a day when his partner was absent. He stated that he overcame this difficult by “being more precise [and] reading”. The other student who mentioned difficulty said that he still questions why his seed did not sprout and that since the lab is over now, he cannot overcome it.

Of the observable behaviors related to problem solving, the highest observed behavior was troubleshooting. As shown earlier in Figure 7, this behavior was observed at a rate of 24.1% of all observed behaviors. One specific example of this troubleshooting behavior involved

students determining how many seeds to place in each section of the seed tray. Students were observed asking their partners how many seed should go in each section of the tray, lab papers showed math indicating division of the number of slots in the tray by the number of seeds, and the teacher and co-teacher were asked if it was okay if there was an uneven number since twenty seeds can't easily divide into six slots.

The data collected in this research helped to analyze the impact of incorporating student led experimental design through a constructivist framework in a high school biology classroom. The data collection involved a mixed methods approach that included pre- and post- tests, a survey, student interview questions, and teacher observation. The data reveal that content retention was most impacted by the abstract conceptualization phase of the learning cycle. Additionally, the career readiness skills enabled by incorporation of the STEELS standards showed that teamwork was positively impacted and that there was little impact on the career readiness skill of teamwork. These analyses led to reflection for the researcher and implications for future practice.

## CHAPTER FIVE

## VALUE: REASONING AND REFLECTION

At the core of this study was the desire to analyze an effective method of teaching experimental design to my high school biology students. Digging into the literature on science education revealed that the methods of teaching recommended in the new Pennsylvania science standards can be found echoed throughout literature all the way back to Kolb's 1984 theory of constructivism. By overlapping concepts found in the Framework for K-12 Science Education with Kolb's theory, I was able to design a learning sequence for the genetics unit that walked through this process and incorporated a treatment period of student-led experimental design. Through quantitative and qualitative data analysis I found that content retention could most clearly be tied to the concrete experience phase, that the skill of teamwork increased and the skill of problem-solving did not notably increased.

Claims from the Study

It has already been stated that the most beneficial portion of the learning cycle for content retention was the abstract conceptualization phase rather than the treatment phase of student-led experimental design. This finding aligns with Kolb's 1984 theory. In fact, in his 1984 work Kolb states that "Ideas are not fixed and immutable elements of thought but are formed and re-formed through experience". I designed the sequence of pre- and post- tests to have two different post-tests at different portions of the learning cycle in an effort to see how student ideas were "formed and re-formed" in this manner. What I found through this testing sequence was that the most significant increase in content knowledge happened early on between the pre-test and post-test 1.

In the time period in between the pre-test and post-test #1, students had completed the “Genetics Pre-Activity”, the experimental design, and worked through one worksheet of Mendelian Genetics practice problems. They had not yet drawn conclusions on their lab as this would take place two weeks later when the seeds germinated. Therefore, the fact that there was a significant increase in scores between the pre-test and post-test #1 points to the effectiveness of the abstract conceptualization such as practice worksheets in this growth of knowledge. Student quotes in the interview portion of my data collection corroborated the importance of this. The fact that there was no significant difference between post-test #1 and post-test #2 shows that this content knowledge obtained from the abstract conceptualization phase was retained through the active experimentation phase. These findings suggest that the incorporation of student-led experimental design in a learning sequence may not directly translate to increased content retention. One possible explanation for this could be the assessment format that was used to measure content retention. Since the questions asked of students were largely memory based, it seems reasonable that the worksheets and practice were be viewed as more beneficial than the student-led experimental design. If I were to do this again, I would change my format of measuring content retention to be more open ended rather than multiple choice questions. This would give a better window into seeing how students’ ideas were “formed and re-formed” (Kolb,1984).

Beyond content retention this study also investigated the development of skills such as career readiness skills of teamwork and problem solving. The reasoning for studying these skills was based on the need for new science professionals in Pennsylvania and the aim of the new three- dimensional STEELS standards to get students there. The career readiness skills were

analyzed using several methods of qualitative analyses and a Likert survey completed by students. Through these I was able to see that the skill of teamwork showed a notable increase among students. Student self-perception identified this increase based on Likert survey results and interview results. Thematic analysis of interview results showed an interesting trend that students with a positive view of group work had a higher chance of self-identifying as a leader within their group. This correlation may be attributed to more confident students having a predisposition to enjoy group work more. As I observed student behaviors throughout this treatment period, I observed behaviors that fell into the category of “leadership” at a rate of 24.1% of all observations made. While I was initially looking for data points surrounding a general skill of teamwork, the data told more of a story about opportunities for leadership as an aspect of teamwork.

Besides teamwork, I also collected data regarding the career skill of problem solving. The data revealed no noticeable pattern of change in problem solving skills for students exposed to the treatment period. It seems to be that the main reason for this was that students had difficulty expressing any difficulties they encountered during the treatment period. Therefore, since there were no problems to overcome, they could not analyze their problem-solving skills. As I attempted to observe student behavior regarding problem-solving, the highest behavior analyzed was trouble-shooting. Often what I counted as a tally for this behavior looked like students asking each other for help or asking myself and the coteacher questions. I attempted to direct students to their partners and critical thinking when these questions were asked, but it was difficult to urge students to problem-solve independently or with their group as students seemed to prefer asking their teacher for the answers. An example of this was seen with the issue of

deciding how many seeds students should place in each slot on their seed tray. This was not a true problem in the sense that it would affect the results of the study, and it was something that was left up to students to decide. Since there were six slots in the seed tray and twenty seeds, several groups of students became bothered that the number of seeds would not be even between each slot. In this instance, students' instinct was to seek validation from their teachers. This need for validation from teachers could be a reason why students were not able to identify any problems. At the end of their experimental design, they knew that they were going to get a stamp of approval from the teacher showing that their experiment had an acceptable design. This sense of security, while necessary for classroom flow, may have limited student's ability to truly problem-solve during this treatment period.

#### Value of the Study and Consideration for Future Research

My main takeaway from this process is that student-led experimental design is meaningful alongside the other portions of the learning cycle described by Kolb. It cannot be done in isolation as I unknowingly attempted to do at the beginning of my career as an educator. I observed the value of scaffolding as students moved carefully throughout the learning cycle. It took much intentionality to design the Corn Genetics Observation Activity in a manner which gave students the knowledge they needed to design an experiment without taking away the inquiry portion of the experimental design.

As I have gone through this personal journey of learning how to be an inquiry teacher, I know the value of this proper form of scaffolding that I have observed. As the young teacher who was excited to try something new and initially dove headfirst into student-led experimental design by giving my students a blank sheet of paper and telling them to design an experiment, I

was met with chaos in the classroom and further suspicion from my colleagues about these new standards. The research conducted on this treatment period about student-led experimental design allows me to bring information to my colleagues and share with them the value of running labs in this format while giving students the appropriate level of scaffolding beforehand.

Since the buildup to this student-led experimental design is so important, it has become clear that some units of learning and some types of labs are better for this than others. For example, in the chemistry classroom where safety protocols on chemical reactions are incredibly important, no amount of scaffolding experimental design will be able to fully take away some step-by-step procedures provided by the instructor.

Based on Kolb's concept of true learning being ideas "formed and reformed", a consideration for future research is to design an action research project focused on assessing students' scientific skills (Kolb, 1984). One way to do this could be to implement a method where the validation of stamping for approval was removed and instead students were assessed on their experimental design set-ups.

#### Impact of Action Research on the Author

As a teacher, this research helped me to see learning as a holistic process where skills and content knowledge are intertwined. I learned that it is possible for students to learn scientific processes in a manner that is driven by them with the correct prompting and groundwork in place. The part of teaching science that is an art is recognizing what that groundwork and prompting is for each subject, each unit in each subject, each group of students, and each individual student.

Another part of teaching science that is an art form is finding a healthy balance of student frustration. Throughout the process of student-led experimental design, students can become frustrated as they are waiting for approval to move on to the next step. This treatment period has impacted me by helping me see that student frustration surrounding a task is not always a bad thing, however excessive frustration can lead to students shutting down and disliking science. Walking this fine line is a skill that this process has grown in me as an educator.

As I worked through completing this action research project, I naturally was mirroring many of the experimental steps that my students completed in their experimental design. As I found myself mirroring their steps, I also found myself mirroring many of the emotions that my students felt as they designed their own experiment. Both my students and I experienced times of frustration, work avoidance, blocks of creativity, and more. However, the most important emotion that I can say this process has mirrored with that of my students' is confidence in my ability to do hard things.

At the end of the day, I hope that teaching through the lens of student-led experimental design instills this same confidence in my students. It is this confidence in their abilities that will lead to the best results possible-- both for my teaching practice and their test scores and future careers. As I move on from this treatment period into planning more lessons and more units of learning, I cannot help but see my content through the lens of the learning cycle used in this treatment. I am excited to continue growing my practice in this direction and to continue monitoring how students respond! I am convinced that this action research has made me a better educator, and I hope that because of it I can continue to grow in giving my students the steps that they need to conduct their own experiments in a beneficial manner.

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## APPENDICES

APPENDIX A: EXEMPTION MSU INSTITUTIONAL REVIEW  
BOARD

Hello Bodisch, Madelyn,

Your protocol was reviewed by the IRB and has been approved.

PI: Bodisch, Madelyn

Approval Date: 12/17/2025

Title: Beyond the Lab Manual: Student- Led Experimental Design to Boost Content Retention and Career Readiness in High School Biology

Protocol #: 2025-2347-EXEMPT

Review Type: Exemption

Expiration Date: 12/17/2030

Work described under this protocol may now commence. The PI is responsible for ensuring that the protocol accurately describes research practices being conducted.

APPENDIX B: CORN GENETICS OBSERVATION ACTIVITY

**Part 4 - Corn Observation Activity:** Complete this portion when you are called to the back lab station.

Corn is an ideal organism for studying Mendelian genetics. Instead of having thousands of individual plants, an ear of corn houses a generation of hundreds of offspring. Generally, an ear of corn has about 200 kernels, and each kernel on an ear of corn represents an offspring. The color of kernels is an inherited trait.

**Instructions:** Observe the parental generation of corn. Count the kernels and fill in the chart below.

**F<sub>1</sub> Generation Observations:**

|                                   | # of Purple Kernels | # of Yellow Kernels | Total Number of Kernels |
|-----------------------------------|---------------------|---------------------|-------------------------|
| F <sub>1</sub>                    |                     |                     |                         |
| Percent (# of each color / total) |                     |                     |                         |
| Ratio of purple to yellow         |                     |                     |                         |

The Purple corn was allowed to self pollinate to create an F<sub>2</sub> generation (F<sub>1</sub> x F<sub>1</sub> = F<sub>2</sub> ).

→ Observe TWO different offspring from the F<sub>1</sub> generation and record your data in the table below.

**F<sub>2</sub> Generation Observations**

|                                                                            | # of Purple Kernels | # of Yellow Kernels | Total # of Kernels |
|----------------------------------------------------------------------------|---------------------|---------------------|--------------------|
| F <sub>2</sub> Offspring #1                                                |                     |                     |                    |
| F <sub>2</sub> Offspring #2                                                |                     |                     |                    |
| SUM                                                                        |                     |                     |                    |
| Percent (sum of each color / total) x 100                                  |                     |                     |                    |
| Ratio of purple : yellow (divide purple/yellow and round to whole numbers) |                     |                     |                    |

- Based on your data for the F<sub>2</sub> generation, which phenotype appears to be dominant? \_\_\_\_\_
  - What evidence (DATA!) supports that claim? \_\_\_\_\_
- Based on your data for the F<sub>2</sub> generation, which phenotype appears to be **recessive**? \_\_\_\_\_
  - What evidence (DATA!) supports that claim? \_\_\_\_\_
- Which of Mendel's laws is being investigated? Support your answer using information from your notes or the images in part 2.
- Use R for purple and r for yellow. List the genotype for the F<sub>1</sub> generation: \_\_\_\_\_
- Based on this, what must be the genotype of the parental generation? \_\_\_\_\_

## APPENDIX C: EXPERIMENTAL PLANNING TEMPLATE

## 4. PLAN &amp; PERFORM EXPERIMENT

**Stamp:** You are approved to set-up your experiment!

Research Question: \_\_\_\_\_

Determine Variables:

**Independent Variable:** Phenotypes and Genotypes of seeds

**Dependent Variable:** \_\_\_\_\_

**Constants (s):**

\_\_\_\_\_  
\_\_\_\_\_  
\_\_\_\_\_

Numbered List of Steps that You Will Take (Procedure)

Sketch and Label the Lab Setup:

Materials Needed:

- 20 random seeds from the "salesman" (your teacher)

## APPENDIX D: GENETICS PRE- AND POST- TESTS

Genetics Pre-Test

**Instructions:** Circle the best answer for each question below.

1. The genotype RR is...
  - a. Homozygous dominant
  - b. Homozygous recessive
  - c. Heterozygous
2. The genotype Rr is...
  - a. Homozygous dominant
  - b. Homozygous recessive
  - c. Heterozygous
3. If purple corn kernels are dominant to yellow corn kernels, for the genotype Rr, choose the correct phenotype below.
  - a. Purple corn kernels
  - b. White corn kernels
  - c. A mix of purple and yellow corn kernels
  - d. It is impossible to tell
4. A recessive trait can be described as...
  - a. The stronger allele that only needs one copy to be seen
  - b. A weaker allele that needs two copies to be seen
  - c. A genotype that is lighter in color
  - d. A genotype that is darker in color
5. Purple starchy corn (RR) is dominant to yellow starchy corn (rr). Two heterozygous corn plants are allowed to freely cross-pollinate. What would you expect the offspring ratio to be?
  - a. 3 yellow to 1 purple
  - b. 3 purple to 1 yellow
  - c. 1 yellow to 3 purple
  - d. 1 purple to 3 yellow
6. In corn seedlings, it is observed that tall and dwarf seedlings are present. What type of dominance is this representative of?
  - a. Incomplete dominance
  - b. Multiple Alleles
  - c. Complete dominance
  - d. Codominance

**OVER →**

7. Corn seedlings germinate in a ratio of 3 tall seedlings: 1 dwarf seedling. Tall is dominant to dwarf. What must have been the genotype of the parents?
  - a. DD and dd
  - b. Dd and Dd
  - c. dd and dd
  - d. DD and DD
8. If two homozygous dominant tall corn plants are cross pollinated, what would be the expected offspring phenotypes?
  - a. 100% tall
  - b. 100% short
  - c. 50% tall, 50% short
  - d. 75 % tall, 25% short
9. One allele for corn color could be...
  - a. Homozygous
  - b. Purple
  - c. Heterozygous
  - d. Tall
10. Information is passed from parents to offspring in the form of...
  - a. RNA
  - b. Random assortment
  - c. DNA
  - d. Homozygous assortment

Genetics Post-Test 1

**Instructions:** Circle the best answer for each question below.

1. The genotype  $rr$  is...
  - a. Homozygous dominant
  - b. Homozygous recessive
  - c. Heterozygous
2. The genotype  $RR$  is...
  - a. Homozygous dominant
  - b. Homozygous recessive
  - c. Heterozygous
3. If purple corn kernels are dominant to yellow corn kernels, for the genotype  $rr$ , choose the correct phenotype below.
  - a. Purple corn kernels
  - b. Yellow corn kernels
  - c. A mix of purple and yellow corn kernels
  - d. It is impossible to tell
4. A dominant trait can be described as...
  - a. The stronger allele that only needs one copy to be seen
  - b. A weaker allele that needs two copies to be seen
  - c. A genotype that is lighter in color
  - d. A genotype that is darker in color
5. Purple starchy corn ( $RR$ ) is dominant to yellow starchy corn ( $rr$ ). Two heterozygous corn plants are allowed to freely cross-pollinate. What would you expect the offspring ratio to be?
  - a. 3 yellow to 1 purple
  - b. 3 purple to 1 yellow
  - c. 1 yellow to 3 purple
  - d. 1 purple to 3 yellow
6. In corn seedlings, it is observed that tall and dwarf seedlings are present. What type of dominance is this representative of?
  - a. Incomplete dominance
  - b. Multiple Alleles
  - c. Complete dominance
  - d. Codominance

**OVER →**

7. Corn seedlings germinate in a ratio of 3 tall seedlings: 1 dwarf seedling. Tall is dominant to dwarf. What must have been the genotype of the parents?
  - a. DD and dd
  - b. Dd and Dd
  - c. dd and dd
  - d. DD and DD
8. If two homozygous recessive dwarf corn plants are cross pollinated, what would be the expected offspring phenotypes?
  - a. 100% tall
  - b. 100% short
  - c. 50% tall, 50% short
  - d. 75 % tall, 25% short
9. One allele for corn color could be...
  - a. Homozygous
  - b. Purple
  - c. Heterozygous
  - d. Tall
10. Information is passed from parents to offspring in the form of...
  - a. RNA
  - b. Random assortment
  - c. DNA
  - d. Homozygous assortment

Genetics Post-Test 2

**Instructions:** Circle the best answer for each question below.

1. The genotype Rr is...
  - a. Homozygous dominant
  - b. Homozygous recessive
  - c. Heterozygous
2. The genotype rr is...
  - a. Homozygous dominant
  - b. Homozygous recessive
  - c. Heterozygous
3. If purple corn kernels are dominant to yellow corn kernels, for the genotype RR, choose the correct phenotype below.
  - a. Purple corn kernels
  - b. White corn kernels
  - c. A mix of purple and yellow corn kernels
  - d. It is impossible to tell
4. A dominant trait can be described as...
  - a. The stronger allele that only needs one copy to be seen
  - b. A weaker allele that needs two copies to be seen
  - c. A genotype that is lighter in color
  - d. A genotype that is darker in color
5. Purple starchy corn (RR) is dominant to yellow starchy corn (rr). Two heterozygous corn plants are allowed to freely cross-pollinate. What would you expect the offspring ratio to be?
  - a. 3 yellow to 1 purple
  - b. 3 purple to 1 yellow
  - c. 1 yellow to 3 purple
  - d. 1 purple to 3 yellow
6. In corn seedlings, it is observed that tall and dwarf seedlings are present. What type of dominance is this representative of?
  - a. Incomplete dominance
  - b. Multiple Alleles
  - c. Complete dominance
  - d. Codominance

**OVER →**

7. Corn seedlings germinate in a ratio of 3 tall seedlings: 1 dwarf seedling. Tall is dominant to dwarf. What must have been the genotype of the parents?
  - a. DD and dd
  - b. Dd and Dd
  - c. dd and dd
  - d. DD and DD
8. If two homozygous recessive dwarf corn plants are cross pollinated, what would be the expected offspring phenotypes?
  - a. 100% tall
  - b. 100% short
  - c. 50% tall, 50% short
  - d. 75 % tall, 25% short
9. One allele for corn color could be...
  - a. Homozygous
  - b. Purple
  - c. Heterozygous
  - d. Tall
10. Information is passed from parents to offspring in the form of...
  - a. RNA
  - b. Random assortment
  - c. DNA
  - d. Homozygous assortment

APPENDIX E: CORN GENETICS SURVEY

**Corn Genetics Survey**

**Instructions:** Reflect on your experiences in the corn genetics pre-activity and laboratory experience. Please circle the number that best correlates to your opinion. Your responses will help me understand the effectiveness of these experiences. Please answer the following questions honestly. This form is entirely anonymous and any opinions shared will not affect your grade.

**Confidence In Genetics Understanding:**

1. I felt confident in my understanding of Mendelian Genetics before the corn genetics pre-activity
  1. Completely Disagree
  2. Somewhat Disagree
  3. Somewhat Agree
  4. Completely Agree
2. My understanding of Mendelian Genetics grew because of my experiences in the corn genetics pre-activity and laboratory experience.
  1. Completely Disagree
  2. Somewhat Disagree
  3. Somewhat Agree
  4. Completely Agree
3. The genetics corn activity and laboratory experience was more valuable to my understanding of Mendelian genetics concepts than worksheets regarding these concepts.
  1. Completely Disagree
  2. Somewhat Disagree
  3. Somewhat Agree
  4. Completely Agree

**Teamwork in the Laboratory Experience:**

1. I benefited from working with others in the genetics corn laboratory experience.
  1. Completely Disagree
  2. Somewhat Disagree
  3. Somewhat Agree
  4. Completely Agree
2. I felt comfortable sharing my ideas with my team.
  1. Completely Disagree
  2. Somewhat Disagree
  3. Somewhat Agree
  4. Completely Agree

3. My team communicated well with each other.
  1. Completely Disagree
  2. Somewhat Disagree
  3. Somewhat Agree
  4. Completely Agree
4. Amongst my group, roles and responsibilities of team members were defined and team members worked together well.
  1. Completely Disagree
  2. Somewhat Disagree
  3. Somewhat Agree
  4. Completely Agree

**Problem-Solving in the Laboratory Experience:**

1. I gained a new skill or insight from having to troubleshoot in this laboratory experience that I would not have gained otherwise.
  1. Completely Disagree
  2. Somewhat Disagree
  3. Somewhat Agree
  4. Completely Agree
2. This laboratory exercise challenged me and caused me to think critically.
  1. Completely Disagree
  2. Somewhat Disagree
  3. Somewhat Agree
  4. Completely Agree
3. When an unexpected issue arose during the laboratory experience, my group was able to successfully modify and adjust to compensate for the issue.
  1. Completely Disagree
  2. Somewhat Disagree
  3. Somewhat Agree
  4. Completely Agree
4. When our group encountered the most challenging problem in this lab, I felt confident and empowered to find a solution on our own.
  1. Completely Disagree
  2. Somewhat Disagree
  3. Somewhat Agree
  4. Completely Agree

## APPENDIX F: STUDENT INTERVIEW QUESTIONS

**Student Interview Questions**

**Content Retention**

1. In the genetics unit, what do you think was the most helpful tool or activity that helped you to learn the key vocabulary? Why?
2. In the genetics unit, what do you think was the most helpful tool or activity to learn how to solve genetics problems? Why?

**Teamwork**

1. Tell me about your experience working with your group on the lab. Did you enjoy it? Not enjoy it? Learn from it?
2. What type of role did you take in your group? For example, were you a leader, a helper, problem-solver?

**Problem- Solving**

1. Did you experience any major setbacks or confusion during this lab? If so, what did these look like?
2. If yes, what did it look like to overcome these setbacks? How did it feel when you successfully did?

APPENDIX G: TEACHER OBSERVATION RUBRIC

### Teacher Observation Rubric

| Career-Readiness Skill | Observable Behaviors                                                                                                                                                                    | Tally of Moments Behavior is Observed |
|------------------------|-----------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------|---------------------------------------|
| <b>Teamwork</b>        | <b>Role management:</b> student is seen or heard assigning a role or task to a specific partner (example: “You measure, I’ll record” )                                                  |                                       |
|                        | <b>Collaboration in Procedure Design:</b> student is seen or heard communicating with group members about experimental design (example: “Do you think we should do this next?”)         |                                       |
|                        | <b>Leadership:</b> student is seen or heard taking an active leadership role by asking quiet group members for their contributions                                                      |                                       |
| <b>Problem Solving</b> | <b>Initiative and Student Empowerment:</b> student or group is seen or heard implementing a corrective action without raising their hand to ask their teacher for help                  |                                       |
|                        | <b>Troubleshooting:</b> student or group is heard articulating a specific error in their process                                                                                        |                                       |
|                        | <b>Aha Moment:</b> student or group is seen or heard correcting misconceptions or making a cognitive jump as they work through the laboratory experience (example: “Oh, I get it now!”) |                                       |