INCREASING STUDENT ENGAGEMENT WITH

CITIZEN SCIENCE

by

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A professional paper submitted in partial fulfillment
of the requirements for the degree

of

Master of Science

in

Science Education

MONTANA STATE UNIVERSITY
Bozeman, Montana

July 2022

DEDICATION

This is dedicated to my daughter, who supported me with endless coffee refills.

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ABSTRACT

Students actively engaged in their lessons will learn better. The current model of many science courses uses standard labs covering concepts that have been taught in the classroom. Students are doing experiments that have already been done before and already have an answer. They know it is not real. It is simply an assignment. This project implemented citizen science into the classroom. Students were given real projects and evaluated on their learning outcomes. The citizen science units were compared to standard teaching units. The data suggests a positive relationship between using citizen science as a teaching technique and student learning outcomes.

CHAPTER ONE

BACKGROUND AND INTRODUCTION

<u>Context of the Study</u>

The purpose of this study was to determine if student engagement and learning outcomes are improved by the implementation of citizen science and real world projects in the classroom when compared to standard laboratory assignments. The standard laboratory assignment is very removed from the work scientists do. Students are given the materials, the procedure, and are trying to recreate a known outcome. Scientists are not conducting experiments that have known outcomes. Students inherently know they are not doing anything more than an assignment. By introducing citizen science projects, the goal was to create a more meaningful and therefore more engaging lessons.

I want to enable my students to learn about science and the world around them. It is my experience, in the many years that I have taught science, that motivated students learn better, self-facilitate their learning, and gain a deeper understanding of the scientific process. There are several ways that I have used to motivate my students, but I have found two that seem compelling: fieldwork and citizen science. In my constant search for best practices, I have established what I believe is a compelling argument to utilize both fieldwork and citizen science projects as motivational experiences for my science students. Citizen science enlists the public in collecting large quantities of data across an array of habitats and locations over long spans of time. Citizens are helping scientists with the gathering of the information. Many citizen science projects help participants learn about what they are observing and to experience the process by

which scientific investigations are conducted (Bonney, 2009). In terms of pedagogy, these practices include constructivism, both open and directed inquiry, authentic tasks, and project based learning (Moutinho, 2015). Even though I had experienced what I believe to be a significant impact using these practices, I performed a study to try and better quantify this perception. The study was conducted at the Jewish Educational Center High School in Elizabeth, New Jersey. This is a private, all boys, college preparatory school. The treatments were done in an honors freshman biology class.

One of the main goals of my teaching is to create meaningful, authentic, and useful knowledge in my students in conjunction with them gaining valuable thinking and processing skills. A straightforward constructivist approach is most often used. (Ahmad, 2012; Zion, 2010). A question that constantly arises in my work is how to create classroom environments and curricula that are authentic to the students, to the real world, and to the professionals they will become?

For many science teachers, best practices often involve the integration of research proven methods such as inquiry labs, authentic and/or formative assessments, project-based learning, and other constructivist activities (Olga, 2013; Stoica, 2010). The goal is to teach students about the nature of science and engaging them in inquiry. My goal was to gauge the impact of purposeful fieldwork and see if linking fieldwork with citizen science has a greater impact on their motivation towards scientific inquiry. The involvement of citizen science, without a fieldwork component, will be used to better understand the impact of citizen science on its own merits (Nicosia, 2014).

Focus Statement

The purpose of this study is to determine if student engagement and learning outcomes are improved by the implementation of citizen science projects in the classroom instead of standard laboratory assignments.

CHAPTER TWO

CONCEPTUAL FRAMEWORK

Constructivist Theory of Learning

Constructivist teaching is meant to motivate the student as well as improve their learning of the content and skills in science. Improving the achievement, participation, and the student's outlook on science are the main goals behind utilizing a constructivist approach. Success has been observed in several studies supporting the benefits of student-centered learning and their satisfaction with the study of science (Travis, 2004). Constructivist theory of learning is based on the principle that learning is an active process in which the learner uses information gathered and constructs their own meaning out of it. (Srivastava, 2021). The understanding that knowledge cannot be passed on from one person to another, but it must be constructed by the learner. Students cannot simply sit and listen to a presentation and be effectively learning the material. They must be active in the process of learning (Narayan, 2013).

Project Based Learning

There are several pedagogical methods for implementing a constructivist approach in the teaching of science. The utilization of problem/project-based learning is demonstrated to have lasting impact on the students overall scientific learning experience. This is often referred to as open inquiry or directed inquiry, even deeper learning, but any definition necessitates a constructivist approach such that the student comes to their own realization of the various merits of their learning. The inquiry-based approach improves student understanding of the social and

cultural aspects of their science learning as well as reinforcing the students' emphasis on creativity and imagination in solving scientific problems (Moutinho, 2015).

Along with most research that shows a support for inquiry, it is shown that dynamic inquiry, whether guided (directed) or open, has lasting impact on a student's motivation towards learning science. It is a goal of the student to perform well and to achieve a high understanding of their work. By enabling the student to use learning as a process rather than as a goal, they are focused on the end understanding as opposed to constantly asking themselves whether their concept of skill development is happening fast enough. The student driven inquiry puts the onus on the student to gauge their success, yet at the same time drives the student to achieve a project goal (Sadeh, 2009).

Another aspect of dynamic inquiry that motivates students involves collaboration. The ease of facilitation with regards to allowing the students to function as teams is shown to enhance the student participation and motivation during their inquiry. This does not remove the student-centeredness of constructivist learning, but rather brings out leadership ability and group dynamics as fundamental to a student success (Zion, 2010).

<u>Citizen Science</u>

One way to motivate science students is to involve them in research activities. This helps them to elucidate scientific concepts and come to a higher level of understanding of their topic. It is important for students to realize what science can and cannot be used for, along with how scientists know what they are doing. This can best be done by exposing the students to research. This is especially the case when we are trying to teach the skills of science. As students become

independent inquirers, they attain a higher performance level and are more motivated in their inquiry (Stoica, 2010).

By having the student reach outside their classroom to partake in research, they are exposed to the holistic nature of scientific inquiry. Enabling student work outside of their usual classroom setting to inquire about multi-level and multi-component systems facilitates the students setting project-based learning goals for their understanding. This approach motivates students through real-world experience and yet challenges their creativity and encourages the participation of the students in many ways. As the student comes to realize that they can address big, real-world problems by project-based activities, the student is motivated to find solutions as well as gain understanding (Olga, 2013).

The project-based learning approach will challenge the students, get them thinking from a metacognitive perspective, and enhance their motivation. By formulating these projects along the lines of active learning, meaningful inquiry, and research, the students are highly motivated to succeed at their learning, even knowing that a final understanding might not be attainable. By involving collaborative research, citizen science activities, the student's creativity and imagination is crucial in addressing their learning. Whether it involves competitive challenges, or devising solutions to research areas, the dynamism of the inquiry is utilized towards the benefit of the learning of the science student (Zion, 2012).

A rewarding motivator for students is becoming literate in science. Successful process learning is done by guiding the student towards making good observations, gathering and analyzing their data accurately, and critiquing their evidence. Project-based dynamic inquiry learning emphasizes that the student approaches their work in a methodical, creative, and open-minded way (Savage, 2014).

The best research needs to be collaborative. The teacher needs to enable this collaboration, not only between students, but also with outside educators and researchers. This is a key factor in allowing the creative and motivated student to see where their work and learning can have the most impact. It also opens the student to learning about the fact that science is not done in a vacuum, but rather is part of a larger community-based approach (Colston, 2015).

<u>Next Generation Science Standards</u>

The Next Generation Science Standards are a set of performance expectations that are a collaborative state-led process. The standards are rich in content and practice and aligned across disciplines and grades. (States, 2013). They are not a body of content knowledge or a curriculum. The focus of the standards is to have students design solutions to problems. These problems, like real-world problems, are multifaceted and involve multiple concepts (Wendell, 2014).

The Next Generation Science Standards are a way to integrate the sciences with crosscutting concepts. There are ideas and concepts that apply to all divisions of science which are not specifically tied to a subject, like biology. They are universal in nature and deal with the ideas of cause and effect, structure and function, scientific reasoning and so forth (Wysession, 2013).

Citizen science projects are a way to implement the Next Generation Science Standards. These projects require students to actively participate in their learning. A traditional science test is concerned with memorization. Having the student take an approach to their learning that involves cross cutting concepts will significantly enhance their motivation to learn the connections to the real world. A modern science classroom will provide scientific concepts within a framework that is concrete, understandable, and relevant to society (Wysession, 2015).

There is a perception that a student's actual science learning environment is not their preferred learning environment, which is based on a constructivist approach. Attention needs to be paid to educational facilities, the physical learning environment, and technical specifications to properly ensure a constructivist learning environment (Ahmad, 2012).

Instead of standard science abilities, Next Generation Science Standards place an emphasis on science and engineering practices. Students are now expected to know scientists ask questions about nature, use models, and require evidence as a basis for explanations. There is a focus on how a scientist does their work (Bybee, 2014).

CHAPTER THREE

METHODOLOGY

Demographics

The students in this study were from The Jewish Educational Center High School. This is

a private, all boy's college preparatory school for Modern Orthodox Jewish students. The

students come from either urban or suburban communities around Elizabeth, New Jersey. The

high school is small with a population of about 200 students. After graduation 100% of the

students attend a four year college. The average graduate's SAT score is 1370 out of 1600

(Neuman, 2021).

Upon acceptance into the school, students are tested in mathematics and then placed into

their science course, either physical science or honors biology. They do not choose to take

honors biology or physical science. No consideration is given for student preference or interest in

science. The small school has three levels of science all taught at the same time by different

instructors. It was not feasible to run the project with more than one classroom of students.

Students in honors biology were given three different citizen science projects instead of standard

laboratory practices used in prior years. While honors students are typically a more motivated

group of students, these are freshman who are beginning their high school careers and they may

not have developed an interest in science or an understanding of the nature of science. By giving

them an opportunity to participate in a real science project, the goal is to improve their

engagement in the study of science topics and increase their awareness of the nature of science.

<u>Treatments</u>

This study was conducted in a single freshman honors biology class. The first part of the study was simple data collection on three units of study, mitosis, meiosis, and Mendelian genetics. A pre, post, and delayed post-test was given for all three units. These tests served as a base line comparison for the treatment units. Then as treatment, the students were given three different experiences involving citizen science projects while following all appropriate guidelines. The research methodology for this project received an exemption from Montana State University's Institutional Review Board and compliance for work with human subjects was maintained (Appendix A).

The first treatment was a unit on ecology. Students were given an opportunity to participate in data collection in the Cedar Creek Ecosystem. Motion activated cameras are installed throughout the park. These cameras take more images than scientists can identify. The citizen science project involved classifying the images to help scientists use the data gathered. The students were trained on how to classify the organisms and then were given class time to conduct research. Students gathered their own information from the images they classified and used this data to construct food webs (Figure 1).
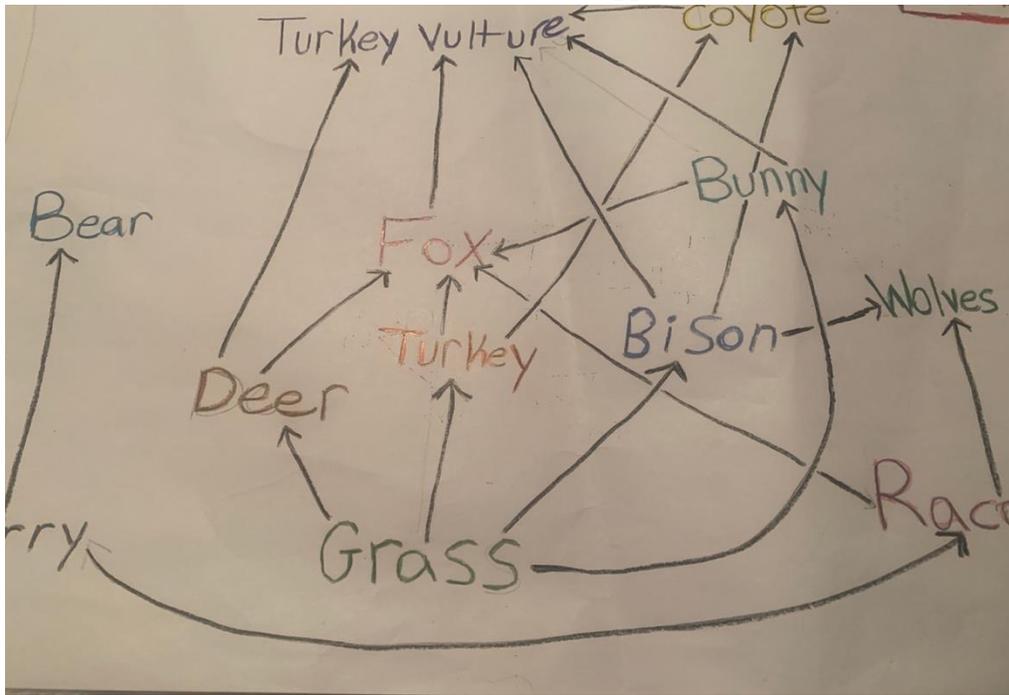
Figure 1. Student drawn food web of the Cedar Creek Ecosystem.

The second treatment was a unit on evolution. The students utilized another computer based citizen science project. They examined the leaf structures in both modern and fossil ginkgo leaves. The students examined images and classified both normal cells and stomata. These counts are used to calculate the stomatal index. This optimum number of stomata is dependent on environmental factors, primarily carbon dioxide concentrations. Students used the content they had learned in class about natural selection and applied it to the citizen science project which examined how a species demonstrated stabilizing selection over time (Figure 2).
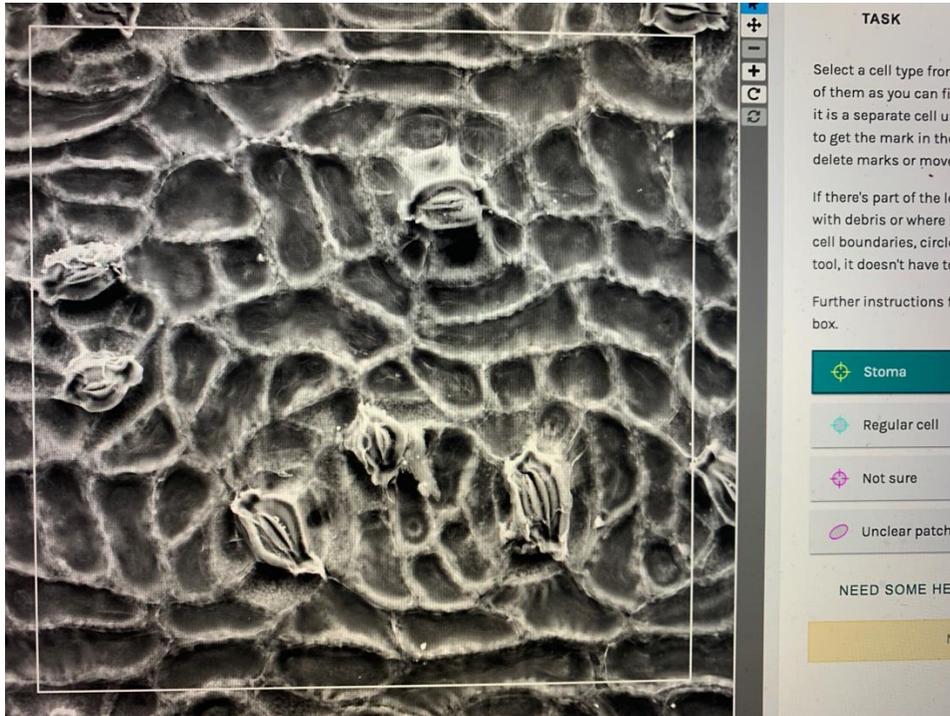
Figure 2. Image of Zooniverse stomata count.

The third treatment incorporated another real-world application of scientific information. Students were given Wisconsin Fast Plants to explore ideal growing conditions. Students then used this information to design bucket gardens. These gardens are self-contained and designed for an urban patio. The goal of the bucket garden was to provide a cheap and easy source of fresh vegetables to the school community (Figure 3).

Figure 3. Image of student herb garden.

Data Collection Strategies and Analysis

The first three units, mitosis, meiosis, and genetics were taught with traditional classroom techniques. The second series of three units were treatment units. For each unit a set of analytical tests were created. post-test and the post-test. First a series of homoscedastic t-tests were created: single-tailed Pre-Test v. Post- Test, a single-tailed Pre-Test v. Delayed Post, and a two-tailed Post-test v. Delayed Post. Followed by a normalized gains test to calculate the gain for the student's tests throughout the respective unit.

Before each unit was taught, students were given a test covering the basic concepts of the unit. The Ecological Pre/Post and Delayed Test covered basic concepts of biotic and abiotic factors, food chains and food webs. The Ecological Pre/Post and Delayed Test was given at the end of the unit as a post test and also administered one month later to determine if the learning goals were maintained (Appendix B). Normalized gains were calculated between the Ecological

Pre Test and the Ecological Post Test. A t-test was calculated to determine if the results were statistically significant for the ecology unit. Normalized gains were also calculated between the Ecological Pre Test and the Ecological Delayed Post-Test. A t-test was again calculated to determine if the results were statistically significant.

The students were also given the Ecological Concepts Survey both before and after each treatment (Appendix C). Which took the less specific strongly agree, agree, disagree, strongly disagree and compared it to a set standard for each criterion. Means, medians, and modes were compared to see if there was any change in the student's self-assessment of their understanding. A t-test was calculated to see if the results were statistically significant. This survey covered the three major concepts covered in the unit, identifying the parts of an ecosystem, energy flow, and abiotic/biotic factors. Finally, at the end of the unit a randomly selected group of students was given the Citizen Science Survey and interviewed about their experience with the project (Appendix D). Qualitative data was collected by the Citizen Science Survey and student interview responses on the citizen science treatments to determine the student's perspective on the effectiveness of the real-world treatment. This data was compared to the normalized gains on the pre/post-test and the pre/delayed post-test. This data was examined for trends in student perspectives. A triangulation matrix was conducted to draw out the themes from the data sources.

The second treatment on evolution was conducted with the same pattern as the ecology. The Evolution Pre/Post and Delayed Test covered concepts of natural selection, populations, and mutations. The Evolution Pre/Post and Delayed Test was given at the end of the unit as a post test and also administered one month later to determine if the learning goals were maintained (Appendix B). Normalized gains were calculated between the Evolution Pre Test and the Evolution Post Test. A t-test was calculated to determine if the results were statistically

significant for the ecology unit. Normalized gains were also calculated between the Evolution

Pre Test and the Evolution Delayed Post-Test. A t-test was again calculated to determine if the

results were statistically significant.

The students were also given the Evolutionary Concepts Survey both before and after

each treatment (Appendix C). This took the less specific strongly agree, agree, disagree, strongly

disagree and compared it to a set standard for each criterion. Means, medians, and modes were

compared to see if there was any change in the student's self-assessment of their understanding.

A t-test was calculated to see if the results were statistically significant. This survey covered the

three major concepts covered in the unit, natural selection, speciation, and the theory of

evolution. Finally, at the end of the evolution unit a randomly selected group of students was

given the Citizen Science Survey and interviewed about their experience with the project

(Appendix D). Qualitative data was collected by the Citizen Science Survey and their interview

responses on the citizen science treatments to determine the student's perspective on the

effectiveness of the real-world treatment. This data was compared to the normalized gains on the

pre/post-test and the pre/delayed post-test. This data was examined for trends in student

perspectives. A triangulation matrix was conducted to draw out the themes from the data sources.

The third treatment also followed the same pattern as the previous two. The Botany

Pre/Post and Delayed Test covered which covered plant structure and function was given at the

beginning of the unit. The Botany Pre/Post and Delayed Test was given at the end of the unit as

a post test and also administered one month later to determine if the learning goals were

maintained (Appendix B). Normalized gains were calculated between the Botany Pre Test and

the Botany Post Test. A t-test was calculated to determine if the results were statistically

significant for the ecology unit. Normalized gains were also calculated between the Botany Pre

Test and the Botany Delayed Post-Test. A t-test was again calculated to determine if the results were statistically significant.

The students were also given the Botany Concepts Survey both before and after each treatment (Appendix C). This took the less specific strongly agree, agree, disagree, strongly disagree and compared it to a set standard for each criterion. Means, medians, and modes were compared to see if there was any change in the student's self-assessment of their understanding. A t-test was calculated to see if the results were statistically significant. This survey covered the three major concepts covered in the unit, identifying the parts of a plant, seed germination, and cross pollination. Finally, at the end of the unit a randomly selected group of students was given the Citizen Science Survey and interviewed about their experience with the project (Appendix D). Qualitative data was collected by the Citizen Science Survey and their interview responses on the citizen science treatments to determine the student's perspective on the effectiveness of the real-world treatment. This data was compared to the normalized gains on the pre/post-test and the pre/delayed post-test. This data was examined for trends in student perspectives. A triangulation matrix was conducted to draw out the themes from the data sources (Table 1).

Table 1. Data Triangulation Matrix.

Focus Questions	Data Source 1	Data Source 2	Data Source 3
Primary Question: Will student learning outcomes be increased with citizen science and fieldwork projects?	Pre-Test Scores of Treatment and Non-Treatment units	Post- Test and Delayed Post-Test Scores of Treatment and Non-Treatment Units	Ecology (Unit 4) , Evolution (Unit 5), Botany (Unit 6) Surveys.
Secondary Question: Will the use of citizen science projects impact student engagement?	Interviews on Citizen Science Units and Citizen Science Surveys	Ecology (Unit 4), Evolution (Unit 5), Botany (Unit 6) Surveys	Data Analysis of Pre and Post, Delayed Post Tests of both Treatment and Non-Treatment Units, (Units 1-6)
Secondary Question: Will student attitudes and motivation involving citizen science projects be impacted?	Interviews of Citizen Science Units and Citizen Science Surveys	Ecology (Unit 4), Evolution (Unit 5), Botany (Unit 6) Surveys	Data Analysis of Pre and Post, Delayed Post Tests of both Treatment and Non-Treatment Units, (Units 1-6)

CHAPTER FOUR

DATA ANALYSIS

Results

For the first unit, mitosis, the majority of the students on the Mitosis Pre Test were

clustered around the mean of 53% as the 25/75th percentiles were at 40% and 62.5% respectively.

The student scores on the Mitosis Post and Mitosis Delayed Post-Test were higher with means of

72.5% and 69% respectively. Testing for a .05 alpha value, there was a statistical significance in

respect to pre-test in comparison to either of the post tests, thus allowing the rejection of the null

hypothesis and accepting the alternative hypothesis that the two student samples were

statistically significant include the p value and the variance was not due to merely chance

variation. However, there was not enough statistical evidence dictating the potential difference

between a delayed post-test and the post-test. Thus, the null hypothesis is not rejected and there

was no statistical difference between the post-tests. Using the standard interquartile range (IQR)

to determine outlying data, the students who earned a perfect score were the only individuals that

seemed like true outliers. .In addition to the t-test, the other more advanced metric used for data

analysis was normalized gains. The normalized gains for the post-test were .408. The normalized

gains for the delayed post-test were .333, gains greater than 0.7 are considered high (Hake,

1998). This illustrated a 40% and a 33% gain in comparison to the pre-test.

The second standard educational unit was based on meiosis. The mean pre-test grade was

a 26% with a median value of 25%. The lack of difference between the mean and median values

illustrates a lack of skew in the dataset and the class collectively scored this value. Using the

interquartile range (IQR) again there were no outliers in the pre-test, highly likely due to the fact

the highest grade was 50%. The post-test had a class average of 52%, and the highest grade was a 75%. The delayed post-test had similar numbers to the standard-post-test with an average of 47% and a highest grade of also 75%. Testing for a .05 alpha value, there was statistical significance sin respect to the pre-test in comparison to either of the post-tests, thus allowing the rejection of the null hypothesis and accepting the alternative hypothesis that the populations were in fact different and unlikely to have the variance be due to chance. A very small p-value was created for both of the pre-test comparisons. A p-value less than .005 was obtained for both of the tests in comparison to the pre-test. However, there was not enough statistical evidence dictating the potential difference between a delayed an the standard post-test. Thus the null hypothesis, that there is no difference between the two sample means, cannot be rejected. A normalized gains test was also completed for the post-test and delayed post-test, gains greater than 0.7 are considered high (Hake, 1998). A g-value of .34 and .28 were collected respectively .

The third unit without treatment was on Mendelian genetics. Like the previous two units, the same techniques were implemented. The pre-test had a mean grade of 19% and a high grade of 50%. A median grade of 20% demonstrates that the data had no evidence of potential skewness. Again using Interquartile Range, there was only one outlier, a 100 on the delayed post- test. The average increased moderately following the pre-test with the values of 42.5 and 43.5 with the same median in the sets of 40. The hypothesis testing created marginally small p-values, and therefore we conclude with statistical significance and reject the null hypothesis. However, this was not the case with between the post-test and the delayed post-test (Figure 4). In addition to the t-tests, another metric was used. Normalized gains resulted in g values of .29 and .30 and gains greater than 0.7 are considered high (Hake, 1998).
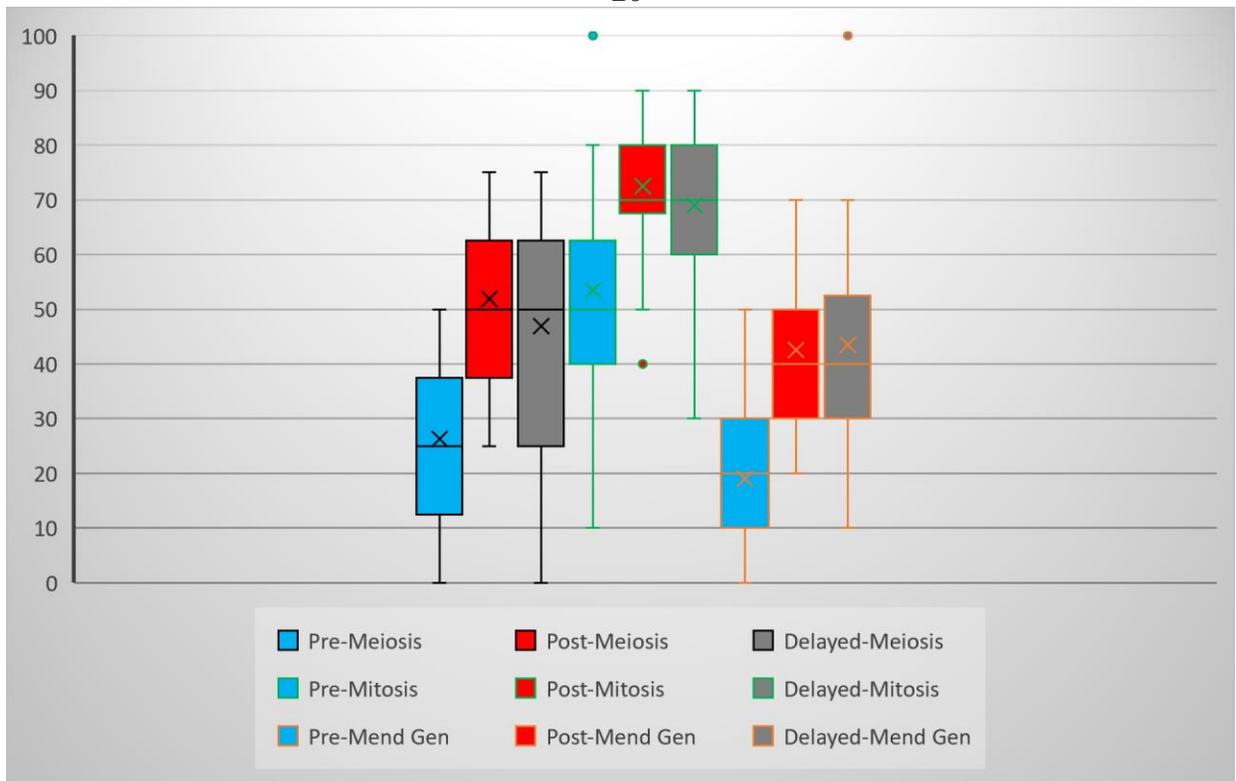
Figure 4. Summary of Non-Treatment Pre, Post, and Delayed Post Tests, (*N*=20).

The fourth unit was the first one that involved a treatment utilizing citizen science. Beginning with the means of the pre, post, and delayed post-test were: 43, 77, and 76 respectively. In addition the medians were 43, 79, and 79. Following these values, t-tests were calculated. As with the previous non-treatment units, the same tests were conducted, homoscedastic t-tests: a single tailed pre-test versus a post-test, a single tailed pre-test versus a delayed post-test, and a two-tailed post-test versus a delayed post-test. Testing for a .05 alpha value, there was statistical significance in respect to pre-test in comparison to either of the post tests, thus allowing the rejection of the null hypothesis and accepting the alternative hypothesis that the students did learn some material and that the methods of the teacher had some statistical significance. However, likewise with the prior units, the two-tailed t-test failed to represent any

sort of change between the two post-tests. Following the t-tests a series of normalized gains were created to generate the g-values of .59 and .58. A gain of .7 is considered large (Hake, 1998). The students showed a 59% and 58% gain in the remaining field of test points available (Figure 5).
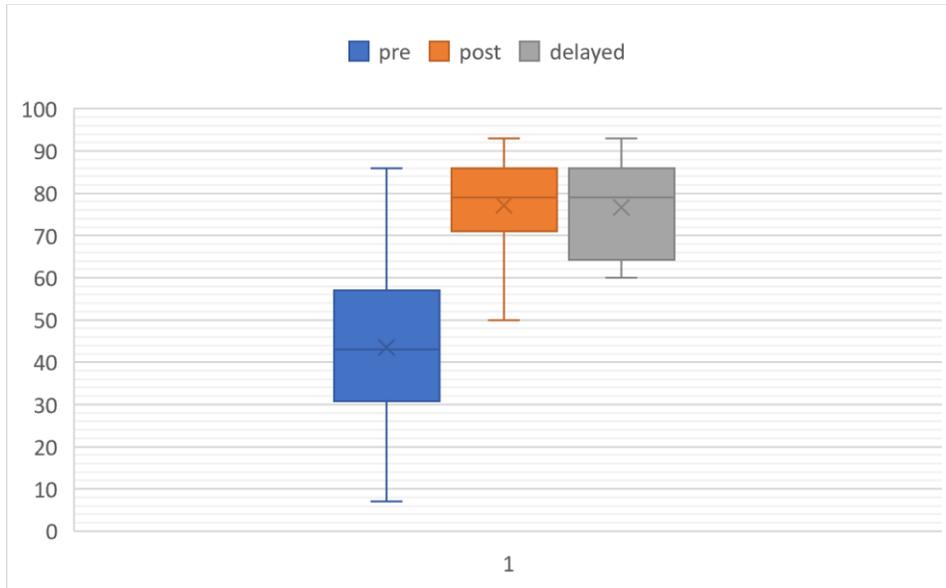
Figure 5. Summary of Ecology Unit Pre, Post, and Delayed Post-Tests, (*N*=20).

The second treatment unit and the fifth unit of the project was on the theory of evolution. The pre-test mean was 49% in comparison to the post-test of 63.5%, and a delayed post-test of 60%. Using the same methods as on previous units, no outliers were found in the data. Creating the same series of t-tests resulted in the rejection of the null hypothesis. Testing for a .05 alpha value, there was statistical significance in respect to pre-test in comparison to either of the post tests, thus allowing the rejection of the null hypothesis. Granted due to the nature of the posts-tests means being closer to the pre-tests means the p-value was the largest yet to report. That of .009 and .02 in relation to post-test and delayed post-test respectively. However, the t-test of the two post-tests found nothing of consequence in terms of p-values and thus it is unable to be conclusive on rejecting the null hypothesis. In addition to the t-tests, normalized gains were also

concluded. A value greater than .7 is significant (Hake, 1998). The results for those being, g

values of .28 and .21, meaning that the student gained an additional 28% and 21 % of remaining

knowledge following the original pre-test (Figure 6).
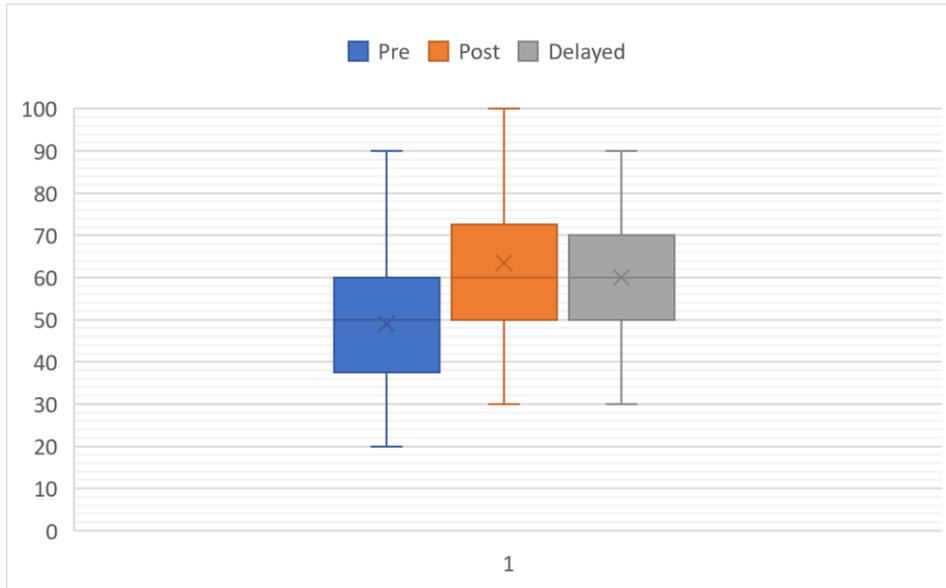
Figure 6. Summary of Evolution Pre, Post, and Delayed-Post Tests, (N=20).

The final treatment unit and the final unit of the study was on botany. The Botany Pre-

Test displayed a mean score of 28% and a highest value of 53%. This is indicated a lack of

generalized knowledge of botany as a subject. Using the same methods as the previous five units,

there was only one outlier in this entire subsection of data, and that is the maximum value for the

pre-test of 53%. The median value was relatively in line with the mean value, 27% in

comparison to the means 28%. Thus demonstrating the lack of any skewness in the data despite

there being an outlier. The post-test saw a dramatic increase. The mean grade was 83% for an

average gain of 55 percentage points. The lowest grade in the post-test, 65%, was higher than the

highest value of the pre-test (Figure7). Following the same tests as previously discussed, there

was statistical significance in respect to pre-test in comparison to either of the post-tests, thus

allowing the rejection of the null hypothesis and accepting the alternative hypothesis that the

students grades fluctuated by more than just chance variation. The p-values were substantially smaller than any previous outcome prior to this portion. Again, likewise the other five sections the post-test and the delayed post-test showed no statistical significance. Thus representing once again that the students grades did not change substantially between the post and delayed post-tests. Following the t-tests were two normalized gains calculations. In them, the g-value has a resounding .76 and .72 for the post and the delayed post-tests. A value of .7 or greater is large (Hake, 1998). Thus meaning the students gained 76% and 72% of the knowledge left needed to gain perfect scores. A more drastic increase than in any other unit in the project.
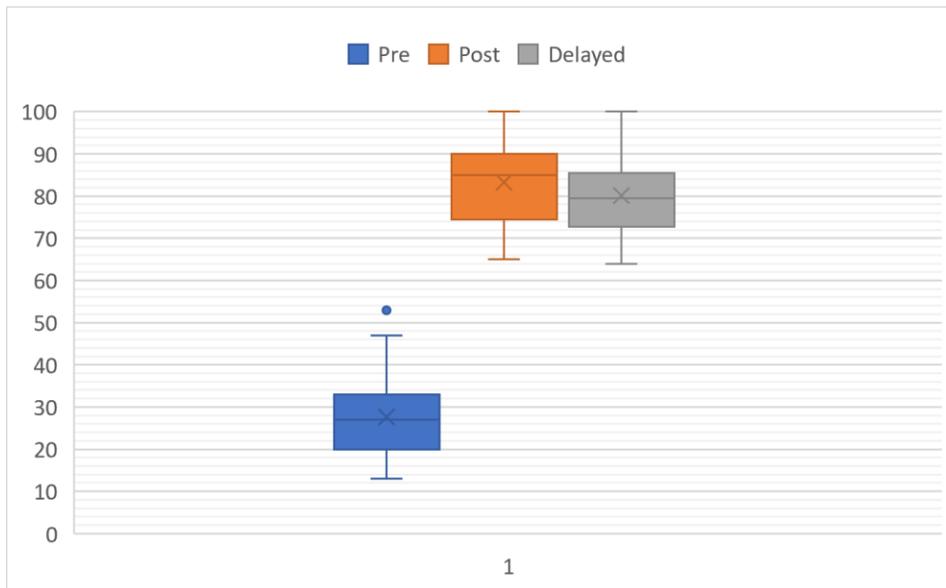
Figure 7. Summary of Botany Unit Pre, Post, and Delayed Post-Tests, (*N*=20).

Following the completion of the unit, an additional two-tailed t-test was created. That compares the post-test results of the different non-treatment units, specifically the meiosis unit, in comparison to the treatment units, specifically, botany. Testing for a .05 alpha value, there was statistical significance in respect to pre-test in comparison to either of the post tests, thus allowing the rejection of the null hypothesis and accepting the alternative hypothesis. The p-value between the Mitosis Post- Test and the Botany Post- Test was .01. This supports the belief

that the methods of the treatment units were indeed effective. In addition to this, a graph with all

of the post and delayed post-test data was created (Figure 8).
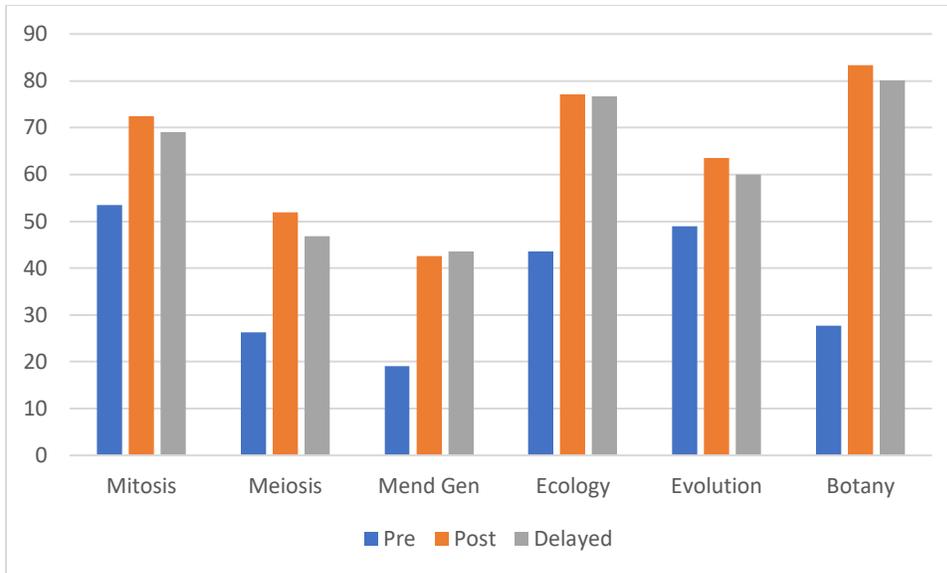
Figure 8. Summary of All Units Pre, Post and Delayed Post-Test Scores, (*N*=20).

Trends that emerge from this data are supported from the surveys administered. The overarching

theme of citizen science treatment units being more effective versus standard instruction is

supported by the data. One type of survey given was used to explore how the students felt about

a content topic. The first three questions on each Likert style survey were general questions

about the content of the unit. For example in the evolution unit students were asked if they could

explain the process of natural selection. Then they were asked specifics about the content on the

following three Likert style questions. Instead of simply asking about natural selection, students

were asked if they could easily provide an in-depth description of fitness and explain how it

relates to reproduction. The Likert survey was designed to assess students comfort with the topic.

For the botany unit, when students were asked if they had confidence in their ability to identify

plant parts, their response was 2.95 out of 4.0. Again first three questions were designed this

way. The students were asked general questions about botany. The second set of questions was

more specific. Question four related to question one with specific knowledge. Instead of generally asking if students were comfortable identifying parts of a plant. Students were given specific parts. Students were asked if they were confident in their ability to identify plant structures and the differences between monocots and dicots. This pattern is continued with question 2 correlating to question 5. The surveys were measuring the depth of student confidence (Appendix C). This survey data was then correlated for all three units. The quantitative data indicates that students retained content better and the qualitative data supports this with positive survey feedback (Figure 9). The figure illustrates student responses to their understandings before and after the treatment. The data indicates students felt more confident in their knowledge after the treatments were conducted. The average pre-test score in the botany unit was 27%. The students did not have a basic understanding of plant structure. When given the survey, they confidently stated they knew how to identify the parts of a plant in question 1, but in question 4 when asked for specifics about plant structure, they were no longer confident. After the treatment the class average was 83%. This is also conveyed in their confidence surveys. When asked the general confidence about the topic questions 1-3 and compared to the more specific questions 4-6, the interval difference between the two bars is significantly more consistent. Students are confident in their knowledge even when asked for specifics (Figure 9).
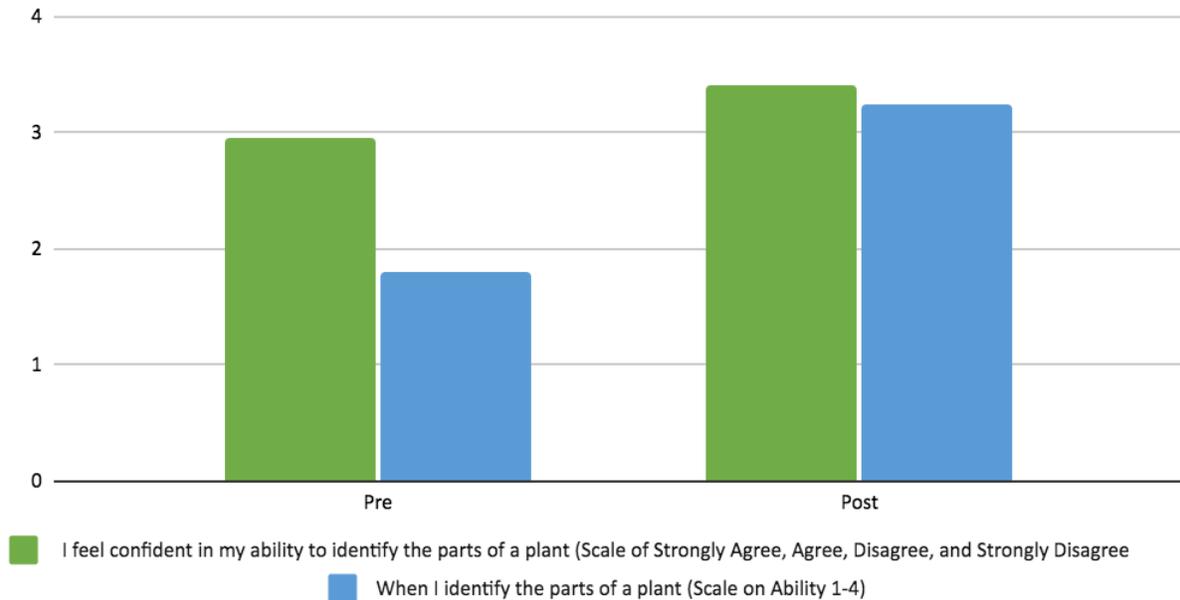
Figure 9. Student Confidence: Botany Survey, (*N*=20).

These surveys were also compared to student interviews and surveys on citizen science projects. The Citizen Science Survey was administered twice. The first survey was administered after the first Citizen Science unit on Ecology. When asked if the citizen science project was more meaningful the class average was 2.6 on a Likert scale of 4.0. The initial project produced a lower result than the second Citizen Science Survey. The second survey was conducted at the conclusion of the treatment units. When asked if the science project being real and therefore more meaningful the class average was 3.1 on a Likert scale of 4.0. The data indicates a favorable response to the treatments as indicated.
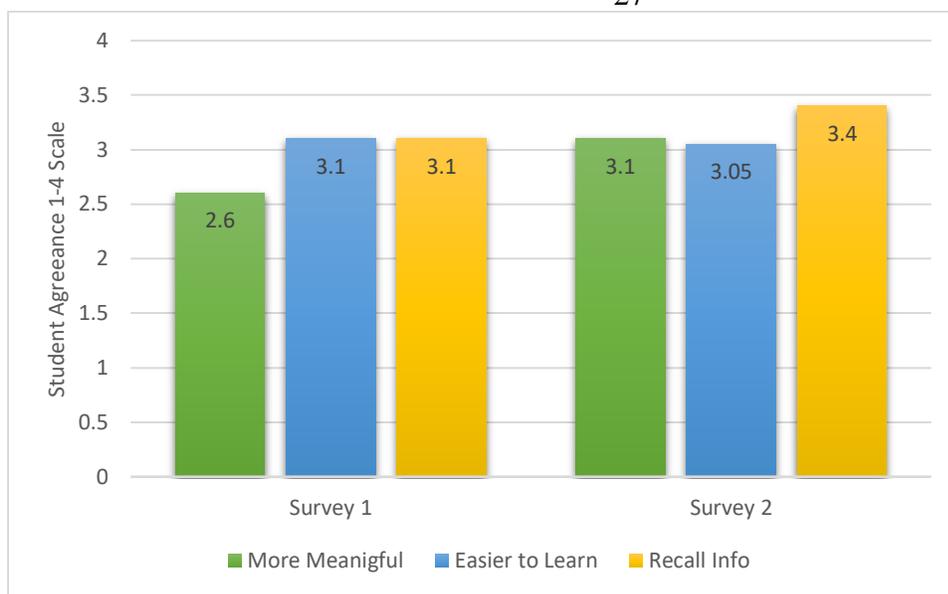
Figure 11. Citizen Science Survey. Scale of 1-4. Strongly Disagree (1) , Disagree (2), Agree (3), Strongly Agree (4), (*N*=20).

Student survey responses were positive after the first citizen science treatment and were even stronger after all of the citizen science treatments were completed.

The student interview questions were also evaluated. When asked about participating in the treatment units students responded with a yes, 87.5 % for the ecology unit, 62.5% for the evolution unit, and 100% for the botany unit. Overall students enjoyed the treatment units and considered them more meaningful. When asked if the citizen science units were more meaningful 91.7% of the students interviewed said yes. As one student said, " this was real and I thought what I was doing was important." Finally students would like to participate in more citizen science projects, 83.3% of the students would recommend doing citizen science projects again. A student said, " I enjoyed learning this way because I paid more attention."

CHAPTER FIVE

CLAIM, EVIDENCE, AND REASONING

Claims From the Study

The primary question of the study was to determine if the inclusion of citizen science and

fieldwork projects had an impact on student learning outcomes. The study makes a solid case for

including citizen science projects for students within an educational setting. The learning

outcomes as evidenced by the pre-,post-, and delayed post-tests were substantially higher for the

citizen science units. The normalized gains for the treatment units were significantly higher. The

treatment unit on botany was the highest. Students learned more with the treatment units than

with the non-treatment units. Students also realized they knew more as evidenced by their

confidence surveys. When asked specific questions about the content students were more

confident in their knowledge.

The secondary question of this study dealt with student engagement. The study was

designed to discover student if students were more engaged in the material. The Likert surveys

given on citizen science projects indicated that students were more engaged and interested in the

material. The Citizen Science Survey was administered twice. The second survey was even more

positive than the first one. Students enjoyed the lessons and continued to enjoy it during

subsequent units. The class collectively agreed that the citizen science projects were more

meaningful. The class was also surveyed to assess their opinions on if learning material using

citizen science projects was easier. Students felt the material was easier to learn if presented as

part of a real world project. The final question they were asked assessed whether or not the

information was going to be easier to recall and harder to forget.. Students felt the material was easier to learn and recall if it was presented as a citizen science or fieldwork project.

This survey data is also relevant in assessing student attitudes and motivation. It is valid to claim the students were more motivated and engaged in citizen science projects. The students felt the citizen science units were more meaningful, easier to learn, and more likely to be recalled. The students also were interviewed about their experience with citizen science projects. A common theme emerged from the Citizen Science Interviews. Students felt the need to be more careful with data collection. The project was real. They needed to be more careful. One student said, "I needed to be careful because someone was counting on me." Another stated, "it was important for me to be accurate." Students were more careful with their data collection and paying closer attention to their work.

Value of the Study and Consideration for Future Research

The value of putting citizen science projects into the classroom setting is clear. Students were more engaged, motivated, and felt as though the learning mattered. Students were more focused on research days and were taking careful measurements. Their learning outcomes improved with higher test scores and larger normalized gains. The value of the study was muddied by the topics chosen to be covered. The second treatment unit on evolution was a difficult unit to teach within a religious setting. Several students were uninterested in considering any other ideas besides creationism. This skewed the results for the class because several students were not participating. Several students voiced the material as not being relevant because it was not in the Bible. Twenty five percent of the students randomly selected to be interviewed said it wasn't real. One student said, "fossils aren't in the Bible." This impacted the

class as a whole. Several students were open to the ideas, but unwilling to be vocal and offend the other students. This particular topic was a difficult one to explore. The botany treatment unit was the citizen science project that was not computer based. This unit evidenced the most gains. While the online citizen science projects did have a meaningful and significant advantage over the standard unit. The unit where students were actually physically creating something had a marked advantage. The botany unit had the largest gains. The class pre-test average was 27% versus a post-test average of 83.

Future studies worth considering would be to examine the gains in science skills that students potentially received. Students reported in the Citizen Science Interviews they were more careful with their data. They also reported a consistent negative about the data collection being repetitive in nature. It was the most common statement from students who did not like the citizen science project. The nature of science is different from what students often think. Students often want to run three trials and average the information. Repeating a citizen science study after a unit on data collection and some instruction on the nature of science may yield more significant gains.

Impact of Action Research on the Author

The impact of this project on my teaching has been profound. One of the most interesting things was not the effectiveness of citizen science treatments, it was the glaring low values of the standard teaching practice. Students were learning and retaining the information, but at a much lower rate than anticipated. This data has encouraged me to do more active learning pieces and less frontal instruction. The students learning, doing, and figuring things out themselves is where the major learning and understandings occurred. This is supported by the pre, post, and delayed

post-tests. Overwhelmingly the scores were better with the citizen science units versus standard instructional lessons. The weakest treatment unit on evolution still saw a higher post-test average 62.5 % than any of the standard units. The use of citizen science projects was helpful to drive engagement and learning. Online programs have value for those topics that are beyond the scope of a typical high school setting. Whenever possible I feel it is imperative to utilize physical concrete citizen science projects. This saw the greatest learning and had the most impact on my students.

Students were engaged in the online citizen science projects more so than standard laboratory experiments. They felt it was more real and were more careful with their data collection. They knew what they were learning before the citizen science treatment would be immediately used and counted on by others. This led to higher scores and better learning outcomes. Interspersing citizen science projects throughout the year that built upon previous units is a way I plan to improve the standard teaching practices. I don't think it is feasible to always do citizen science projects. I also don't feel that it will continue to have the same level of novelty or motivation. However, putting in a citizen science project that utilizes several teaching units is a way that I can capture their interest and improve their learning outcomes. Another major consideration I am taking from this project is the knowledge I gained from using a citizen science project that was not online based. Students were even more engaged and motivated. Having larger hands-on projects that matter demonstrated the greatest learning outcomes and motivation.

As a reflective educator, now I am more aware of the short comings of standard teaching practices. I am more convinced that mastery learning is only achieved when students are truly engaged and want to learn the material. Real world learning is more meaningful to students and

it empowers them to take charge of their learning. I want to embed this instructional technique

into my classes and improve student outcomes. It is a tool that is useful but not all encompassing.

I feel as though it can be used to drive interest and engagement, but it will only be effective if

given at intervals throughout the year. This project has inspired me to continue to seek out best

practices and to incorporate data techniques to determine the lessons effectiveness.

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APPENDICES

APPENDIX A

EXEMPTION BY MONTANA STATE UNIVERSITY INSTITUTIONAL REVIEW BOARD

MONTANA STATE UNIVERSITY
Request for Designation of Research as Exempt
<u>**MSSE Research Projects Only**</u>
(6/16/14)

****
THIS AREA IS FOR INSTITUTIONAL REVIEW BOARD USE ONLY. DO NOT WRITE IN THIS AREA.
  Confirmation Date: 11/30/21   *Mark J. Quinn*
  Application Number:
****

DATE of SUBMISSION: 11/22/2021

-Okay as exempt
-MSSE Classroom assessment
-Little/no risk
-Principal approved
-No concerns
   MQ 11/30/21

Address each section – do not leave any section blank.

I. INVESTIGATOR:

    Name: **Robyn Brewer**
    Home or School Mailing Address: **330 Elmora Ave, Elizabeth NJ 07208**
    Telephone Number: **609-731-8222**
    E-Mail Address: **SuzyDesigns42@gmail.com**
    DATE TRAINING COMPLETED: <u>**11/14/2021**</u>   *[Required training: CITI training; see website for link]*

    Investigator Signature **_Robyn Brewer_____**

    Name of Project Advisor: (**Carl**) **John Graves**
    E-Mail Address of Project Advisor: **carl.graves@ecat1.montana.edu**

II. TITLE OF RESEARCH PROJECT: **Increasing Student Engagement with Citizen Science**

III. BRIEF DESCRIPTION OF RESEARCH METHODS (If using a survey/questionnaire, provide a copy).
     Students will be given a pre/post-tests, surveys, and an interview about their experience with three citizen science projects. They will be conducting an investigation using web camera data compiled from the Gorongosa National Park. They will be conducting an investigation on fossil atmospheres with the Smithsonian Institution. Finally, they will be constructing urban gardens for community outreach.

IV. RISKS AND INCONVENIENCES TO SUBJECTS **(do not answer 'None')**:
     No known risks are expected with this study.

V.   SUBJECTS:

      A. Expected numbers of subjects: _____**24**_____

      B. Will research involve minors (age <18 years)?   <u>**Yes**</u>   No
          (If 'Yes', please specify and justify.) **The work will be done in a high school classroom.**

      C. Will research involve prisoners?   Yes   <u>**No**</u>

      D. Will research involve any specific ethnic, racial, religious, etc. groups of people?
          (If 'Yes', please specify and justify.)   <u>**Yes**</u>   No
          The work is at a Jewish high school.

APPENDIX B

PRE/ POST TESTS

Ecological Pre/Post Test and Delayed Test
Participation in this research is voluntary and participation or non-participation will not affect a student's grades or class standing in any way.
*Please fill in the questions using the word bank provided. **There are more words** than you need and you may use a **word more***

than once.

WORD BANK

Abiotic, Biotic, Chemosynthesis, Downwards, Environment, Food Chain(s), Food Web(s), Matter, Organism(s), Phosphorus,

Photosynthesis, Pyramids, Upwards, Energy, Producer, Consumer

1. Ecology is the study of relationships between _____ and the _____.
2. Every ecosystem has _____ and _____ factors.
3. _____ factors are nonliving things.
4. _____ obtain their energy through _____ and _____.
5. _____ and _____ show the energy flow of an ecosystem.
6. _____ are complex illustrations of the interconnected relationships between multiple organisms in an ecosystem.
7. _____ cycles throughout an ecosystem.
8. _____ factors such as water, oxygen, carbon, nitrogen and _____ all cycle in and out of ecosystems.
9. _____ show the spread of energy and matter in an ecosystem.
10. _____ flows from _____ to _____ in an ecosystem.

Short Answer.

Please answer in complete sentences.

1. What is the difference between a food web and a food chain?

2. How do abiotic factors affect biotic factors in an ecosystem?

3.   What is an ecological niche?

4. What is niche partitioning and can you provide an example of it?

Evolutionary Concepts Pre/Post Test and Delayed Test
Participation in this research is voluntary and participation or non-participation will not affect a student's grades or class standing in any way.

Part I: Write down the first three words you think of for natural selection.

Part II: Circle all answers you think are accurate about each statement.

1. Natural selection applies to …
individuals

populations

everything but humans

all organism

nothing

2. The measure of success in nature is….
age reached

enemies killed

mating opportunities

surviving offspring

food gathered

3. Changes result from ...
organisms learn to modify their bodies

random mutations

genetic material is passed on

loss of body parts

supernatural intervention

Part III: Complete the following questions.

4. Natural selection is the best supported explanation for the diversity of life on Earth.

Strongly Agree   Agree   Disagree   Strongly Disagree

4   3   2   1

5. Natural selection helps explain why organisms took the way they do.

Strongly Agree   Agree   Disagree   Strongly Disagree

4   3   2   1

6. Natural selection applies to all organisms on Earth.

Strongly Agree   Agree   Disagree   Strongly Disagree

4   3   2   1

7. Natural selection affects humans.

Strongly Agree   Agree   Disagree   Strongly Disagree

4   3   2   1

Plant Biology Pre/Post Test and Delayed Test

Participation in this research is voluntary and participation or non-participation will not affect a student's grades or class standing in any way.

*Please fill in the questions using the word bank provided. **There are more words** than you need and you may use a **word more than once**.*

WORD BANK

Angiosperms, Botany, Carbohydrates, Chemosynthesis, Chlorophyll, Fruit, Guard, Increases, Leaves, Nitrogen, Oxygen, Phloem, Photosynthesis, Reduces, Roots, Stem, Water, Xylem

1. _____ is the scientific study of plants.
2. The cuticle _____ the amount of _____ a plant loses through its leaves.
3. The amount of water the _____ absorb is controlled by the _____.
4. Plants primarily obtain their energy through _____.
5. _____ and _____ are parts of the vascular system in plants.
6. Plants are unable to use atmospheric _____.
7. Plants synthesize food which is stored as _____.
8. _____ is the green light trapping pigment found in plants.
9. _____ are flowering plants with their seeds borne within a _____.
10. _____ cells help control _____ in plant leaves.

Short Answer.

Please answer in complete sentences.

1. Draw a diagram of a flower and name it's parts?

2. Describe methods of cross-pollination?

3. What are the requirements for seed germination?

4. Contrast the germination of a bean seed with that of a corn kernel.

5. In what ways do plants ordinarily reproduce asexually?

APPENDIX C

PRE/POST SURVEYS

Ecological Concepts Survey
Participation in this research is voluntary and participation or non-participation will not affect a student's grades or class standing in any way.

1. I feel confident in my ability to identify the parts of an ecosystem.
   Strongly Agree
   Agree
   Disagree
   Strongly Disagree

2. I feel confident in my ability to analyze the energy flow in an ecosystem.
   Strongly Agree
   Agree
   Disagree
   Strongly Disagree

3. I feel confident in my ability to understand the abiotic and biotic factors in an ecosystem.
   Strongly Agree
   Agree
   Disagree
   Strongly Disagree

4. When I identify the parts of an ecosystem
   A) I can easily identify the producers and consumers. I can order all of the organisms into their proper categories without any difficulties.
   B) I can usually figure out all of the producers and consumers. Sometimes I have a bit of difficulty classifying a few of them.
   C) I often have trouble getting the organisms sorted into the right categories. I can get some of them, but I would be confused part of the time.
   D) I have lots of difficulty deciding which organism is a producer or a consumer. I might get some of them right, but I would have trouble doing it without help from my lab partner.

5. When I analyze the flow of energy in an ecosystem
   A) I can provide an in-depth analysis of the energy flow. I can group the organisms into trophic levels and confidently explain how energy moves through the ecosystem.
   B) I can figure out the energy flow of an ecosystem. I will be able to group most of the organisms into trophic levels and explain how energy moves through the ecosystem.
   C) I often have trouble understanding how energy moves through the ecosystem. I can figure out some of the trophic levels, but not all.
   D) I have lots of difficulty explaining how energy moves through an ecosystem. I would ask for help and might be able to explain what trophic levels are.

6. When I think about abiotic and biotic factors
   A) I can readily identify them and see the relationships between nonliving and living organisms. I could explain why a nonliving factor has an impact on living organisms
   B) I can identify living and nonliving factors in an ecosystem. I might have trouble explaining the relationship between living and nonliving factors.
   C) I might get all of the living and nonliving factors identified. I would need help explaining relationship between them in an ecosystem.
   D) I would need help identifying the living and nonliving factors in an ecosystem. I really don't

understand how they are related to each other.

Evolutionary Concepts Survey

Participation in this research is voluntary and participation or non-participation will not affect a student's grades or class standing in any way.

1. I feel confident in my ability to explain evolution.
   Strongly Agree
   Agree
   Disagree
   Strongly Disagree

2. I feel confident in my ability to describe the process of natural selection.
   Strongly Agree
   Agree
   Disagree
   Strongly Disagree

3. I feel confident in my ability to explain the process of speciation.
   Strongly Agree
   Agree
   Disagree
   Strongly Disagree

4. When I am asked to explain evolution
   A) I can easily provide an in-depth explanation. I can describe the concepts and provide a historical timeline of the theory.
   B) I can provide an explanation. Sometimes I have a bit of difficulty explaining how it works.
   C) I often have trouble explaining how it works. I can get some of the ideas, but I would be confused part of the time.
   D) I have lots of difficulty explaining evolution. I understand some of the theory.

5. When I describe the process of natural selection.
   A) I can easily provide an in-depth description. I can explain what fitness means and how it relates to reproduction.
   B) I can provide a description of how natural selection works.
   C) I often have trouble explaining the entire process, but I can explain some of it.
   D) I have lots of difficulty explaining natural selection. I would ask for help and might be able to explain some of it.

6. When I think about speciation.
   A) I can readily identify the different techniques, explain how they work, and compare it to the tree of life.
   B) I can readily identify the different techniques and explain how they work.
   C) I might get all of the speciation conditions identified. I would have trouble explaining some of them.
   D) I would need help identifying any of the speciation processes. I really don't understand how they work.

Botany Concepts Survey

Participation in this research is voluntary and participation or non-participation will not affect a student's grades or class standing in any way.

1. I feel confident in my ability to identify the parts of a plant.
    Strongly Agree
    Agree
    Disagree
    Strongly Disagree

2. I feel confident in my ability to construct ideal conditions for a seed to sprout.

    Strongly Agree
    Agree
    Disagree
    Strongly Disagree

3. I feel confident in my ability to explain cross-pollination.

    Strongly Agree
    Agree
    Disagree
    Strongly Disagree

4.When I identify the parts of a plant
A)I can easily identify the plant structures. I can identify monocots and dicots without any difficulties.
B) I can usually figure out all of the plant structures. Sometimes I have a bit of difficulty classifying monocots and dicots.
C) I often have trouble getting the plant structures identified. I can get some of them, but I would be confused part of the time.
D) I have lots of difficulty identifying the parts of a plant. I might get some of them right, but I would have trouble doing it without help from my lab partner.

5.   When I construct the ideal conditions for seed germination.
 A) I can provide an in-depth description. I can utilize the right temperature, light, and water conditions.
B) I can figure out the proper setup for germination. I will be able to use most of the proper conditions.
C) I often have trouble understanding the right conditions. I can figure out some of the requirements for seed germination, but not all.
D) I have lots of difficulty creating the proper conditions for seed germination. I would ask for help and might be able to explain what trophic levels are.

6.When I think about cross-pollination.
A) I can readily identify the different techniques, explain how they work, and compare it to self-pollination.
B) I can readily identify the different techniques and explain how they work.
C) I might get all of the cross-pollination techniques identified. I would have trouble explaining some of them.
D) I would need help identifying the cross-pollination techniques. I really don't understand how they work.

APPENDIX D

CITIZEN SCIENCE SURVEYS

Citizen Science Survey
Participation in this research is voluntary and participation or non-participation will not affect a student's grades or class standing in any way.

1.   When I did the citizen science project, I felt the material was more meaningful to me as a student. It mattered to me that the data was used for real.

   Strongly Agree   Agree   Disagree   Strongly Disagree

   4   3   2   1

2. When I did the citizen science project, I felt that it was easier to learn the material.

   Strongly Agree   Agree   Disagree   Strongly Disagree

   4   3   2   1

3.   After I did the citizen science project, I feel like I will remember the information I learned.

   Strongly Agree   Agree   Disagree   Strongly Disagree

   4   3   2   1

Citizen Science Interview Questions

Participation in this research is voluntary and participation or non-participation will not affect a student's grades or class standing in any way.

    1. Are you familiar with citizen science projects?

Follow up- Can you describe one project?

    2. Would/Did you like participating in the citizen science project?

Follow up- What was/would be the best/worst thing about the project?

    3. Would? Did collecting data for scientists to use make the classwork more meaningful for you?

Follow up- Was it more important for you to be careful when collecting data?

    4. Would you recommend citizen science projects in your science classes?

Follow up- Would/Did it motivate you to learn the material because it was an actual

experiment?

<u>APPENDIX E</u>

NON TREATMENT PRE POST TESTS

Mitosis Pre/Post Test and Delayed Test
Participation in this research is voluntary and participation or non-participation will not affect a student's grades or class standing in any way.

Multiple Choice
Please circle the best answer choice.

1. During which phase do chromosomes first become visible?
    A) interphase
    B) telophase
    C) metaphase
    D) prophase

2. A cell with 10 chromosomes undergoes mitosis. How many daughter cells are created? _____ Each daughter cell has _____ chromosomes?
    A) 2,10
    B) 10,2
    C) 1,10
    D) 2,20

3. What structure is responsible for moving the chromosomes during mitosis?
    A) nucleolus
    B) nuclear membrane
    C) spindle
    D) cytoplasm

4. Cytokinesis begins in which phase?
    A) interphase
    B) telophase
    C) metaphase
    D) prophase

5. During which phase do chromosome first become visible?
    A) anaphase
    B) telophase
    C) metaphase
    D) prophase

6. Cells will generally divide when?
    A) they are 10 hours old
    B) they become infected
    C) they become too large
    D) they have no food

7. During which phase does the DNA make a copy of itself?
    A) interphase
    B) telophase
    C) metaphase
    D) prophase

8. Each chromosome consists of 2 _____?
   A) centrofibers
   B) chromatids
   C) daughter cells
   D) centriole?

9. Which of the following is NOT part of the chromosome?
   A) centrofibers
   B) chromatids
   C) daughter cells
   D) centriole

10. Compared to the X Chromosome, the Y chromosome is :
    A) much larger
    B) much smaller
    C) more twisted
    D) inherited more often

Adapted from: https://www.biologycorner.com/quiz/qz_mitosis.html

Meiosis Pre/Post Test and Delayed Test
Participation in this research is voluntary and participation or non-participation will not affect a student's grades or class standing in any way.

Multiple Choice
Please circle the best answer choice.?

1. Meiosis results in _____.
   A) 2 haploid daughter cells
   B) 4 haploid daughter cells
   C) 2 diploid daughter cells
   D) 4 diploid daughter cells

2. Which of the following cells undergo meiosis?
   A) sperm cells
   B) liver cells
   C) unicellular organisms
   D) All of these

3. Crossing over occurs during?
   A) anaphase 1
   B) metaphase 1
   C) telophase 1
   D) anaphase 2

4. Meiosis is a type of cell division that produces:
   A) zygotes
   B) chromosomes
   C) DNA
   D) gametes

5. During which phase do chromosome first become visible?
   A) interphase
   B) telophase
   C) metaphase
   D) prophase

6. Which of the following distinguishes prophase 1 of meiosis from prophase of mitosis?
   A) homologous chromosomes pair up
   B) spindle forms
   C) nuclear membrane breaks down
   D) chromosomes become visible

7. A cell with a diploid number of 24 undergoes meiosis, how many chromosomes are in each daughter cell?
   A) 6
   B) 12
   C) 24
   D) 48

8. During which phase do chromosome first become visible?
   A) interphase
   B) telophase
   C) metaphase
   D) prophase

9. During which phase do chromosome first become visible?
   A) interphase
   B) telophase
   C) metaphase
   D) prophase

10. The picture below depicts what phase of meiosis ?
    A) prophase   1
    B) telophase   1
    C) metaphase 2
    D) prophase   2
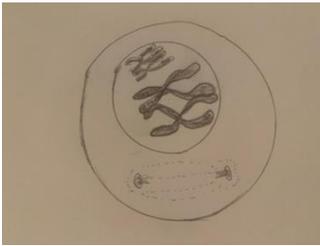
Adapted from: https://www.biologycorner.com/quiz/qz_meiosis.html

Genetics Pre/Post Test and Delayed Test

Participation in this research is voluntary and participation or non-participation will not affect a student's grades or class standing in any way.

Multiple Choice

Please circle the best answer choice.

1. During which phase do chromosome first become visible?
   A) interphase
   B) telophase
   C) metaphase
   D) prophase

2. During which phase do chromosome first become visible?
   A) interphase
   B) telophase
   C) metaphase
   D) prophase

3. During which phase do chromosome first become visible?
   A) interphase
   B) telophase
   C) metaphase
   D) prophase

4. During which phase do chromosome first become visible?
   A) interphase
   B) telophase
   C) metaphase
   D) prophase

5. During which phase do chromosome first become visible?
   A) interphase
   B) telophase
   C) metaphase
   D) prophase

6. During which phase do chromosome first become visible?
   A) interphase
   B) telophase
   C) metaphase
   D) prophase

7. During which phase do chromosome first become visible?
   A) interphase
   B) telophase
   C) metaphase
   D) prophase

8. During which phase do chromosome first become visible?
   A) interphase
   B) telophase
   C) metaphase
   D) prophase

1. During which phase do chromosome first become visible?
   A) interphase
   B) telophase
   C) metaphase
   D) prophase

Adapted from: https://www.biologycorner.com/quiz/qz_mendel_genetics.html