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ASSESSING THE EFFECTS OF AN AUTHENTIC PROJECT-BASED INTERVENTION ON SECONDARY STUDENTS' UNDERSTANDING OF ECOSYSTEMS AND THEIR ATTITUDES TOWARD AND INTERESTS IN STEM

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ASSESSING THE EFFECTS OF AN AUTHENTIC PROJECT-BASED INTERVENTION ON SECONDARY STUDENTS' UNDERSTANDING OF ECOSYSTEMS AND THEIR ATTITUDES TOWARD AND INTERESTS IN STEM

DISSERTATION

A dissertation submitted in partial fulfillment of the requirements for the degree of Doctor of Philosophy in the College of Education at the University of Kentucky

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ABSTRACT OF DISSERTATION

ASSESSING THE EFFECTS OF AN AUTHENTIC PROJECT-BASED INTERVENTION ON SECONDARY STUDENTS' UNDERSTANDING OF ECOSYSTEMS AND THEIR ATTITUDES TOWARD AND INTERESTS IN STEM

There is a need for secondary schools to provide more authentic, hands-on experiences in science, technology, engineering, and mathematics (STEM), and specifically, project-based investigation (PBI) environments in the classroom that focus on real-world problems relevant to students' experiences, interest, and lives that manifest the Next Generation Science Standards (NGSS) following practices they prescribe. This study investigated how, to what extent, a contextualized aquaponics PBI (APBI) 10-week model unit affected high school students' attitudes toward STEM in general, and aquaculture and aquaponics in particular, and interests in future STEM-related disciplines and/or STEM career pathways. This study also measured changes in students' understanding of standard-based ecological relationships and concepts concerning interactions in ecosystems and specifically the phenomena carrying capacity and bacterial nitrification process. Currently, there is very little research literature on how APBI may engage students in learning science, initiate affective attitudes and interest in their local environments, and potentially pique their interests in STEM, and aquaculture/aquaponics fields as a career choice.

Using a quantitative methods, quasi-experimental research design, three different student groups who participated in the authentic, hands-on APBI intervention (i.e., treatment groups) were given a pre- and post-attitude/interest survey (N=55). The 12 survey items were rated by a 5-point Likert-type scale that measured changes in student interest and attitudes toward STEM as discipline and area of interest. In addition, the survey included a profile of the respondents with the demographic items. Further, the treatment groups and control group were given a pre- and post-content-aligned test (N=88) which measured changes in students' ecological knowledge.

The results in this study revealed that the intervention contributed to the treatment group students' positive attitudes toward STEM in general, and aquaculture and aquaponics in particular, and developing an interest in STEM disciplines and/or STEM career pursuits. Results also demonstrate that the project-based intervention, utilizing a real-life aquaculture/aquaponics context, was an effective method to provide meaningful learning and content understanding of standard-based ecological concepts and relationships. The evidence from this study suggest that authentic instructional experiences can facilitate students' understanding of standard-based ecological concepts and knowledge of ecosystems as the three treatment group students showed statistically significantly higher mean difference (improvement) sum scores after taking the pre- and post-content-aligned assessment when compared to the control group (Group 1).

Overall, the gain in understanding and appreciation for and interest in STEM and aquaculture can be attributed to the project-enhanced unit implemented in this study. The implications of this study suggest APBI models may create authentic science learning environments that promote student learning of scientific concepts while piquing their interest in STEM related disciplines and/or career pathways. The intervention design and findings in this study may provide educators new insights and ideas on how to incorporate and use contextualized, aquaponics project-based instruction as a teaching and learning tool. In addition, APBI can offer engaging curricula that articulates NGSS.

KEYWORDS: STEM, Project-Based, Attitudes, Interests, Understanding, Aquaponics

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05/5/2020

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DEDICATION

I dedicate this dissertation to my two kids, Brett Allen Thompson and Kennedi Elaine Thompson. What kept me going was the idea that my hard work, determination, and relentlessness would motivate them to develop an uncanny zeal and grit (i.e., effort, passion, and perseverance) to achieve their personal goals in life. Brett and Kennedi you are my world. This is for you.

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CHAPTER 1. INTRODUCTION

1.1 Statement of the Problem

Science teachers have different ways and routes to teach a topic to hook students' interest and help them have enduring understanding. Teacher-centered instruction mainly use lecture strategy that often promotes students to memorize facts and the information may not be connected with their past experiences, prior knowledge, and/or interests. Furthermore, traditional, fact-based methods to teaching may limit students' opportunities to share ideas and information freely with each other. One possible solution to address this problem is to make students more active learners in science classrooms and embrace curricula that fosters student-centered learning in authentic, problem-based environments. This approach may help students develop a deeper and more connected understanding of scientific concepts rather than a focus on scientific facts. The present project wanted to create an environment that was practical to help students better understand the ecological concepts and gain a deeper insight into STEM and aquaculture. The project was designed to keep students' interest and curiosity and provide students opportunities to apply what they learn in school to their daily real-life situations. In addition, the project offers secondary schools a potentially powerful learning model in aquaculture. This is in agreement with the release of the Next Generation Science Standards (NGSS Lead States, 2013) that ushered in new reforms in science education focusing on making sense of natural phenomena and applying scientific understanding to solve authentic, real-world problems (Jin et al. 2019).

The present study addresses the problem of the need to strengthen students' learning of science, technology, engineering, and mathematics (STEM) knowledge and skills; applying STEM content and skills in problem-solving contexts (i.e., solve real-world problems) prescribed by Next Generation Science Standards (NGSS); and developing students' interest in STEM as a discipline and/or as a career choice. There is also a need for more authentic, project-based investigations (PBI) students can engage in that manifest NGSS following practices they prescribe. Further, there is a need for research to help us better understand how PBI projects, particularly in aquaculture, can foster students' knowledge and skills in STEM discipline(s), interest in STEM, and interest in pursuing coursework and/or careers/hobbies in STEM disciplines. Currently, there is very little research literature on how aquaponics PBI may engage students in learning science, initiate affective attitudes and interest in their local environments, and potentially pique their interests in STEM, and aquaculture/aquaponics fields in particular, as a career choice. The present project fits well with a PBI framework due to its focus on a real-world problem students' investigate in the classroom. Researchers (Blumenfeld, Krajcik, Wilhelm, and others) call for selecting real-world issues relevant to students' experiences, interest, and lives.

1.1.1 **Engaging Students in Authentic Learning Experiences**. There is a need for schools to provide authentic learning experiences in STEM. Lee and Songer (2003) calls for using "authentic tasks" when structuring science curriculum. Fusco (2001) calls for making science curriculum "relevant" to enhance science engagement. Other researchers have touted the benefits of promoting community connections and building from local contexts (Bouillion & Gomez, 2001; Hammond, 2001; Brickhouse, 1994). These are common features in today's science education reform initiatives, according to Rivet and Krajcik (2008). The authors contend that such efforts to "contextualize instruction" attempt to leverage from students' prior knowledge and experiences to foster understanding of challenging science concepts. Providing secondary students more authentic, relevant, and community connected project-based investigations they can engage with may capture their interests in STEM subjects and careers. Basu and Barton (2007) reported that many urban, low-income students describe science as a discipline that generates sentiments such as boredom, anxiety, confusion, and frustration. The authors claim that students do not like science because it is not connected to their personal experiences and interests. They suggested that while many students do, in fact, develop sustained interest in science, that interest is not always cultivated in traditional venues like school science. Hammond (2001) suggested that science needs to become more inclusive and meaningful for students in a way that parallels natural significance in particular communities while complementing standard-based curricula. She reported that students who entered her science methods class, do not enter with a positive view of science.

Students have a belief that science is just facts and computations (p. 984). Science education researchers have argued that a "disconnect" between school and home/community life may result in students feeling that science is impractical, alien, and in contradiction with the beliefs and practices of their lives (Boullion & Gomez, 2001; Brickhouse, 1994). Gonzalez and Moll (2002) explored a particular avenue of research coined "funds of knowledge" whereby connection between students' real-world and relevant life experiences, cultural knowledge of a community, and personal goals they are passionate about outside of school are strategically linked with academic instruction and student-centered, project-based activities (via group project research) in the classroom. Basu and Barton (2007) explained that funds of knowledge incorporation into academic instruction is grounded on strategic knowledge and activities for achieving the goals a student has for his/her out-of-school life (p. 468). Earlier studies on the role of "funds of knowledge" in science teaching and learning has been documented when situated in science education to enhance science engagement and learning (Boullion & Gomez, 2001; Hammond, 2001; Seiler, 2001). Bouillion and Gomez (2001) argued that youth should feel what they learn in school empowers them to shape the communities and world in which they live. The authors indicated that when students found education to be empowering and transformative, they were likely to embrace and further investigate what they were learning, instead of being resistant participants.

1.2 Rationale

The rationale for this study was to engage secondary students in authentic, hands-on project-based investigation (PBI) environments in the classroom that mirrors real-life work of aquaculture scientists through enriching experiences that develop a depth of learning of standard-based ecological relationships and concepts regarding interactions in ecosystems and the concept carrying capacity. Further, gain greater awareness of the field of aquaculture. Aquaponics is the integration of aquaculture and hydroponics. Aquaponics project-based investigations (APBI) can be generally defined as students actively engaged in real-world aquaponics experiential learning opportunities over an extended period of time. This small scale aquaponics project served as a vehicle for fostering students' understanding of the phenomenon *carrying capacity* and the interactions among biotic and abiotic factors within an ecosystem as students assume the roles of scientists and aquaculturalists. Likewise, the aquaponics unit connected with many of the Next Generation Science Standards (NGSS). Students investigated and collected meaningful data throughout the unit and were exposed to a real-world, authentic agriculture science, technology, engineering, and mathematics (ag-STEM) experience. They designed, experimented, and grew their own fish and plant systems in the classroom which allowed for a real-life, hands-on learning experience. Consequently, the project was created to conceivably foster interest in aquaculture, aquaponics, or STEM more broadly through participation in authentic, inquiry-based experiences. Areas of interest might take the form of some students becoming more aware of the following: 1) the need to preserve the environment within their local communities; 2) the need to reduce the impact of human activities on the environment through aquaculture and aquaponics; 3) the need to sustain our capacity to produce safe and reliable food (i.e., sustainable food production).

Research suggests that aquaculture is an effective *teaching tool* because it easily integrates many disciplines including biology, chemistry, economics, math, physics, and provides hands-on experiences for students (Conroy & Peaslely, 1997; El-Ghamrini, 1996; & Wingenbach, 2000). These reports are in agreement with Hart et al. (2013) who asserted that aquaponics education provides a practical, hands-on way to get students in touch with basic STEM concepts due to its interdisciplinary nature. The authors stated that through aquaponics students can conduct interdisciplinary activities involving chemistry, physics, biology, and sustainability. The present study explored the effectiveness of using a “real-life” aquaculture and aquaponics context to bridge students’ understanding of ecosystem processes and their attitudes toward and interests in STEM. Thus, the underlying rationale of this study is to examine how the intervention contributes to, and helps refine, students’ understanding of ecological concepts and mediate directly in the development of more favorable attitudes toward and interest in STEM fields of study and career pathways such as aquaculture.

1.2.1 **Engaging students in authentic aquaculture STEM learning experiences**.

Situated in a 10-week contextualized project-based investigation (PBI) curriculum unit, students were engaged in investigation that encompasses real-world scientific inquiry pertaining to the field of aquaculture. Contextualized PBI often takes the form of real-world examples or problems and the tasks students do in the classroom are relevant and meaningful to their lives and to the local and scientific community (Rivet & Krajcik, 2008). The authors explained that in a contextualized PBI student learning environment, it facilitates more links to connect information to students' prior experiences and knowledge while anchoring ideas to everyday contexts. Incorporating real-world aquaculture activities in the science classroom may be a unique approach for teachers to enhance science engagement and capture students' interest in STEM disciplines and/or career pathways. Applying funds of knowledge strategies and contextualized PBI in a science classroom when integrating aquaculture may foster students' appreciation for STEM and may even promote long-term aspirations to make it into a career. Overall, it may promote a more successful STEM learning experience and, most importantly, students gain a foundational understanding of the target concepts during the inquiry learning process. The present research study on the PBI project actively engaged students in practical, hands-on authentic tasks that focused on real-world problems they investigated in the classroom. These were unique "experiential learning" environments that got students in touch with basic STEM concepts and skills as they connected with aquaculture and aquaponics, which is a sustainable method of growing plants and fish together in a closed recirculating loop system. These super-efficient systems provided students opportunities to develop their critical thinking and problem solving skills as they created and managed an ecosystem while studying the interactions of fish, plants, and bacteria. Students participating in the project were engaged in various hands-on activities integrating aquaculture and hydroponics (i.e., aquaponics) in the classroom while studying a "living" ecosystem. Likewise, students working in small groups were assigned a real-world STEM job (via different STEM career pathways) that made connections to their daily lives and community with weekly rotations. Participants were engaged in agriculture STEM in the classroom while learning the ideas of hydroponics and aquaculture, which is sustainable food production. Students took ownership of their learning while investigating, exploring, analyzing, interpreting, and reflecting amongst their peers the tasks at hand, which may foster positive learning outcomes.

1.2.2 *Little research exists in this context*. Currently, there is a lack of documented research on helping us better understand how integrating aquaculture-based PBI projects during a short term curricular unit in the science classroom can foster students' knowledge and skills in STEM, attitudes toward STEM and aquaculture in particular, and interest in pursuing STEM coursework (via STEM disciplines) and/or careers/hobbies (via STEM career pathways). While much literature has touted the benefits of contextualized science instruction to improve learning, few studies have explored in the context of using aquaponics project-based investigation (APBI) in the science classroom. The present study assessed student learning outcomes and the benefits of implementing aquaponics education at three different public high school classrooms. Schneller et al. (2015) stated in a fairly recent case study that future research should assess outcomes when the technology and curriculum relating to aquaponics is implemented in a public primary school with different social and administrative climates and those that require greater adherence to Common Core State Standards and NGSS. Interestingly, Hart and colleagues (2013) concluded in their qualitative study that it is not known how educators actually use aquaponics for teaching and learning. The authors suggested that documenting the actual use of aquaponics as a teaching and learning tool will be critical for the expansion of aquaponics in education and the development of appropriate aquaponics-based curricula. Further, Hart and colleagues (2013) concluded that research into the effectiveness of aquaponics as a teaching and learning tool, as well as how it is used, would greatly strengthen the body of knowledge on aquaponics in education and most likely allow for broader implementation. Hence, while the purpose of the study is to examine the effects of aquaculture PBI on student learning and attitudes, the intervention design and findings may also provide new insights and ideas on how to incorporate and use contextualized aquaponics instruction as a teaching and learning tool and thereby, develop appropriate curricula for secondary K-12 classrooms while adhering to the NGSS. Hence, the project-enhanced unit utilized in this study will have direct implications to the classroom.

1.3 Purpose of the Study

The purpose of this study was to examine the effects of participation in a short-term, 10-week long APBI unit, on the attitudes of high school students toward STEM in general, and aquaculture and aquaponics in particular, and whether they are interested in taking part in future STEM-related disciplines and/or STEM career pathways. The hope is that their experiences in the classroom might encourage them to take more STEM classes in high school and consider a future STEM-related career such as aquaculture. This study will assess the potential impacts of this authentic APBI unit has on participants which has never been investigated. A quantitative methodology was used to examine these possible effects the project might have which could lead to a measurable change in attitudes toward STEM and aquaculture and to see a possible impact on future career choices of the students participating in the project. In this study, a pre- and post-questionnaire were used to test if the participation in the hands-on APBI unit lead to a shift in attitudes and interest in a STEM-related discipline and/or career pathway of the high school students engaged in the intervention.

Another key objective of this study was to measure changes in students' understanding of the target concepts (i.e., carrying capacity, bacterial nitrification process) and their knowledge of ecosystems and related ecological relationships. Students were also tested on their ability to analyze and interpret real-world scientific data in the form of charts and graphs as it related to the target concepts (context). Quantitative methods were again used to measure changes in students' understanding of standard-based ecological relationships and concepts regarding interactions in ecosystems and the phenomenon carrying capacity as a result of their direct experiences in the project. In this study, a pre and post content-aligned assessment were used to test if students improve their thoughtful consideration and knowledge of the delicate nature of ecosystems and their interactions among biotic and abiotic factors when engaged in a contextualized APBI model unit.

Lastly, another goal of this study was to contribute to the growing body of research on the effects of authentic, hands-on APBI intervention on student learning. Notably, a constructivist worldview philosophy was employed in this study and the strategies of inquiry were to establish the meaning of the phenomena under study from the viewpoints and responses of the students who were the unit of analysis in this study.

1.4 Research Questions

This study addressed the following research questions:

1) How does participation in the aquaponics project-based unit affect high school students' attitudes toward STEM in general, and aquaculture and aquaponics in

particular, as a result of their direct experiences in the project? (e.g., self-reported engagement, interest, attention, curiosity, drive, passion, and enjoyment)

2) How does participation in the aquaponics project-based unit affect high school students' interest toward a STEM-related discipline and/or career pathway as a result of their direct experiences in the project? (e.g., short-term academic and career aspirations, decisions, actions, choices)

3) How does participation in the aquaponics project-based unit affect high school students' understanding of standard-based ecological relationships and concepts as a result of their direct experiences in the project? (e.g., knowledge of ecosystem processes and their interactions among biotic and abiotic factors, bacterial nitrification process, carrying capacity)

1.5 Significance of the Study

As mentioned previously, there is only a handful of researchers who have explored aquaponics-based teaching in an educational setting with little existing research on student outcomes (i.e., attitudinal, positive knowledge gain, and behavioral) when integrated in secondary classrooms. Hart et al. (2013) reported that peer-reviewed articles on the use of aquaponics in education are almost nonexistent and claims are not substantiated by empirical research. At the same time, the authors explained that aquaponics, or the combination of aquaculture and hydroponics, is emerging as a teaching tool throughout the country, and has the potential to enhance interdisciplinary science education. Hart et al. (2013) measured the use of aquaponics systems in schools across North America using a qualitative research approach interviewing educators (teachers) who currently or had in the past five years used an aquaponics system in a formal educational setting. The purpose of their study was to explore aquaponics in formal education as a step toward addressing the lack of research on educational aquaponics systems and solutions to potential challenges. While no student outcomes were reported in this study, the authors found at least three categories which encompass the reasons for aquaponics incorporation in classrooms. These include: (a) applicability to academic subjects Science, Technology, Engineering and Math education (STEM); (b) benefit of hands-on, experiential, and integrating learning; and (c) connection to food, agriculture, and global trends. Wardlow et al. (2002) reported that their Aquaponics in the Classroom program was very successful based on a brief survey of teachers using the systems as they had positive perceptions of the project. However, the authors reported the need for more information on how the units are actually used. Carver and Wasserman (2012) reported that teaching experiential indoor aquaponics and hydroponics systems could provide a surrogate framework for introducing students to sustainable food systems and community environmental issues.

The present study addresses the need to assess student learning outcomes when engaged in a "real-life" aquaculture/aquaponics context that incorporates a PBI intervention that is goal-oriented (via purposeful events) and connects with the NGSS. Students will learn about how their closed recirculating systems functions. They will come to realize the following: 1) ecosystems are complex systems; 2) an understanding of the interactions of living things and identify *interdependent relationships in ecosystems* as part of a disciplinary core idea in life sciences; 3) reasoning to understand the crosscutting concept of *systems and system models;* 4) and thinking about systems in terms of component parts and their interactions, as well as in terms of inputs, outputs, and processes, gives students a way to organize their knowledge of a system, to generate questions that can lead to enhanced understanding (NGSS Lead States, 2013; National Research Council (NRC) framework, 2012).

1.6 Delimitations of the Study

The three biology teachers participating in the authentic, hands-on intervention were selected by the researcher because they taught the aquaponics unit twice to two different groups of students during the 2018-2019 academic year and participated in the pilot project. As a result, they were knowledgeable about the unit content, benchmark lessons, and had experience facilitating their students' own aquaponics investigations in the classroom. Likewise, the researcher and the three teachers met in person as a group prior to the study to discuss various topics such as modifications to benchmark lessons, sequencing of the lessons, and students' aquaponics research investigations (i.e., 8-week whole-class project and 4-week student-driven projects). It is important to note that these three teachers participated in the development of the project. It was advantageous in preparation for this study that they all had the same level of training and comparable experience with the unit materials. In addition, they had comparable expertise in teaching biology with similar educational backgrounds. Further, other criteria for selection was that they had comparable experience and expertise implementing the STEM job rotations. Therefore, teacher selection was on the basis of consistency. It was expected that these teachers would implement the unit materials with fidelity, since they had worked collaboratively with the researcher during the unit's development. Lastly, the sites selected by the researcher also constituted a good representative sample of students outside this population frame (via those who did not participate in the project). The students participating in the present study were high school students (grades 9-10) located in four different small towns surrounded by farmland (i.e., includes the control group).

1.7 Limitations of the Study

The teachers and the researcher devised a plan to improve fidelity of the unit's implementation across the three student treatment groups. A 10-week unit outline was created by the teachers and researcher that served as a pacing guide to keep the teachers on track each week (see Table 3.12). However, teachers participating in the project were flexible with the content to meet the class needs. For example, the teacher may need to go deeper into a topic to support students' understanding and develop their critical thinking skills. Consequently, this may set the teachers back somewhat on the planned outline material. Further, it could be that students are not understanding the concepts and therefore re-teaching may be necessary. While ensuring fidelity of the unit was a top priority in the present study, these in-class situations could not be controlled by the researcher. The need to provide teachers flexibility in their instruction throughout the unit seemed reasonable and was implemented. It is important to note that the study examined outcomes when the unit was presented in everyday classrooms where small setbacks such as re-teaching a lesson, reviewing content, or diving deeper into a specific unit topic are common happenings. Thus, the study examined the effects of the unit in situ.

1.8 Assumptions of the Study

This study included the following assumptions (are accepted as true by researchers and peers):

1. This originally-designed 10-week aquaponics project-based unit (APBI) may be useful for a widespread group of educators to obtain new insights and ideas while at the same time adhering towards the Next Generation Science Standards (NGSS).
2. Aquaponics education provides unique interdisciplinary learning opportunities to engage students' in the science, technology, engineering, and mathematics (STEM) through relevant, real-world investigations and problem solving opportunities in the classroom.
3. Aquaponics can be used as a viable teaching tool for education by providing opportunities for students to go in-depth with various STEM subjects such as biology, chemistry, math, engineering, physics, and technology while also learning transferable life skills such as responsibility, communication, problem solving, and self-confidence that are sought after in numerous growing fields.
4. Hart et al. (2013) reported that using aquaponics in education may serve the dual purpose of preparing future practitioners while giving students the opportunity for *active* learning. The authors also proposed that aquaponics be viewed as a "living" teaching tool because it can be used to grow living organisms in an educational setting, especially for the application of academic subjects and hands-on learning.

5. This parallels the goals of contemporary science education in the United States (National Research Council, 2012) according to the authors.
6. Survey responses from the student participants accurately reflect their perceptions, openly and honestly.
7. Content-aligned assessment responses from student participants accurately reflect their understanding of the target concepts.

1.9 Definition of Terms

Aquaculture. The farming of aquatic plants and animals in a controlled environment (Nash, 2011) and in recirculating aquaculture, water is cleaned and recycled in a closed-loop system (Timmons and Ebeling, 2007).

Aquaponics. Fox et al. (2010) defined aquaponics as the integration of aquaculture and hydroponics, where fish wastewater is utilized as a nutrient source for the plants grown in soilless culture. Aquaponics is considered an efficient sustainable method of growing plants and fish together in a closed recirculating system. Schneller et al. (2015) defined aquaponics as a way to simultaneously grow edible plants and raise fish in a closed-loop system. Further, he asserts that, the technology can increase the availability of food, thus addressing food security.

Aquaponics production systems. Bernstein (2011) defines aquaponics production systems as a technique for food production that combines aquaculture and hydroponics in a symbiotic relationship. Aquaponics production systems allow the chemical nutrients needed for hydroponic plant growth to be replaced with fish wastes that might otherwise be discharged and cause potential environmental degradation. Hart et al. (2013) define aquaponics as a possibility to raise both fish and plants together in a balanced system that closes the aquaculture waste stream and adds a second source of income from plant harvests.

Aquaponics project-based investigation (APBI) curriculum unit. The APBI unit is the intervention the study's participants took part in. The effects on STEM attitude in general, and aquaculture and aquaponics in particular, interest in a STEM-related discipline and/or career pathway, and understanding of standard-based ecological relationships and concepts regarding interactions in ecosystems and reaching carrying capacity were under investigation.

Authentic learning experiences/opportunities. An authentic learning experience engages a child in a practical or real-life scientific, technological, engineering, or mathematical problem. Likely, an authentic experience will integrate several or all dimensions of STEM.

Ecosystems have carrying capacities. Carrying capacity concept is the maximum number of species the ecosystem can support (Monte-Luna et al. 2004). In terms of this study, students will learn through their scaled aquaponics models that there are capacity limits to their biological and mechanical filters based upon final data measurements (i.e., evidence).

Project-based investigation (PBI). PBI engages students to design and carry out investigations that relate to a central driving question as they work together to solve real-world problems in their schools and communities (Blumenfeld et al. 1991). The driving question is the focus for scientific inquiry as students must determine how they will answer the question which leads to artifact production (Hmelo-Silver 2004). Students engage in scientific inquiry cycles as they design experiments, make predictions and observations, then construct explanations of why their prediction was or was not correct in a collaborative group setting.

STEM. An acronym used for the fields of study including science, technology, engineering, and mathematics. In the case of the particular STEM intervention implemented in the present study, all fields of study are integrated into the structure of the authentic learning activities as it relates to aquaculture and aquaponics.

The following chapter of this study explores the literature related to learning about ecosystems and project-based instruction while the subsequent chapter delineates the research design and methodology utilized to examine the potential impacts of this aquaponics project-based unit has on the participants (i.e., high school students). Chapter 4 presents an analysis of the data and the findings. Chapter 5 presents the discussion of the findings, implications, limitations, recommendations for future research, and conclusions based on the findings of the effects of participating in the project has on student learning and their attitudes and interests toward STEM and aquaculture.

1.10 Reflecting on Personal Experiences, Ideas, and Biases

The researcher's education background in aquaculture research, past work experiences, and being a mentor for numerous youth in hands-on aquaculture projects helped shape the direction of the present study. The original concept and idea when creating the unit was essentially to bring the aquaculture science lab into the high school classroom and allow participants to "learn by doing" and be inspired to consider a STEM discipline or career pathway. Such STEM investigative activities participants were engaged in are similar to undertakings of a real-world aquaculture scientist. The belief also is that teachers may become more aware of ways to encourage students to enjoy science and mathematics if they introduce aquaculture and aquaponics (i.e., agriculture-based teaching) in the classroom as a representation of an authentic field of scientific study.

Patton (2002) suggests for the researcher to share “any personal and professional information that may have affected data collection, analysis, and interpretation” (p. 566). Thus, the researcher shares his personal views on the topic in the form of a short narrative. Because of its personal nature, the researcher will refer to himself in the first person. Personally, I have a bias toward aquaculture with the belief that aquaculture education can be an ideal vehicle to facilitate integration of academic and vocational subject matter when it is infused into secondary or other agriculture curriculum. It is my belief that secondary agriculture and biology teachers can employ aquaculture in the classroom as a means to teach and reinforce other content STEM areas and integrate the types of activities that occur within various academic areas. I also have a bias that aquaculture can help enhance students’ mathematics and science performance due to its hands-on nature and spark students interest based upon my personal experiences working with youth. Likewise, it is my belief that interventions as it relates to aquaculture connects well with engineering and technology as learners assume the roles of aquaculture scientists in the classroom. For example, students engaged in aquaculture interventions in the classroom may gain more confidence to become a chemical or environmental engineer. I personally believe that aquaculture is a suitable match for integration into the science curriculum because of its nature of being a hands-on discipline. I do believe that aquaculture is an excellent tool for instruction in most science and mathematics classrooms if facilitated by a person having a solid background in both subject areas and has administrative support. Hence, I do foresee potential barriers when implementing this type of instruction. I also think these aquaculture-related interventions in the classroom are useful to academic educators, since it gives students opportunities to connect learning to real world events that might be relevant to their daily lives.

I have been fortunate to work with various aquaculture demonstration projects, youth outreach and extension-related initiatives to support STEM education and awareness, and various research projects mentoring students in the laboratory and/or outdoor pond investigations over the years. It has been my desire to get youth more engaged and interested in STEM (through hands-on aquaculture), since I am so passionate and excited about it. Clearly, my past experiences have helped shape the direction of this research study and whether this unique aquaculture project in the classroom has an effect on students' attitudes and interests in STEM and the field of aquaculture.

Results from this study may demonstrate a positive effect toward student learning and their depth of knowledge in ecosystem concepts and processes regarding interdependent factors, interactions, carrying capacity, and nitrogen cycle from their active hands-on aquaculture and aquaponics inquiry-based (intervention) engagements in secondary school classrooms. Likewise, the intervention may prove to have a positive effect on teachers' instructional practice and create student interest and positive attitudes toward STEM as a field of study or career choice. The curriculum was structured in a way that participants would learn more about STEM by means of hands-on activities that were challenging to the participants' intellectually while at the same time spark their interest in STEM and perhaps shift their attitudes as well which are linked.

1.11 Summary

To date, few if any, studies on the effects of this project-enhanced unit on participants' STEM attitudes and interests and/or their understanding of ecosystems have been conducted in this context. A quantitative methods design was employed to answer the overarching question(s): How participating in the APBI unit affects secondary students' attitudes toward STEM and interest in STEM disciplines and/or careers? How participating in the APBI unit affects secondary students' understanding of standard-based ecological relationships and concepts regarding interactions in ecosystems and the phenomena carrying capacity?

CHAPTER 2. LITERATURE REVIEW

In this chapter, the researcher starts out with a review of the current literature related to learning about ecosystems and the phenomenon *carrying capacity* based on NGSS. Following is a review of current research on students' attitudes toward and interests in STEM. The next section provides the theoretical framework used for this research and then shifts to a review of the characteristics of authentic, hands-on student-centered learning environments (SCLEs) and experimentation. The review continues providing an overview of the strategies and components of project-based investigation (PBI) inside the classroom. Following is an overview of how PBI affects student learning and engagement of STEM. The review continues with the integration of academic and vocational subjects and then shifts to the integration of real-life aquaculture and the barriers. The next section provides a discussion of the lack of understanding and awareness students may have towards aquaculture and aquaponics and then shifts to a review of aquacultural production systems. Following is a review of how the project contributes to the scholarship of engagement. The review concludes with a discussion of the potential student learning outcomes of the project and personal comments by the researcher.

2.1 Learning about Ecosystems and the Phenomenon Carrying Capacity based on NGSS

The high school classroom intervention was designed to increase students' understanding of ecological relationships and concepts regarding interactions and processes in ecosystems and namely the limiting interdependent factors that affect carrying capacity of ecosystems at different scales. Likewise, the idea was that students who engage in these various in-school scientific inquiry-based experiences may ultimately stimulate their curiosity and interest in STEM disciplines (i.e., short-term academic), aquaculture and aquaponics in particular, and promote their aspirations to pursue a career in a STEM-related field. Overall, the signature project learning goals were to provide students with real-world research engagement experiences that was practical and aligned with project-based science learning environments in the classroom while exposing them to following: developing and using models related to their recirculating aquaculture system (RAS); defining problems and designing solutions for engineering their closed recirculating system; planning and carrying out investigations related to the phenomenon *carrying capacity* and learning about the biotic and abiotic interactions in ecosystems; monitoring the nitrogen cycle and water quality aspects; usage of real-life mathematics application such as investigating growth performance of fish, plants, and feed efficiency; analyzing and interpreting quantitative and qualitative data; acquire skills making charts and graphs; collaborating with their peers (i.e., rotating jobs); and acquire skills and techniques needed to operate aquaculture STEM research instruments commonly used by real-world scientists.

Hui et al. (2019) reported that currently, a reform in science education is under way. The authors described that *A Framework for K-12 Science Education* (National Research Council, 2012) and the *Next Generation Science Standards* (NGSS) (NGSS Lead States, 2013) provide “a vision for education in the sciences and engineering, in which students, over multiple years of school, actively engage their understanding of the core ideas in these fields” (NRC, 2012, pp. 8-9). Hui et al. (2019) asserted that this vision is called three-dimensional science learning, as it emphasizes the integration of disciplinary core ideas, crosscutting concepts, and scientific and engineering practices which is outlined in *A Framework for K-12 Science Education*, the original source. There is a need to develop curriculum that integrates all three dimensions for teachers to teach NGSS in their science classrooms. The present study examined the effects of an authentic PBI unit in a specific context model system (i.e., aquaculture and aquaponics) on students' conceptual understanding of ecosystems and the interdependent relationships that exist. The NRC framework and the NGSS identify *Interdependent relationships in ecosystems* as part of a disciplinary core idea in life sciences and systems and system models as a crosscutting concept that makes connections across disciplinary boundaries (NGSS Lead States, 2013; NRC, 2012).

Carrying capacity is the central concept of the NGSS life science core idea Ecosystems: Interactions, Energy, and Dynamics (NGSS for Lead States, 2013), heretofore referred to as the core idea of Ecosystems. The unit addresses ecosystem performance expectations HS-LS2-1 through HS-LS2-4 and HS-LS2-6. See Appendix D for a delineation of these selected performance expectations. These target performance expectations drew upon practices of mathematical and computational representations to support explanations of factors that affect *carrying capacity* of ecosystems at different scales. Notably, the boundary clarification statement explains that emphasis is on quantitative analysis and comparison of the relationships among interdependent factors including boundaries, resources, climate, and competition. Mathematical comparisons may include graphs, charts, histograms, and population changes gathered from various data sets.

The unit addressed three of the disciplinary core ideas (DCI) contained within the core idea of Ecosystems. The first DCI is LS2.A: Interdependent Relationships in Ecosystems, which states: Ecosystems have *carrying capacities*, which are limits to the numbers of organisms and populations they can support. These limits result from such factors as the availability of living and nonliving resources and from such challenges such as predation, competition, and disease. Organisms would have the capacity to produce populations of great size were it not for the fact that environments and resources are finite. This fundamental tension affects the abundance (number of individuals) of species in any given ecosystem (NGSS for Lead States, 2013).

The crosscutting concepts of HS-LS2-1 indicates that the significance of a phenomenon is dependent on the scale, proportion, and quantity at which it occurs. The science and engineering practices of this NGSS-HS-LS2-1 involves using mathematics and computational thinking such as using representations of phenomenon or design solutions to support explanations.

Carrying capacity was the central phenomenon and concept under study and students actively participating in this intervention received real-world opportunities to learn the concept that ecosystems have *carrying capacities* which are limited to the number of organisms and populations they can support. They were to understand how quantity affects these capacities of an ecosystem. They would learn through their scaled aquaponics models that there are capacity limits to their biological and mechanical filters based upon final data measurements (i.e., evidence). A goal was to ensure that students participating in the intervention would have a better understanding of the needs of living things including plants, fish, and bacteria (i.e., biotic factors) and how these species depend on each other and form a close symbiotic interdependent relationship within the ecosystem. They looked at actual patterns at which they grew (i.e., population growth) throughout the intervention. Further, students were provided opportunities to measure many "non-living" parts in the ecosystem including water temperature, dissolved oxygen, alkalinity, ammonia, nitrite, nitrate, and pH (i.e., abiotic factors). Consequently, students learned the interactions between biotic and abiotic factors, the concept of reaching carrying capacity, and an understanding of the limiting factors as a result of their direct experiences in the intervention. The underlying question, "What is the effectiveness of using a *real-life context of aquaculture* to bridge students' understanding of ecological relationships and concepts (via carrying capacity and the nitrogen cycle)?", was examined in the present study.

Hokayem and Gotwals (2016) stated that ecosystems are complex, open systems and understanding interdependent relationships in ecosystems (a component of a core idea in life sciences) requires systemic reasoning. The authors asserted that systemic reasoning is also part of the reasoning to understand the crosscutting concept of systems and system models. The NRC Framework emphasizes that "…thinking about systems in terms of component parts and their interactions, as well as in terms of inputs, outputs, and processes, gives students a way to organize their knowledge of a system, to generate questions that can lead to enhanced understanding" (NRC, 2012, p. 93). An important aspect of understanding complex systems is to identify patterns at the system level and connect those patterns to behaviors and interactions of constituent components (Capra, 1996; Chi, 2005). Hokayem and Gotwals (2016) states that empirical studies suggest that identifying system level patterns in ecosystems is very challenging for students.

Shepardson (2005) found that relationships between biotic and abiotic components and their interdependences could not be explained when investigating upper grade students' statements while describing ecology, how they interpret the world, and what does the world mean to them. The author indicated that students constructed the concept of ecology through a limited ecological point of view. For students in this study, ecology is a field or habitat where animals live or a place that helps animals to live. The upper grade students stated nutrition, water, and habitat requirements in their explanations. However, majority of the students did not mention about energy flow, matter cycle, and nutritional relationships or they did not have an understanding of the subject according to the author. Cetin (2003) asserted that students have still some problems in science concepts and specifically the concept of ecology. Hui et al. (2019) asserted that ecosystems are complex systems because they have "nested" hierarchies – subsystems at a smaller scale are combined to form a system at a larger scale. The hierarchy extends from molecules and cells to individual organisms, populations, communities, and ecosystems. Yorek et al. (2010) employed a qualitative investigation of students' understanding of ecological concepts concerning ecosystem and the cross relationships among the living things and its components. The sample of the study was ninth-grade students' (n=165) and six biology teachers teaching in these students' schools. Results of the study revealed that participating students had difficulty in constructing ecosystem and food web concepts which are at the heart of ecological concepts. Analyses of the responses revealed that students had misconceptions of nutritional relationships among the animals (via grasshopper, rat, and hawk) which interfered with their understanding about ecosystems. The authors concluded that students' misconceptions are the main obstacles for realizing ecological concepts, and getting a better understanding. This is in agreement with Eilam (2012) who conducted a study, in which ninth grade students studied a live ecosystem and manipulated variables in a lab. The results suggest that students seldom connected individual processes at the microscopic level of ecosystems. Gallegos et al. (1994) also reported that learning about these processes and their interdependence in ecosystems is difficult for secondary students.

Jordan et al. (2014) reported that teaching life systems can be difficult because systems are dynamic and often behave in a non-linear manner. Researchers in this study conducted an investigation into the collaborative learning processes and outcomes in which aquaria were used to teach systems thinking. Seventh grade students from a Northeastern United States public middle school participated in an eight-week technology-rich ecosystems unit in their science classroom. Overall, sixty-six students participated. In total, the authors analyzed data from 35 students who completed all the tasks. Prior to the study, the classroom had a physical aquarium installed and maintained for about one month. The teacher used the NetLog-based Rep-Tools toolkit software (see examples at reptools.rutgers.edu) to help students learn about aquatic ecosystems. The students explored the software in their groups about the living aquarium, ponds, and estuaries and these processes were taught to comprehend complex ecosystem phenomenon such as carrying capacity. In addition to their computer models, students were asked to complete a pre- and post-test focusing on systems based relational thinking and a series of homework questions which asked for basic descriptions of general ecosystem processes. Finally, students were given a series of drawing tasks where they were asked to draw what was happening in the ecosystem. Results from their study demonstrated that the ecosystem concept *carrying capacity*, which required an understanding of limiting factors, was not depicted in any students' model drawing, thus they could not assess student understanding of this concept via the model drawing task. However, the researchers did find that students most accurately described *carrying capacity* well in writing in their homework assignments versus their model drawings. Overall, the authors found that many of the concepts associated with their intervention tended to have incomplete explanations and illustrated depictions. This study was part of an on-going investigation (Eberbach et al. 2012) who asserted that exposing students to systems thinking and modelling where phenomena are presented with multiple and interrelated components (via aquaria) may aid in the development of ecosystem reasoning skills. Hence, certain instructional strategies may assist students' restructuring of ideas. In fact, some empirical studies have suggested that given appropriate scaffolding, secondary students are able to understand interactions in ecosystems (Eliam, 2002, 2012; Hmelo-Silver et al., 2007; Hogan, 2000; Assaraf & Orion, 2010; & Plate, 2010).

Jordan et al. (2014) also cited research about secondary students' understandings and their conceptual difficulties in environmental science. These certain fundamental ecosystem processes pertained to how students learn photosynthesis (Barker & Carr 1989a; Stavy et al., 1987; Wayheed et al., 1992; Canal, 1999; & Ozay & Oztas, 2003), secondary students' misconceptions of photosynthesis and respiration in plant (Haslam and Treagust, 1987), students' thinking about nutrient cycling in ecosystems (Hogan et al. 1996), and preconceptions by children in the construction of the food chain (Gallegos et al. 1994). In addition, these ecosystem dynamics has been explored with college-age students such as their understanding of the carbon cycle, cellular respiration, or photosynthesis (Anderson et al., 1990; Hartley et al., 2011; & Songer et al., 1994). Manzanal et al. (1999) investigated the relationship between ecology fieldwork and Spanish secondary school students' attitudes (aged 14-16) towards environmental protection. Results showed that fieldwork contributed to the students' understanding of ecological concepts and their positive attitudes toward the protection of the ecosystem.

While previous research has identified strategies for fostering student understanding of certain fundamental ecosystem processes and skills development, the present study intervention aspects (e.g., collaborative groups, assignment of roles, building a sustainable living ecosystem, maintaining a mini ecosystem – measuring total ammonia nitrogen, nitrite, nitrate, and problem solving, etc.) may add to the research literature on student understanding of ecosystems and ecosystem dynamics. In particular, secondary students understanding of the phenomena carrying capacity and nutrient cycling in ecosystems. Further, the intervention may help foster student engagement, since the unit employed more active learning strategies in the science classroom instead of traditional instruction methods. Cetin (2003) indicated that traditional instruction does not help to encourage students to work together and to share ideas and information freely with each other.

The aquaculture/aquaponics intervention introduced in the present study may prove to be a good platform and fruitful way to get students thinking about their system(s) and specific ecosystem processes, and thereby, increase their understanding of interactions in ecosystems and the limiting factors. Hence, these authentic hands-on models used in this study may enable students to integrate ideas into whole ecosystem concepts as described by Jordan et al. (2014), and thereby, enhance their reasoning skills such as reaching carrying capacity. Secondary students in the present study were engaged in authentic real-world phenomena inside the classroom. They were provided first hand experiences in authentic environments that mirrored outdoor field work or laboratory work of professional aquaculture scientists. This in agreement with Rickinson et al. (2004, p. 24) who stated, “fieldwork can have a positive impact on long term memory, due to the memorable nature of the fieldwork setting and there can be reinforcement between the affective and the cognitive, with each informing the other and providing a bridge to higher order learning”.

Participants in this study learned about “microscopic” living things in different aquatic ecosystems and the interactions with other living (i.e., plants and fish) and non-living components (i.e., water quality parameters) within their complex system as well as learning about the inputs, outputs, and processes. Specifically, student participants were to not only learn about the phenomena *carrying capacity*, but also about the bacterial nitrification (i.e., nitrogen cycle) concept and processes including: 1) the steps in nitrification; 2) knowledge and importance of nitrifying bacteria present in recirculating aquaculture systems (RAS); 3) and knowing where bacterial nitrification occurs in RAS. For example, a measurement of high total ammonia nitrogen (TAN) and/or nitrite may signify that there is insufficient nitrifying bacteria *Nitrosomonas* and *Nitrobacter* present in the water recycle system which could subsequently have a negatively effect on fish growth and health over time.

Students were given opportunities to apply their knowledge, see patterns and connections, and solve real-world problems throughout the project. Overall, providing students opportunities to study “living” aquatic ecosystems may enhance their understanding that every living thing performs a function. Experiences in this intervention may promote students understanding of the concept *carrying capacity*. For example, they may be able to describe well in writing what factors might limit a population of organisms' ability to survive in a particular environment. Further, thinking about different populations of organisms that may or may not reach carrying capacity due to limiting factors. In this instance, students are able to think about both ideas and processes and bring them together which requires an understanding of both. A specific example illustrating how students needed to use their data to assess population levels within the system was the amount of feed introduced (e.g., feeding rate) daily and how that may affect the ecosystem dynamics and possibly inhibit population growth due to the non-living factors (e.g., water quality) in the environment. In so doing, students may be challenged to think about the ecosystem concept carrying capacity, which requires an understanding of limiting factors in the environment (e.g., space, shelter, quantity of food, water quality conditions, disease, and predation).

2.2 Overview of Current Research: Students' Attitudes toward and Interests in STEM

There is a growing worldwide interest in developing student knowledge, skills, and attitudes toward science, technology, engineering, and mathematics (STEM) education in formal and informal learning environments (National Science Board, 2010; National Research Council [NRC], 2012). Olsen and Riordan (2012) reported that economic projections point to a need for one million more STEM professionals than the United States will produce over the next decade. This is in agreement with Maltese and Tai (2011) who reported a STEM "pipeline problem" exists in the United States, where

STEM careers are growing rapidly. Barker et al. (2014) stated that providing opportunities for student engagement in STEM education has extended to various contexts among countries during the last decade. Recent educational reforms call for research that will ultimately produce STEM innovators who become leading STEM professionals and improve society (National Science Board, 2010).

Personal interest and motivation are key components in inspiring students to pursue careers and paths in STEM learning (Mohr-Schroeder et al. 2014), contributes to their success in retaining STEM content (Bell et al. 2009), and exposure to a variety of STEM opportunities will have a long-term effect on individuals and the overall STEM education community (Wai et al. 2010). Mohr-Schroeder et al. (2014) asserted that many students have a lack of interest and proficiency in mathematics and science, specifically students of underrepresented populations. While research has emphasized that all students be prepared and inspired to learn STEM content, there is a need to focus specifically on students of color, females, and students from low socioeconomic backgrounds (Elam et al., 2012; Muzzatti & Agnoli, 2007; National Alliance for Partnerships in Equity, 2009; & President's Council of Advisors on Science and Technology [PCAST], 2010). In the PCAST 2010 report, they asserted that there exists both an interest and achievement gap among African Americans, Hispanics, and females in the STEM fields, which limits participation in STEM-related jobs. This is in agreement with Steinberg and Diekman (2017) who stated that continued underrepresentation of certain groups from STEM fields suggests that the full range of talent is not being utilized.

Currently, there is a need for research to implement formal and informal educational models. Mohr-Schroeder et al. (2014) exposed middle-level students, particularly underrepresented populations, to a variety of out-of-school contextual experiences related to robotics, astronomy, and neurobiology that are STEM fields and they were engaged with STEM professionals through hands-on project-based learning experiences in order to increase their interest in STEM. The authors asserted that their five-day, informal camp intervention held on the campus of a major university in the mid-south enabled students to participate in authentic real-world problem-solving activities that cannot be found in course textbooks. The authors used embedded mixed methods in order to answer the following research question: To what extent does participating in a summer STEM camp influence middle-level students' interest toward STEM content and STEM careers? The results from their study revealed an increase in their motivation and interest in STEM fields as after one week there was a 3% increase from pre to post in STEM careers. They also reported that participants found the STEM content sessions "fun" and engaging, specifically citing the hands-on experiences they received. It is important to note that this research study did not demonstrate how short-term STEM interventions affect students' long-term goals of education and career choice. Steinberg and Diekman (2017) reported the need for evidence-based interventions that can inspire interest in STEM at various developmental stages (p. 236).

The attributes of the short-term STEM educational model used in the present study integrates well with the cited studies interventions described previously by providing students opportunities to hands-on project-based learning experiences in order to increase and foster their engagement and interest in STEM disciplines and/or careers.

The student-centered intervention exposed high school-level students to a variety of in-school contextual experiences related to STEM, and aquaculture and aquaponics in particular, that may be relevant and useful to their daily lives outside the classroom (i.e., contextualized instruction; utility value). Hence, this study provides much needed research on approaches to implement formal classroom educational models utilizing project-based instruction with the goal to increase student engagement and interest in STEM.

Teachers participating in this study integrated the intervention into their formal science classroom and emphasis was on developing students' mathematics and scientific skills after engaged in a real-life context (i.e., aquaculture). It is important to note that although the three teachers had unequal class time, they did have the same training time and resources available to effectively implement the intervention. The student-centered tasks in this intervention were designed to be enjoyable and relevant or useful for a current or future goal (e.g., utility value). Rozek et al. (2017) stated that researchers have recently focused on increasing students' perceived utility value with interventions because it is viewed as malleable to outside forces. As a result, this might promote increase enrollment in STEM courses in high school (short-term pursuits) and later their interests in STEM may be translated to the college level. Correlational and longitudinal research support these assertions which have shown that utility value is significant predictor of mathematics and science course-taking and STEM major enrollment (Maltese & Tai, 2011; Simpkins et al., 2006; Updegraff et al., 1996).

As mentioned previously, the overarching goal of the study was designed to positively influence (i.e., increase) and inspire students' attitudes toward and interest in

STEM educational disciplines and/or STEM career pathway pursuits. Likewise, participants engaged in authentic, hands-on aquatic ecosystem investigations may spark their interest and curiosity particularly in aquaculture and aquaponics, and thereby encourage them toward this unique STEM content and STEM career pursuit after high school and in college. Besides examining if the intervention may help shape youth's attitudes, interests, and short-term academic STEM career choices, a central goal of the project was to examine if students' academic achievement (i.e., performance and improvement) of the target concepts (i.e., carrying capacity and nitrogen cycle) and ideas taught in the student-centered intervention are positively impacted and thereby shifted in a positive direction from the pre and post-intervention. The hypothesis is that developing students' STEM skills and knowledge, while learning about ecological relationships and concepts, may indirectly increase their aspirations to pursue STEM courses in high school and beyond as well as increase their STEM career pursuits. Rozek et al. (2017) indicated the importance of high school STEM preparation and can be seen when examining students' STEM career pursuit after high school and in college. The authors cited evidence to support the present study hypothesis as research demonstrates that high school STEM preparation (e.g., developing STEM skills and knowledge) and increase exposure to STEM topics are crucial predictors of STEM major enrollment in college and career pursuits (Maltese & Tai, 2011; & Schmidt et al., 2015). Hence, results in the present study may find a correlation between growth in learning and their attitudes toward and interest in STEM and career pursuits among the student groups. The researcher in the present study measured students' interest in future opportunities to study aquaculture and aquatic science subjects for high school and advanced credit and the findings are presented in Chapter 4. Students were also engaged in real-world problem-solving activities to help develop their technology skills, engineering design skills, and scientific inquiry skills. Such projects provided students' authentic, hands-on opportunities that cannot be found in course textbooks which is in agreement with Mohr-Schroeder et al. (2014).

2.3 Theoretical Framework

Eisenhart (1991) states, "A theoretical framework is a structure that guides research by relying on formal theory; that is, the framework is constructed by using an established, coherent explanation of certain phenomenon and relationships" (p. 205). A theory on the other hand, explains why and under what circumstances certain phenomenon occur, predicts what will happen in the future, and defines and relates phenomena by bringing observations, events, and facts into some meaningful relationship and order. There are several theoretical frameworks to consider such as behaviorism (e.g., behaviorist theory) or sometimes referred to as environmentalism, (Piaget's cognitive constructivism, and Vygotsky's social constructivism).

Researchers often find themselves focusing on a specific theoretical framework that guides their research to try to explain and predict certain phenomenon. Referring to an "environmentalist" perspective in terms of how students learn, researchers in this worldview believe that all knowledge derives from the external world (e.g., the environment) and the human mind is a tabula rasa (blank slate) on which environment writes and thereby the individual is "reactive" to a stimuli. Hence, from an environmentalist perspective, a students' knowledge is a function of his environment. It follows that a researcher can theoretically investigate what a student knows through manipulation of his or her environment. This particular worldview is all about behavior modification and discounts that learners can look inside themselves (i.e., reflect upon) and think. Feelings and opinions can't be studied from an environmentalist perspective. Researchers tend to focus on something observable and measurable with no attention on the individual. For example, a researcher can isolate teacher behaviors, tasks, activities, (e.g., control of the environment) as the stimulus and see how the individual reacts. For some, it is a perplexing thought to think that students are only driven by external stimuli with no regard to internal thought processes and emotion. While behaviorism maintained dominance for nearly 60 years, some more recent educators and scholars have the different belief that learners can look inside themselves and think about their own thinking between the environment (stimulus) and the behavior (response). In other words, learners have a choice and they can interpret what is occurring between the stimulus and the response.

This leads to a constructivist perspective or worldview in terms of how students learn. A constructivist theoretical framework fits well with the present study. Jean Piaget's theory of cognitive constructivism believe that individuals are "active" learners who construct meaning for themselves (e.g., self-created). For example, a constructionist view of a student's mathematical knowledge is a function of what the student constructs out of his own activity. The basic principles of Piaget's cognitive constructivism framework on how students learn encompasses the following: 1) it is stage dependent as humans learn best at certain developmental stages; 2) learning should be self-directed/self-initiated; 3) we learn best through *experimentation*, independent mastery, and plain old *discovery*; 4) children construct knowledge through their actions on the world; 5) and to understand is to invent. Wadsworth (1971) described Piagetian views and stated, “The child is a *scientist*, an *explorer*, an *inquirer*, and is critically instrumental in constructing and organizing the world and his or her own development” (p. 4). This statement is in agreement with the present study as students were engaged in various hands-on, experiential projects that allow them to explore, create, invent, experiment, and problem solve phenomenon as it related to aquaculture and aquaponics. Wadsworth (1971) also states, “The teachers’ role according to Piaget is to encourage, stimulate, and support exploration and invention (construction)” (p. 11). This aligns well with the present study and a PBI unit framework as teachers participating in the project encouraged students to explore and invent while facilitating the unit.

Clearly, different perspectives can greatly influence how research should be conducted and evaluated. The present study did encompass a constructivist theoretical framework that focused on the individual (e.g., student) and examined how he/she reflected upon and constructed knowledge through experience in the intervention. This study centered on students’ understanding, interest, and attitudes and interpretations using a quantitative methods approach. However, the study also considered the environmental factors present in the space where the study occurred. For example, the students who participated in the intervention adopted this procedure when assuming the roles of an aquaponics researcher. They tested environmental factors and its components that affect aquatic organisms and incorporated a control and treatment(s) during their student-driven investigations. The participants of this study were provided opportunities to study natural phenomenon and apply scientific understanding to solve authentic, real-world problems and trouble-shooting techniques were employed to solve them. Hence, these authentic experiences mirrored the actions of a real-world aquaculture scientist working in a laboratory and/or outdoor field setting. Likewise, students situated in a specific context where activity occurs (i.e., classrooms) may have a change in mental models through interactions with the physical environment and this might pertain to the classroom environments, school environment, community environment from where students come from, the students such as peer interaction, teacher instructional styles, role of the teacher and researcher that might have influenced the learning in any way, culture of the individual classroom, personal everyday experiences, collaborative tasks, and activities to name a few.

Of course, there is also a social component to consider as described by Vygotsky's social constructivism perspectives concerning how students learn which recognizes the social, cultural, and historical aspects of learning. It is important to note that while Piaget focused on the individual learning, Vygotsky focused on social constructivist view where individuals negotiate meaning with others in the learning environment. Vygotsky believed that mental development can be equivalent to what you can do with the assistance of others which refers to the zone of proximal development (Vygotsky, 1978). The thought is that what a child can do with assistance today she or he will be able to do herself or himself tomorrow. Vygotsky's theory emphasized the activity of both the teachers and students and the importance of a child interacting with people and his or her environment and/or collaboration with their peers to awaken learning. This aligns very well with the present study as students interacted with each other in a "teamwork" fashion (i.e., rotating jobs). For instance, students worked in small groups throughout the unit and monitored and analyzed water quality parameters (environmental scientist job) in the classroom. The goal was to promote social interaction and teamwork skills over time. The basic principles of Vygotsky's social constructivism framework on how students learn best focuses on: 1) knowledge is dependent on the instruction; 2) students learn best through an assisted learning process that leverages an individual zone of proximal development (ZPD); 3) students learn best through scaffolding; 4) and language is a critical component to development as students have to explain their findings. These principles align well with the PBI unit in the present project. Some of the critique within this framework is that it may tend to force the child to rely on others instead of thinking for themselves and it's important to consider the child's intrinsic interest as well. Indeed, theories are instruments and a researcher can find strengths of each perspective. The theoretical framework of the present study embraces the diversity of worldviews represented by constructivist and environmentalist perspectives represented in situated learning theory. Constructivist strategies are consistent with inquiry approach, discovery approach, and cooperative learning, instructional approaches that can be effective classroom tools to facilitate conceptual change (Cetin, 2003). Environmental and social constructivist perspectives encompass the influences of individuals and interventions inherent in these learning environments.

2.3.1 Situated Authentic Learning Theory and Practices. Situated learning theory was the specific theoretical framework that guided the present study. Situated learning theory stresses that knowledge is obtained through social processes situated in specific contexts, which is influenced by activities, interaction, and participation of the learner (Comas-Quinn et al., 2009; Edmonds-Cady & Sosulski, 2012; Lave & Wenger, 1991). Goel et al. (2010) defined the concept of situated learning theory as a change in mental models that happens through social interaction. According to the theory, a person constructs his reality by engaging his mental model based on the interaction with the physical environment that he is in by drawing on prior mental models to make sense of the environment, and by incorporating new information gained from the environment into existing mental models (Dartnall, 2005). They to argue that an enquiry into how people learn is pertinent to the physical environment. Lave and Wenger (1991) articulated that learning arises from participation in the learning curriculum of the community. The authors suggested that as newcomers increase their participation in the community, their knowledge and skills increase. A later study revealed that students who work in a collaborative learning environment (i.e., peer groups) are given opportunities to own the ideas they construct and experience as active participants within the community (Goos, 2004). Mohr-Schroeder (2014) stated that ideally, learning occurs in a community of learners in which participants are actively engaged and in which learners are involved in authentic activities. Brown et al. (1989) reported that situated learning theory explains that knowledge, thinking, and the contexts for learning are inextricably tied and situated in practice. Sawyer (2006) indicated that rather than treating knowledge as isolated content to be processed, elaborated, and retrieved, student-centered learning environments (SCLEs) promote authentic practices that situate knowledge-in-use. Barab and Duffy (2000) upheld previous research that contended students should be engaged in practicing the kinds of problems and skills that may be encountered in real-world, out-of-school contexts and communities. Bell et al. (2009) also affirmed that making connections to everyday contexts guides students to develop meaningful, long-lasting interests and understandings. Bransford et al. (2000) also were in agreement that when learning is anchored in everyday contexts, learners are more likely to understand how concepts are applied and why they are useful, thus facilitating transfer. In an earlier study, Grubb et al. (1991) reported that academic educators suffer criticism for developing curriculum that lacked opportunities for students to connect learning to real world events. Borko and Putnam, (2000) stated that that the educational research community has focused on how learning in schools might be better contextualized so that students may transfer knowledge to out-of-school settings. It is believed that SCLEs often utilize familiar problems or local issues to prompt personal theories and experiences and thereby activities and contexts that readily connect to learners' experiences are believed to increase relevance and engagement according to Land et al. (2012). Weaver (1998) reported that students found topics more interesting when they have some relevance to their daily lives or experience. Cetin (2003) acknowledged that students should be able to apply what they learn in school to their daily life situations. Conroy and

Walker (2000) interviewed students who participated in an aquaculture hands-on learning activity and found that they believed aquaculture had enhanced their academic performance in mathematics and science, and made those areas more relevant for them. Further, participants in this study believed that aquaculture also generated interest and visibility for them, and may have led to the increased likelihood of integration through enhanced interactions with other teachers and students. Barab and Duffy (2000) stated several ideas to promote better knowledge transfer and understanding which includes: students' need to be actively engaged in *learning by doing*, take ownership of the inquiry that is confronted to them, opportunities for reflection is crucial, students should work in teams, and be socially-driven and prepared to share their ideas. Edelson and Reiser (2006) is in agreement with Barab and Duffy (2000) who found that engaging in active *learning by doing* will become more obvious to the learner and thereby increase understanding. Interestingly, Edelson and Reiser (2006) suggest that the essential tasks for teachers when creating these learning environments is to situate authentic practices in meaningful contexts, reduce the complexity of authentic practices, make implicit elements of authentic practices explicit, and sequence learning activities according to a developmental progression. Savery (2006) stated that situated authentic practices are the core foundations and tied to hands-on project-based science and design in which students find solutions to an ill-defined problem and participate in project-oriented activities that can make connections to everyday life.

2.4 Authentic Hands-On Student-Centered Learning Environments (SCLEs) and Experimentation

Hannafin and Land (1997) reinforced the notion that SCLEs provide interactive, complimentary activities that enable individuals to address unique learning interests and needs, study multiple levels of complexity, and deepen understanding. Land et al. (2012) affirmed from published reports that SCLEs, tacitly or explicitly, are designed to support individual efforts to negotiate meaning while engaging in authentic activities and real-life learning research and practice. Furthermore, they acknowledged that SCLEs are grounded in a constructivist view of learning, where meaning is personally rather than universally defined and are related to situated cognition. Land et al. (2012) articulated that SCLEs favor rich authentic learning, student-centered, goal-directed inquiry, and it supports personal perspectives which is in contrast with other pedagogy such as fully-guided, direct instruction. In a well-designed SCLE, it has been shown that students are actively engaged in self-directed in which they may conduct an experiment, determine a solution based upon their own ideas, and then compare results amongst their peers or experts upon completion of their investigation, and reflect on the differences (Land et al. 2012). Likewise, they supported the idea that the activity typically allows students to make connections to everyday experiences, allows opportunities for students to collect real data, learners are required to make their own choices and build upon what they know, and most notably take responsibility for their own learning (Land et al. 2012). Research indicates that instructional environments that are learner-, knowledge-, and community-centered are the most conducive to support learning (NRC 1999). Wilhelm and Confrey (2005) stated that a project-enhanced classroom incorporates all these features, which when implemented with effective design and instruction create an ideal environment for learning. Research has shown that in traditional instructional environments, learners are often denied opportunities to develop the decision-making, self-monitoring, and attention-checking skills necessary to optimize learning experiences (Perkins, 1993; Sawyer, 2006).

Authentic hands-on activities allow learners to make connections to everyday experiences, provide students opportunities to collect real-world data which might be new to learners, requires learners to make their own choices and build upon what they know, and most notably taking responsibility and ownership for their own learning. Students engaged in authentic “agriscience” projects, such as aquaculture, either in a laboratory or outdoor field setting exposes them to real-world phenomena that they may not ever encountered before while engaged in hands-on activities. Hmelo-Silver (2004) emphasized that hands-on project-based science (PBS) activities are well suited to helping students become “active” learners because it situates learning in real-world problems that students can understand, see, and relate to within their everyday life. Hmelo-Silver (2004) expressed that PBS approaches to learning have a long history and one of many instructional approaches that situate learning in a meaningful task. Hmelo-Silver (2007) uttered that hands-on PBS activities frequently engage students in exploration and analysis of data that makes connections to the real world. Hmelo-Silver (2004) stated that in PBS, students engage in scientific inquiry cycles in which they design experiments, make predictions and observations, and then construct explanations of their predictions. Overall, research suggests that educators are very aware and interested in hands-on activities because of their emphasis on active, transferable learning and the potential for motivating students, which is essential for knowledge transfer.

Collaboration is another hallmark of student-centered learning environments like PBS. Students often work in small collaborative groups to solve a problem (Hmelo-Silver, 2004; Savery, 2006). In fact, collaborative learning is an essential component for these authentic learning environments. Hmelo-Silver (2000) suggested that the teacher is the facilitator of collaborative learning, and since students are self-directed, they are more prone to acquire the skills needed for lifelong learning.

One example of a project-based situated learning environment that can be implemented by an educator and facilitator of a specific unit (lesson) is to provide students opportunities to create a "constructionist learning environment" which is thought to be more meaningful and motivational when students collaboratively design and construct their own projects and take charge of the task at hand. This is in agreement with Bandura (1977) who poses theoretical support for constructionist learning environments, since it stresses group workings, observation, and social interaction within the process. It has been reported by researchers that these hands-on practical learning activities encourages knowledge-in-use and will ultimately foster deeper understanding for learners. In addition, technology tools that enable scientific measurement and collection of real-time data can be incorporated in these creative constructionist SCLEs for educators which will motivate learners and thereby increase their understanding (Clark and Estes, 1999; Flick and Bell, 2000; Delen and Bulut, 2011).

Notably, it has been suggested that authentic hands-on SCLE activities involving experimentation and problem solving "opens the minds" of learners to explore and thus, students become more motivated to learn various subjects such as mathematics and science (Frykholm & Meyer, 2002; Koirala & Bowman, 2003).

2.5 Strategy and Components of Project-Based Instruction (PBI)

Student engagement and interest in STEM learning have been demonstrated in student-centered instructional strategies such as project-based learning. Project-based instruction (PBI) engages students to design and carry out investigations that relate to a central driving question as they work together to solve real-world problems in their schools and communities (Blumenfeld et al. 1991). The driving question is the focus for scientific inquiry as students must determine how they will answer the question which leads to artifact production (Hmelo-Silver 2004). Blumenfeld et al. (1991) explained that students work as a team and pursue solutions to nontrivial problems by asking and refining questions, debating ideas, making predictions, designing plans (and/or experiments), collecting and analyzing data, drawing conclusions, communicating their ideas/findings to others, asking new questions, and creating artifacts to present their gained knowledge. Typically, artifacts include writings, art, drawings, three-dimensional representations, videos, photography, or technology-based presentations according to the authors. Polman (2000) stated that classrooms that incorporate projects enable learners to "think scientifically", where *learners* encompass both students and teachers. Markham (2011) describes project-based investigation (PBI) strategies as integrating knowing and doing. Students learn knowledge and elements of the core curriculum, but also apply what they know to solve authentic problems and produce results that matter. The author stated that a PBI strategy is to refocus education on the student and not the curriculum.

This may be such intangible assets as drive, passion, creativity, empathy, and resiliency which is notably activated through experience instead of taught out of a textbook. The benefits to the implementation of its strategies in the classroom include a greater understanding of the concepts, broader knowledge base, improved communication and interpersonal/social skills, enhanced leadership skills, increased creativity, and improved writing skills. The components of PBI includes a driving question, scientific investigations (e.g., actual student project), data collection and analysis, collaborative opportunities, and assessment techniques (Krajcik & Czerniak, 2014).

2.5.1 Driving Question. Rivet and Krajcik (2008) reported that a project-based instruction (PBI) model uses a driving question to introduce and structure the context of the project. Typically, the driving question serves as central linchpins of consecutive student investigative experiences and are returned to and highlighted throughout the unit. The driving question is often relatable to what scientists actually do, the phenomenon investigated are of interest to learners, connects with real world issues and student lives, and promotes community connections. Krajcik and Mamlok-Naaman (2006) stated that driving questions should address important content, be contextualized and meaningful to students, sustainable over weeks of instruction, and answerable. Marx et al. (1997) stated that real-world problems that students find meaningful may motivate them to take ownership of the questions, and thereby, thoughtfully pursue answers to them. In earlier study, Krajcik et al. (1994) summed it up well and reported the following: Good questions or problems are *feasible* (students can design and perform investigations to answer the question/problem), *worthwhile* (contain rich science content, related to what scientists really do, and can be broken down into smaller questions), *contextualized* (related to the real world, important), and *meaningful* (interesting and exciting to learners) (p. 486). Driving questions are not only used throughout science units to engage and motivate students by presenting them with a problem they perceive as worth investigating. They also are consistent with curriculum frameworks and thereby they support teachers to maintain curricular coherence by promoting student learning through explicit ties to standards and learning goals (Marx et al., 1997; Forbes & Davis, 2009). This is in agreement with Krajcik and Czerniak (2014) who reported in a more recent study that the driving question should help students' link core ideas, crosscutting concepts, and science and engineering practices (e.g., NGSS). Likewise, it is important that teachers provide students with the necessary materials and resources needed to conduct the student-designed investigations and find answers to their questions. Krajcik and Czerniak (2014) also indicated that the driving question should provide learners opportunities to pursue solutions over a period of time and in great detail. Typically, most teachers prefer projects that last about 6-8 weeks according to Marx et al. (1997) which aligns with the present study.

2.5.2 **Scientific investigation (e.g., actual student project)**. Another component of PBI are scientific investigations which provide students opportunities to engage in planning, designing, and conducting real-world research. These experiences are important for learning because they enable students' opportunities to participate in real-life situations to both learn and apply lesson content. A project-based environment is rich in group project work to improve students understanding of scientific and mathematical practices through problem solving. Likewise, a project-enhanced classroom (via make learning a project) provides hands-on laboratory experiences (via inquiry labs) for students to collect real-time data as students develop their understanding of the concepts while equipped with technological tools as opposed to simply lecture and worksheet work. Students in the classroom get the opportunity to collect and analyze data, draw inferences and conclusions, develop explanations, and reporting findings to others (Marx et al. 1997). The authors pointed out that investigations are not mere activities, but need to be open enough that the method and the answer are not known to students before beginning. The specific aspects of scientific investigations as described by Krajcik and Czerniak (2014) includes the following: learners are given opportunities to engage with phenomena, explore ideas, and ask and refine questions that can be investigated; students then have opportunities to make predictions about the results of their investigations and also find information that will provide direction for their investigation; students are involved in planning and designing investigation procedures and carry out and refine the procedures they design; and the authors suggested that students develop and revise models based on evidence as well as develop and revise explanations based on evidence and reasoning.

2.5.3 ***Data collection and analysis***. Another component of PBI is data collection and analysis. Krajcik and Czerniak (2014) reported that the specific aspects to consider regarding data collection and analysis during the student-centered investigations which includes the following: students are given opportunities to transform and/or analyze their data; students make claims based on evidence and reasoning; students develop scientific explanations using claim, evidence, and reasoning; students are given opportunities to share their ideas with others; and students are given opportunities to continue investigations beyond the initial question

2.5.4 *Collaborative opportunities.* Bruer (1995) stated that collaboration is an essential component of PBI as it provides opportunities for students to share ideas, extend their thinking, draw on the expertise of others, and experience the value of thinking intelligently. Krajcik and Czerniak (2014) described the specific aspects of scientific inquiry pertaining to collaborative opportunities which include: students obtain opportunities for collaboration that encourage them to generate ideas, questions, conjectures, and/or propositions; students engage in intellectual rigor, constructive criticism, and the challenging of ideas as evidenced in milestone/assessment sharing; students are given opportunities to support scientific argumentation and share diverse viewpoints amongst their peers; and students are given opportunities to collaborate with knowledgeable community members such as scientists, industry professionals, and government officials. In terms of how collaborative opportunities foster student interest, engagement, and learning, one might first focus on the teacher's role which is essential in order to accomplish these outcomes. Gasiewski et al. (2012) asserted that collaborative learning strategies require students to work together and is fostered by the engaging instructor, both in- and out-of-class. After engaging instructors explain a concept – for example, the way blood flows through the heart – they will ask students to get into groups and explain the concept to each other. Walking around the room allows the engaging instructor to gauge the general level of understanding while students personally evaluate their own ability to explain the way blood flows through the heart. The engaging instructor also facilitates student excitement in the classroom through humor, enthusiasm, and practical application. The excitement and passion for the subject is contagious, and students begin to have fun and learn in an environment that fosters interest in STEM disciplines. Group projects foster a collaborative spirit amongst students while encouraging students to process the material beyond the lecture. There is no limit to the things the engaging instructor will do to get students motivated in their STEM major and excited about the possibilities of pursuing a STEM career (p. 253). Marx et al. (1997) states that teachers in PBI structure the classroom environment so that students work in groups which is purposely done because group activities can foster collaboration as students' labor together to accomplish a task. The authors stated that teachers and students collaborate with each other as they work on investigations and artifacts (e.g., group presentations). Students who are provided collaborative opportunities in the present study intervention, using physical objects (e.g., recirculating tank systems) to help model the concepts in class, may view aquaculture and aquaponics STEM-related fields as enjoyable because the content can be applied to real-world problems that students can relate to, such as producing healthy vegetables and fish in their local communities (e.g., addressing food insecurity). Thus, object teaching strategies used in this study may not only help students understand the abstract concepts (i.e., carrying capacity and nitrogen cycle) through their collaborative experiences, but also get them motivated in STEM majors and excited and passionate about the possibility of pursuing a STEM career.

2.5.5 *Assessment techniques (or milestones)*. Assessment techniques is another component of PBI. Krajcik and Czerniak (2014) described assessment techniques within a project-based learning unit as follows: assessment techniques is a continuous process that is embedded in instruction and are multidimensional; students are engaged in the assessment process and encouraged to reflect on sub-driving question, investigation design, data analysis and manipulation, and their explanations and understandings; students response to the driving question should be obtained in the final product; the assessment encourages students to reflect on their thinking and thereby build metacognitive skills; assessments measure learning outcomes; and assessment methods are responsive to context and accommodates cultural diversity.

2.5.6 *Contextualizing instruction*. Contextualizing instruction while connected to problem solving is yet another feature of PBI. Rivet and Krajcik (2008) explained, "Within the project-based science model, there are four characteristics of contextualizing instruction" (p. 80). The first two characteristics are aligned to the present project which includes the use of problems and situations as a focus of the instruction that are meaningful to students, and that the meaningful problem provides a need-to-know situation to learn specific science ideas and concepts. In other words, students are motivated and have a reason to understand the content and engage in the authentic tasks as described by Krajcik et al. (2002). The third characteristic of contextualizing instruction, according to Rivet and Krajcik (2008) is the use of some form of anchoring situation or event to engage students with the scientific concepts that are addressed in the problem or situation. The anchoring event is revisited repeatedly during instruction and promotes memory recall (pp. 80-81).

2.6 How PBI affects Student Learning and Engagement of STEM

Rivet and Krajcik (2008) found strong evidence for the role of contextualizing project-based instruction (PBI) in science classrooms to support student learning. The study focused on two (2) eighth-grade classrooms using the framework of project-based science. The 10-week curriculum unit centered on the driving question, "*why do I need to wear a helmet when I ride my bike*?" The unit was designed to lead students through an inquiry into the physics of collisions, including the development of science concepts such as motion, velocity, acceleration, and force. The authors indicated that the driving question situated the project in a context familiar and important to many students – that of riding a bicycle and falling off. Kozma (1991) also found that contextualizing instruction supports learning by providing a cognitive framework onto which *students can connect or anchor ideas*. The author reported that use of *meaningful real-world problems* makes the learning situation "bushier" with more available links to connect information and relationships between new science concepts, prior knowledge and experiences, and real-world examples. Rivet and Krajcik (2008) also showed that not only did PBI motivate students, but also promoted students' thoughtful consideration of the science ideas and relationships. Overall, results from their study demonstrated that contextualizing PBI played a powerful role in facilitating student learning through both motivational and cognitive means.

Project-based science instruction has also been shown to affect student engagement. Blumenfeld et al. (1991) reported that a project-based learning model focuses on teaching by engaging students in investigation. The authors stated that PBI motivate and engage students when encountered with projects and the benefits of how technology can support students and teachers as they work on their projects. They reported that students are more engaged and more focused on the activities when exposed to contextualizing PBI. They explained that within this framework, students pursue solutions to nontrivial problems by asking and refining questions, debating ideas, making predictions, designing plans and/or experiments, collecting and analyzing data, drawing conclusions, communicating their ideas and findings to others, asking new questions, and creating artifacts. Furthermore, project-based learning places students in realistic, contextualized problem-solving environments (p. 371). Rivet and Krajcik (2008) indicated that contextualizing instruction utilizes particular situations or events that are of particular interest to students to motivate and guide the presentation of science ideas and concepts. Further, they reported that these are situations in which students may have some experience with (either directly or indirectly) prior to or in conjunction with the presentation of target ideas in science class, and that students engage with over extended periods of time.

The contextualizing aspects within a project-based model particularly aligns well with the present project. Students' activities in the classroom may connect with their real-life experiences and as a result, support their understanding of concepts. When learning is anchored in everyday contexts, learners are more likely to understand how concepts are applied and why they are useful, thus facilitating transfer (Bransford et al. 2000). In a project-based science model, students develop rich understandings of science concepts within the context of a contextualizing real-world situation guided by a driving question (Krajcik et al. 2002). Rivet and Krajcik (2008) reported the following: Contextualizing science instruction attempts to leverage students' prior knowledge and experience to foster understanding of challenging science concepts. Furthermore, contextualizing often takes the form of real-world examples or problems that are meaningful to students personally, to the local area, or to the scientific community (p. 80). Bell et al. (2009) also reported that making connections to everyday contexts guides students to develop meaningful, long-lasting interests and understandings. Bandura (1977) also suggest that these contexts provide meaningful connection to content because there is a goal-oriented purpose for learning and then applying the content in answering student questions or solving a problem.

An example in which students in the present project may have an interest that is relevant to their everyday life includes the closed recirculating aquaculture systems and aquaponics technologies (e.g., physical models) as these in fact may help their local communities to produce healthy fresh fish and plants. These physical models helps facilitate students learning about living organisms in situ (e.g., on site), ponder possible STEM career opportunities, and contemplate possible work opportunities for rural students and their families. Thus, creating connections to students' everyday experiences, connections to home, and cultural connections. Students were actively engaged with these indoor production systems over an extended period of time. Consequently, these anchoring events may help sustain their interest, promote memory recall, and be more meaningful as they work on their projects.

Students participating in the project were actively engaged in real-world investigations over an extended period of time. Hence, this aligns to a project-based instruction model according to Blumenfeld et al. (1991) who reported that project-based education requires active engagement of students' effort over an extended period of time. As mentioned previously, a signature goal of the present project was that students would be able to connect the science ideas and concepts to their everyday lives and the phenomena in the classroom is meaningful outside of school. For example, the project strived to have students understand a major global and local community challenge which is the need for edible fresh fish and plants as the population continues to grow worldwide. This assertion supporting cultural connections is in agreement with published reports (Rivet and Krajcik 2008; Bouillion and Gomez, 2001; Kozma, 1991; Lee and Songer, 2003). As a result, this concept alone may sustain their attention and interest and recognize that aquaculture is important to their local community, families, and world. While the majority of students who participated in the project had little direct or indirect experience in the field of study, they may be motivated to understand the content, target concepts (i.e., carrying capacity, nitrogen cycle), and engage in the authentic tasks throughout the unit.

Students participating in the present project were actively engaged in several common real world anchoring events such as collaboratively formulating plans, designing, and engineering an indoor recirculating aquaculture and aquaponics system in the classroom as mentioned previously. This common experience allowed learners to relate to new concepts and ideas while they worked in groups and developed a written and/or physical model of their proposed aquaculture filtration and aquaponics system prior to construction. As stated earlier, students were responsible of maintaining their recirculating system in the classroom over the duration of the project. Where problems arise they needed to be responsible to solve them and come up with a solution. Other anchoring events and experiences includes: investigating the phenomenon *carrying capacity*, engaging in water quality practices using real-world scientific instruments, stocking experimental fish and plants, recording data, keeping a log book, tracking progress, evaluating solutions, maintaining recirculating systems, sampling fish, and recording findings (weights, lengths, and total number, and harvesting). Furthermore, as mentioned earlier, they collaboratively harvested their fish and plants and recorded growth performance and feed efficiency data into their respective log books. Students worked in groups and created tables and/or graphs and then analyzed and interpreted the data as a group and then presented their findings in class. This particular anchoring event aligns with a project-based instruction model as there was a culminating experience students took part of at the end. Thus, this culminating event brings closure to the project. The anchoring events of the present project may result in: sustain students' attention, interest, and curiosity (e.g., engagement); promote recall; provide a purpose to know science ideas and concepts (e.g., need-to-know); and be aware that the tasks are relevant and meaningful to their lives and local community. The fourth characteristic of contextualizing instruction within the project-based science model is engagement with the meaningful problem over an extended period of time (Marx et al. 1997). This aligns well with the present intervention regarding the engineering, scientific, and mathematics practices that students were engaged in over the duration of the project.

Project-based instruction fosters students' ownership and engagement, and persistence in problem-solving. While this does not connect with the research questions in this study, the intervention was designed to foster in students a sense of project ownership and thereby improve accountability, since they were responsible for managing their RAS in the classroom from start to finish while working collaboratively in small groups assigned by their instructor (teacher). Further, these project-enhanced experiences may also foster in students' connections to real-world, practical problems that are meaningful to them personally, to the local area, or to the scientific community (e.g., cognitive framework; contextualized instruction).

The present study intervention engaged students' in real-life problem solving situations from the lens of those experiences an aqua-STEM professional would encounter at the workplace. The development of authentic, hands-on weekly job rotation activities in the present study intervention fits well with situated learning theory. It is important to note that more details concerning the implementation of rotating jobs and students collaborating in groups are presented in Chapter 3 under the Intervention (unit) Design section of this dissertation paper.

2.7 Integration of Academic and Vocational Subjects

Numerous researchers have reported that agricultural education, with its natural ties to the biological, chemical, and physical sciences is well-positioned to offer a rigorous and meaningful learning context for applied scientific principles (Balschweid & Thompson, 2002; Balshweid, Thompson & Cole, 2000; Conroy & Walker, 2000; Enderlin & Osborne, 1992; Mabie & Baker, 1996; Roegge & Russell, 1990). Mabie and Baker (1996) stated that "agriculture is by nature a hands-on discipline" and would seem to be a "perfect match for integration into the science curriculum." In an earlier study, Lankard (1992) reported that educational reforms of the Perkins Act encourage collaborations between academic and vocational teachers that can promote transformation of pedagogies toward creating student-centered multidisciplinary, authentic learning experiences. Similarly, Myers and Washburn (2008) found in their quantitative survey research study that a majority of agricultural teachers agreed that integrating science increases their ability to teach students to solve problems.

Studying authentic agricultural issues in science might also motivate students to learn. Conroy and Walker (2000) assert that in order for students to make sense of relationships and patterns, they need to perceive the knowledge as meaningful. This assertion builds on previous theorists' work on learning. Specifically, Bandura (1977) described the goal-oriented nature of human learning, underscoring the essentiality of knowledge to be meaningful for the solving problem at hand. Erickson (1995) asserted that the integration of disciplines helps support and enhance “brain-based learning” as it is a way to facilitate the brain’s search for patterns and connections. Similarly, Conroy and Walker (2000) refer to learning activities that create rich, goal-oriented learning contexts as *brain-based learning*. Taken together, these views suggest that curriculum integrating agriculture and science with authentic, hands-on activities may promote depth of understanding and problem solving in a variety of contexts.

It has been shown that integration strengthens students’ competencies in academic subject areas, critical thinking, and problem solving (Lankard, 1992; Lee, 1997; Mabie & Baker, 1996). Frykholm and Meyer (2002) reported that for students in either subject, the mathematical and science understandings that emerge are likely to be more deeply connected and understood if the two topics are integrated than if they are taught and learned separately. Frykholm and Meyer (2002) also articulated that today’s students need and deserve to know when, where, and how mathematics fits in real-world contexts and one way to help students gain this knowledge is to integrate mathematics with other school subjects whenever possible.

2.8 Integration of “Real-Life” Aquaculture Learning Activities with Academic Subjects

This section also supports the selection of an aquaculture/aquaponics system as the intervention that incorporates authentic, hands-on learning activities when integrated with academic subjects. Moreover, the section underscores the barriers of integrating aquaculture with academic subjects. Conroy and Walker (2000) stated that many educators view aquaculture education as an ideal vehicle to facilitate the integration of academic and vocational subject matter when it is infused into secondary or other agriculture curriculum. Research suggests that aquaculture is an effective "teaching tool" because it easily integrates many disciplines including biology, chemistry, economics, math, physics, and can provide hands-on experiences that complement academic theory (Conroy & Peaslely, 1997; El-Ghamrini, 1996; Wingenbach, 2000). Conroy and Walker (2000) reported that aquaculture provides experiential science and mathematics education to help meet demands for cross-curricular integration. Hence, this provides a basis for using aquaculture to create an authentic STEM PBI experience. Rosati and Henry (1991) found that when infused into high school agriculture curriculum, aquaculture integrates content standards in the disciplines for instruction in basic biology, chemistry, and mathematics concepts required for workers in technical jobs. Researchers have found that using aquaculture to teach principles of math and science through hands-on activities improves student interest and motivation (Conroy, 1999; Conroy and Walker, 2000; Mengel, 1999). Mengel (1999) indicated that "hands-on" science aquaculture activities provide unique opportunities and positive impacts on students and instructional programs and infusing aquaculture as a theme in agricultural education programs allows students to improve basic science and math skills by application and develop occupational skills when based on anecdotal evidence. Conroy and Walker (2000) are in agreement with Mengel (1999) who stated that teachers, students, and administrators viewed aquaculture as having potential to address workplace skills and promote youth development. Hence, the word "potential" evokes that more research is needed to support their assumptions like the current study.

Koirala and Bowman (2003) stated that the construction of learning and teaching units incorporating various disciplines designed around a theme provides opportunities for thematic integration. This may help reduce some of the barriers reported by other researchers. Conroy and Walker (2000) demonstrated that science departments were the primary partners in integration efforts for aquaculture teachers, however math teachers realized the value of infusing aquaculture into their curriculum, and teachers as a whole, felt that a change from the traditional agriscience emphasis resulted in more ability to develop cross-curricular opportunities.

In summary, this section cited position papers whose authors touted the worthiness of agricultural project integration in the science and mathematics disciplines. Their reasoning may appear sound, but little research is available to support these assertions. The purpose of the current study was to learn how an aquaponics unit affects student understanding of standard-based ecological concepts relating to carrying capacity and students' attitudes toward and interests in aquaculture and STEM fields. Findings from this study can provide evidence to support the views presented.

2.8.1 **Barriers for integration of aquaculture with academic subjects**. Research demonstrates that teachers believe time mostly impacts success of the integration of other disciplines (Myers & Washburn, 2008; Conroy & Walker, 2000). Notably, Conroy and Walker (2000) stated specifically that teachers believed that there wasn't enough hours in the day to work, take care of tanks, and discuss lesson plans with others. Myers and Washburn (2008) also indicated that a majority of teachers felt insufficient funding, concerns about large class size, support to plan for implementation, and personal lack of experience in science integration were barriers to integrating science concepts into an agricultural education curriculum. Frykholm and Meyer (2002) is in agreement as they stated that integrated lessons tend to be longer than traditional lessons, require labs or working space, and often involve more than one group of students and facilitating integrated learning opportunities across classes can be an enormous challenge. Grey (1993) also identified similar barriers as it was felt that agriculture teachers may not have strong backgrounds or may feel inadequately trained to teach academics such as science. Grey (1993) is in agreement with other reports who suggest that agriculture teachers might not have the necessary academic backgrounds to teach other subjects to some level of depth (Conroy & Walker, 2000; Johnson, 1996; Miller & Gliem, 1996; Miller & Gliem, 1993). Likewise, it has been found that most science teachers lack content knowledge in advanced mathematics and vice versa (Berlin, 1994; Mosenthal & Ball, 1992) and many teachers lack experience with integration models (Koirala & Bowman, 2003). Conroy and Walker (2000) specifically found that some teachers struggled with integration and indicated that teachers were inadequately trained to teach scientific aquaculture, and they often sought assistance from other science teachers and the teachers from this study expressed a lack of knowledge about teaching science and math and thus, had to rely on other teachers to enhance the rigor of their courses. Another barrier to integration that has been suggested is the physical isolation that exists between the agriculture teacher and their peers according to Grey (1993). Other researchers suggested that agricultural education is considered inferior and nonacademic and territorial issues exist which ultimately hinders collaboration between the various departments (Inger, 1993; Wendt, 1994; & Shelley-Tolbert et al., 2000). However, when teachers work together, cooperation and resource sharing increases and thus, the potential for collaboration between agriculture and science teachers is tremendous according to Wendt (1994). Interestingly, Frykholm and Meyer (2002) found that a team model approach in which more teachers bring various perspectives and increased content expertise in particular, to the collaborative effort is very advantageous as teachers are not required to possess deep content knowledge in both mathematics and science. It is well supported in the literature that professional collaboration is an essential component of successful schools (Leonard & Leonard, 2003; Leonard & Leonard 2001; Little, 1982) and it has been shown that administrators play a crucial role in effective collaboration as adequate administrative support is directly correlated to successful integration according to multiple studies (Conroy & Walker, 2000; Thompson, 1998; Thompson & Balshweid, 1999, 2000). Myers and Washburn (2008) reported that the collaboration among teachers for resources, instructional ideas, and exploring external funding opportunities that involve science integration is very important; while Conroy and Walker (2000) concluded that the key ingredient for effective integration did not lie solely with aquaculture, but successful integration was possible when individual teachers made it happen. Conroy and Walker (2000) also demonstrated that in schools where teachers felt they had administrative support, or where aquaculture was a theme for integrated instruction, time and other issues mentioned previously related to integration and planning were at least partially resolved; however, in schools lacking support, teachers were found to be only as successful as their individual efforts.

2.9 Alternative Ideas Students may have Towards Aquaculture and Aquaponics

While the selection of an aquaculture/aquaponics system is the prime physical object(s) in the intervention to help students understand the concepts along with foster engagement, it is very likely that some students who participated in the project harbored naïve ideas or simply a lack of understanding about aquaculture and aquaponics and may not have grasped the importance that humanity faces major global challenges today, such as the need for safe and clean aquatic food throughout the world. The world population is now over 7 billion people and is projected to climb to 9.5 billion in twenty years (2040). In an earlier report, aquaculture researchers indicated that population growth had increased to the point that capture fisheries alone could only fill two thirds of the current demand for fish, thus almost all future demand will have to be met by aquaculture (Tidwell & Allen, 2002). Students in the project who are from small rural towns in

Kentucky may have also been unaware of the impacts aquaculture and aquaponics can have on local communities. Likewise, lack of awareness of the many potential educational and STEM-related career opportunities that exist today. Some common student naïve ideas or lack of understanding surrounding aquaculture and aquaponics include the following (but not limited to): 1) Aquaculture and/or aquaponics grown in a controlled environment is not a sustainable and viable agriculture practice; 2) aquaculture as a potential food supply is not necessary for the world's growing population; 3) better to obtain fish to eat from wild fish caught environments (i.e., wild versus farmed fish debate); 4) cultural ignorance of some edible fish such as tilapia (commonly used in aquaponics); 5) the ocean is an infinite food resource which is untrue; 6) news about overfishing and shortage of fish populations is phony; 7) aquaculture practices is notorious of releasing pollution and waste into the environment (i.e., environmental-related issue); 8) diet-conscious consumers perceive that fish and plants grown in a closed system may be unsafe to eat; 9) farmed-raised fish taste bad compared to wild caught fish; 10) wild caught fish is much safer to eat compared to fish grown in a controlled environment; 11) fish producing ecosystems are always grown in dirty water and crowded conditions and subsequently harmful on the aquatic organisms; 13) aquaculture is not economical and worthwhile to do often causing overuse and waste of water and natural resources; 14) and aquaculture producers do not care about the environment. Students in the project may have read or heard about some of these viewpoints on the internet, television, local or national newspaper, magazine articles, and information from other media outlets.

Although this was not directly connected with the three research questions, a long-term goal is that students participating in this study may change their naïve impressions and understanding of aquaculture through their own classroom investigations relating to the phenomenon *carrying capacity* and subsequently find answers as a group or individually as it relates to these potential ideas. Overall, students were to find their group and whole-class discussions with the instructor engaging because they can openly share their ideas, concerns, and findings in the classroom. A goal is that they would hear other viewpoints from their peers which might offer new ideas for them to explore and ponder, and thereby, eliminate potential alternative ideas they may have been harboring.

2.10 Aquaculture Production Systems

Students in the present project examined a sustainable aquaculture and hydroponic (i.e., aquaponics) system in the classroom. Valenti et al. (2018) defined sustainability, "as the management of financial, technological, institutional, natural and social resources, ensuring the continuous satisfaction of human needs for the present and future generations" (p. 402). The author defined sustainable aquaculture, "as the cost-effective production of aquatic organisms, which maintain a harmonious and continuous interaction with the ecosystems and the local communities" (p 409). The authors state that the aquaculture production system should be productive and profitable, generating and distributing benefits, and should optimize the use of capital and natural resources, conserving the surrounded ecosystems. They also report that the aquaculture production system should generate employment for local communities, increasing the quality of life, respecting the local culture, promoting human development, and should be resilient in order to persist over time. Students learning the curriculum were to understand a major global and local community challenge which is the need for edible fresh fish and plants as the population continues to grow. It should be noted that aquaculture is one of the fastest growing food-producing sectors worldwide and provides slightly more than half of all fish for human food (FAO, 2016). Aquaculture is the farming of aquatic plants and animals (Nash, 2011) and in recirculating aquaculture, water is cleaned and recycled in a closed-loop system (Timmons & Ebeling, 2007).

In terms of fulfilling human needs worldwide, Froehlich et al. (2018) report that to satisfy the protein demands of an anticipated nearly 10 billion people by 2050, the United States Nation’s Food and Agriculture Organization (FAO) and researchers around the world estimate current animal production will need to grow by an average of 52%. Meeting this need without pushing the environment to the brink is critical, according to the authors. Interestingly, new evidence from this study shows seafood from aquatic farming (e.g., aquaculture) can help feed the future global population and to satisfy the protein demands while substantially reducing one of the biggest environmental impacts of meat production –land use-without requiring people to entirely abandon meat as a food source. The authors in this study found that the amount of cropland required to support future protein needs with more farmed aquatic animals would be significantly smaller than if terrestrial livestock production met those needs. Land savings would be achieved because fish and other aquatic animals are extremely efficient at converting feed to biomass for human consumption. For example, a cow requires anywhere from six to thirty-plus pounds of feed to gain one pound of biomass, while most farmed fish need just one to two pounds of feed to do the same. This efficiency translates into much less cropland required to grow feed for the fish that people eat (Froehlich et al. 2018). Students in the present project were to understand and make connections to this very important concept through their real-world authentic experiences in the classroom while learning how to calculate feed conversion ratio (FCR) in the classroom.

2.10.1 Indoor recirculating aquaculture systems. Students in the present project learned that indoor recirculating aquaculture production systems provide new opportunities for agricultural operations throughout the nation and world as they were exposed to intensive indoor recirculating aquaculture systems (RAS) both inside and outside (e.g., aquaculture demonstration tours) the classroom. Students were to gain knowledge and skills of closed recirculating aquaculture systems (RAS) and how they can be designed to raise large quantities of fish and plants in a relatively small volume of water after they design, set-up, and manage their own small-scale systems. Students were to understand from the curriculum taught that aquatic farmers can rear aquatic animals in a variety of culture systems and new technologies for indoor recirculating systems is the wave of the future to produce fresh fish and plants. Students learned how indoor RAS provides growers the ability to grow aquatic animals in a controlled environment, the ability to recycle and conserve water, and it even allows protection from cold weather for warm water fish species such as tilapia.

2.10.2 ***Aquaponics production systems***. Students in the present project also learned that aquaponics production systems are one of the fastest growing new industries and has become an emerging field of study at the university level across the globe. Bernstein (2011) stated that aquaponics is a technique for food production that combines aquaculture and hydroponics in a symbiotic relationship. The author indicates that combining hydroponics and aquaculture allows the chemical nutrients needed for hydroponic plant growth to be replaced with fish wastes that might otherwise be discharged and cause potential environmental degradation. Hart et al. (2013) stated that aquaponics allows possibilities to raise both fish and plants together in a balanced system that closes the aquaculture waste stream and adds a second source of income from plant harvests. The authors indicate that as a sustainable food production technology, aquaponics can play a key role in increasing the availability of nutritious food in present and future food systems. Graham (2003) reported that consumers are becoming more aware of the impact of their food choices on both their own health and the environment, and aquaponics systems may be able to meet the needs of this growing market. Hart et al. (2013) report that increasing consumer awareness of food choices, combined with the flexibility of aquaponics technology, places the aquaponics industry in an advantageous position for future growth. Students in the present study were to link their indoor recirculating aquaculture system with hydroponic vegetable, flower, and/or herb production. The students' closed aquaponics systems which integrate aquaculture with hydroponics, served as model of a sustainable food production system. Hence, aquaponics provides a framework for cross-cutting and multi-disciplinary learning; students gain an in-depth learning experience in a number of growing workforce fields. Students were to become more aware after participating in the project that aquaculture and aquaponics will likely play a key role in feeding the earth's growing population. Through experiences with aquaponics, students were to understand the needs of living things (e.g., inputs and outputs of fish, plants, and bacteria) and how they interact within an ecosystem and see that every living thing performs a function. For example, students learned that the plants perform a needed function for the fish and is centered on a shared resource, i.e., water. Students also learned about certain nitrifying bacteria that make nitrogen available for the plants (e.g., nitrification process). Hence, students learned how an aquaponics system works, what aquaponics is, and why aquaponics is efficient and popular among educators and food producers nationwide. Students were to make sense of a sustainable agricultural system from aquaponics as plant and animal agriculture are integrated. Students were to understand how these intensive culture systems reuse the water many times and non-toxic nutrients and organic matter accumulate. Students were to grasp the concept that these by-products need not be wasted and can be channeled into secondary crops that have economic value. Students were to gain knowledge of the many benefits of aquaponics systems which include (but not limited to): a) Dissolved waste nutrients excreted directly by fish or generated from the microbial breakdown of fish wastes are recovered by the plants and thereby reducing discharge into the environment (e.g., minimizing pollution); b) daily water exchange rate is reduced in closed recirculating systems, and thereby, reduces the costs of operating these systems in arid climates and heated greenhouses where water or heated water is a significant expense; c) daily application of fish feed provides a steady supply of nutrients to plants; d) nitrate is the preferred form of nitrogen for growing higher plants which is relatively harmless to fish. Hence, students were to learn how these technologies addressed through engineering can have a significant impact on society and the environment overall. Driver (2006) states the following: Aquaponics serves as a model of sustainable food production by following certain principles which include: the waste products of one biological system (e.g., fish tank) serve as nutrients for a second biological system; the integration of fish and plants result in a polyculture that increases diversity and yields multiple products; water re-use through biological filtration and recirculation; and local food production provides access to healthy foods and the local economy enhancement (p. 1). These principle aligns well with Valenti et al. (2018) definition of sustainable aquaculture. Overall, as stated previously, a long-term tangible learning goal after completion of the project is that students are able to relate their experiences and make connections to the natural environment outside of the classroom.

2.11 How the Project Contributes to the Scholarship of Engagement

The scholarship of engagement corresponds to the situated learning paradigm by making connections with real-life problems and providing practical and meaningful experiences to learners' which can increase relevance and engagement. It also ties in with integrating agriculture in science when considering the career pathway model.

Introducing students to agricultural issues such as food shortage in local communities, in addition to solving problems that may arise in aquaponics systems (e.g., engineering design practices), present authentic situations for students to learn about careers in agriculture and STEM. Several educators in this review who promote higher education suggest that curricula should be more connected with real-life community concerns. It seems logical to start with Ernest L. Boyer and highlight some of his explanations and ideas of this emerging concept.

Boyer (1996) states: Our universities and colleges remain the greatest sources of hope for intellectual and civic progress in this country. I'm convinced that for this hope to be fulfilled, the academy must become a more vigorous partner in the search for answers to our most pressing social, civic, economic, and moral problems; and must reaffirm its historic commitment to the scholarship of engagement. (pp. 18-19). As Boyer (1996) explained, Colleges and universities must become more actively engaged with the nation's schools (p. 30). From the author's perspective, every college and university should view surrounding schools as partners. Oftentimes, Boyer suggests, there is an apparent detachment that exists between the university and those individuals and communities outside the academy. Clearly, the author is emphasizing the importance of partnership and suggests that secondary schools in particular often fail due to the lack of these relationships. This leads back to Boyer's account of the *scholarship of engagement*. What does this term actually mean? Spanier (1997) makes the related observation that, "the scholarship of engagement entails reciprocal relationships between universities and communities and is a partnership through which the university opens itself up to society" (p. 8). Notably, he was among the first to articulate the value of integrating the teaching, research, and public service missions: "…it is through their synergies that we will create and support the broad-based and active learning community that is best prepared to cope with society's challenges" (p. 8). Barker (2004) states that the scholarship of engagement is understood to consist of research, teaching, integration, and application scholarship that incorporates reciprocal practices of civic engagement into the production of knowledge. Roper and Hirth (2005) evaluated Boyer's (1996) conception of engagement as "a new twist for higher education: the two-way street of interactions or partnerships between the academy and the outside" (p. 12). Sandmann (2008) also attempted to conceptualize the scholarship of engagement and suggests that it incorporates principles of bidirectional reciprocity expressed through campus-community partnerships, which mirrors what others were theorizing. While there are many others who have studied the concepts of the scholarship of engagement coined by Boyer, it seems sensible to go back to the beginning and dig a little deeper in to Boyer's actual interpretation of the scholarship of engagement for personal clarification. Boyer (1996) states the following: At one level, the scholarship of engagement means connecting the rich resources of the university to our most pressing social, civic, and ethical problems; to our children, to our schools, to our teachers; and to our cities. Campuses would be viewed by both students and professors not as isolated islands but as staging grounds for action. But at a deeper level, the scholarship of engagement means creating a special climate in which the academic and civic cultures communicate more continuously and more creatively with each other, helping to enlarge what anthropologist Clifford Geertz describes as the universe of human discourse and enriching the quality of life for all of us (pp. 32-33). Boyer (1996) explains, the words *practicality* and *reality* and *serviceability* describe the mission of higher learning which is simply, the scholarship of engagement" (p. 19-20). The Kellogg Commission 1999 Report on the Engagement Scholarship.org website defines engagement scholarship as follows: An engaged institution is responsive to the needs of today's students and tomorrow's. It enriches the student experience by bringing research into the curriculum and offering practical experience in the world they will enter. It forms partnerships of faculty, students, and communities to put knowledge and skills to work on today's most critical problems.

The next section more explicitly explains how the present aquaculture project provided experiential learning opportunities to youth, promoted the role of extension, and further contributed to the scholarship of engagement through discovery, integration, knowledge sharing, and application.

2.11.1 Discovery. One way the present project contributed to the scholarship of engagement was by forging partnerships between a Land-Grant university and four K-12 school systems in Kentucky. The university reached out, collaborated, and strived to create a strong K-12 outreach ag-STEM education model program as it related to aquaculture. This endeavor supported one of the university's strategic goals, which is to build stronger partnerships between the university and K-12 school systems, and enhance the institutional teaching, extension, and research mission. Students participating in the project were exposed to rich, authentic learning experiences dealing with "practical" things as it related to aquatic science education. Hence, this partnership strategy afforded students who were actively engaged in the intervention (three student groups total) with real-life, practical, hands-on learning opportunities in the classroom. Hence, they were actively engaged in "learning by doing." These experiential learning opportunities enabled students to discover (or uncover) new ideas and concepts related to the phenomenon *carrying capacity* and, STEM in general, while using aquaculture and aquaponics in particular as a teaching tool. Students discovered the broader educational and career opportunities in the agricultural sciences firsthand. Ultimately, the goal of the project was that this linkage may promote better knowledge transfer of the targeted concepts and help develop the next generation of scientists and leaders in the workforce. This aligns with Boyer's (1996) new paradigm of scholarship, which include one of four essential, interlocking functions: "the *scholarship of discovery* (e.g., discover knowledge through research)" (p. 26). Students in the present project were able to share their ideas amongst their peers and engage in *discovery learning investigations* that mirrored the research practices of real-world aquaculture scientists and the practical aspects of aquaculture producers (e.g., farmers). For example, students in the classroom were engaged in a real-world project and had to engineer and construct their own recirculating aquaculture systems (RAS) at the beginning of the unit. Small groups of students unified and created a written or physical concept map (e.g., model) prior to assembling them. Then, the entire class came to an agreement on the system design components. In addition, students monitored fish growth and performance, feed efficiency, engaged in water quality management, and collected and analyzed the data over the duration of the project. Hence, learners were given opportunities to discover, problem solve, and take ownership of their research-based practices while collaborating with university educators trained in such research.

2.11.2 Integration. Students in the present project were engaged in multidisciplinary, experiential learning opportunities that were integrated into a science curricula facilitated by the teachers. Due to the nature of active participation in these inquiry-based environments, learning was rich in personal meaning and contextual connections. This leads to Boyer's second function. Boyer (1996) stated that while research is essential, we argue that it is not sufficient, and propose a second priority, called the "*scholarship of integration*." There is an urgent need to place discoveries in a larger context and create more interdisciplinary conversations in which the energies of several different disciplines tend enthusiastically to converge (p. 27). Boyer expressed this as integrating knowledge and bringing disciplines together to find interesting patterns, relationships, and solutions to a problem. In the present project, students were engaged in integrated, *multidisciplinary* investigations that encompassed science, technology, engineering, and mathematics (STEM) while meshed with aquaculture and aquaponics. For example, students had opportunities to *do* science integrated with *technology*. Namely, technology was used to support student investigations of research data pertaining to carrying capacity through real-time data collection by the use of portable handheld probe devices for water quality management. Hence, this multidisciplinary project reflected an innovative approach as students who participated in the project were exposed to evidence-based STEM education practices. The idea of converging STEM with an agriculture-based phenomenon is exactly what Boyer was advocating in regard to the aspects of scholarship integration.

2.11.3 ***Sharing knowledge.*** The present project is to be a noteworthy example of Boyer's third function: faculty and staff, and knowledge in linkage to Kentucky K-12 schools, teachers, and students. Boyer (1996) states: Beyond the scholarship of discovering knowledge and integrating knowledge, we propose the third priority of <u>sharing knowledge</u>. Scholarship, we say, is a communal act. Academics must continue to communicate, not only with their peers, but also with future scholars in the classroom in order to keep the flame of scholarship alive (p. 27). Boyer (1996) explains that many secondary schools across our nation lack necessary resources. Teachers are required to spend their own money each year in buying essential school supplies. Thanks to a federally funded grant awarded to the Land-Grant institution, schools and teachers participating in the present project were provided resources for students to carry out their carrying capacity investigations, which included, but were not limited to, a 270-gallon recirculating aquaculture tank system, a hydroponic tray, air and water pumps, submersible heaters, tubing, PVC fittings, various biofiltration media, water quality testing equipment, aquatic animals (Koi carp), plants (summer crisp lettuce), and beneficial bacteria. The researcher also shared his knowledge to participants about aquaculture and offered support through face-to-face interactions and/or video-based lectures that relates to their hands-on aquaculture activities. While it does not reflect the research questions in the present study, a long-term goal is that student groups will discover and integrate knowledge and then freely share what they learned with others (i.e., friends, families, and community). Therefore, the project may help improve a social condition within their own communities.

For example, students may become more aware of how to feed the homeless in their communities from their experiences in the classroom while investigating the phenomenon under study. Boyer (1996) made the point that sharing of knowledge should be an essential part of each project to add to its worth and avoid discontinuity. The researcher in the present study hopes to publish this work in the future and share the information to others who might consider integrating aquaculture and aquaponics into a secondary classroom. In addition, educators in higher education could use this project as a template and create a similar ag-STEM outreach model in the future. Hence, the present project may positively influence other institutions to partner with K-12 schools, teachers and school administrators, as well as intertwining with communities. Thereby, these efforts will indeed contribute to the scholarship of engagement.

2.11.4 *Application*. Students participating in the project were to see the relevance of aquaculture and aquaponics and the need for clean and healthy food as they learned more about this exciting ag-STEM career field. Students who were exposed to the short-term project-based curricula learned how aquaculture and aquaponics plays a key role in feeding the earth's growing population. Further, students in the project were to not only be attentive to the global challenges humanity faces today, but understand how the production of fish and plants can impact their own communities. While it does not directly reflect the research questions in the present study, a long-term goal of the project is to increase students' awareness of the role agriculture has on our society. This leads to Boyer's fourth function, which he calls "*the scholarship of application*." Boyer (1996) stated: Finally, we call for the application of knowledge to avoid irrelevance (p. 27). Boyer promotes the view that an engaged scholar should direct their work toward humane ends. Basically, the author is suggesting that those in higher education should work toward identifying a practical need, investigating it, then trying to solve the pressing issue(s) within a community. As Boyer (1996) explained, I'm convinced that in the century ahead, higher education in this country has an obligation to become more vigorously engaged in the issues of our day, just as the land grant colleges helped farmers and technicians a century ago (p. 28). Boyer stated, Work must be directed toward larger, more humane ends that are practical and useful (p. 28). The present project enriched the student experience by offering practical, hands-on experiences in and outside the classroom. Students participating in the project made usable connections to real world applications. For example, while investigating the phenomenon under study, students gained STEM knowledge and skills in the classroom. A goal of the project was to spark “enthusiasm” and “excitement” among the participants and thereby increase their interests in STEM in general, and aquaculture and aquaponics in particular. Further, they might enter the STEM circuit workforce after graduation and/or pursue a STEM-related major in college. These goals do indeed reflect the research questions in the present study. While it does not directly reflect the research questions in the present study, long-term goals of the project includes: students’ authentic experiential learning experiences will promote recall and apply important aspects of the project years later in life; students have enduring understandings of how aquaculture can enrich the quality of life within their own communities; students understand that their collective actions and what they do in the classroom is meaningful and they are potentially addressing issues of public concern (e.g., civic engagement); students see the “big picture” and share their knowledge and skills with others. Consequently, practical knowledge and skills about aquaculture and aquaponics in particular, and STEM aspects in general, are disseminated from higher education to partnering K-12 schools, teachers, students, families, friends, and then to the community. Unfortunately, many children and families in our cities and country today are malnourished due to a shortage of readily available and affordable healthy food. While it does not directly reflect the research questions in the present study, the long-term impacts of the project may help solve a pressing problem and effect social change in a community. This would be a very rewarding long-term outcome to see in fruition from the researcher's perspective. The researcher is hopeful that the participants' unique experiential learning opportunities, while collaborating with an engaging institution (higher education), is practical and useful to the world they will enter after high school. Further, learning can be applied to real-world situational needs that extends beyond the classroom and effects positive social change within a community.

2.12 Student Learning Outcomes

The project seamlessly integrates STEM disciplines to create a transdisciplinary intervention where learning ecological, mathematical, and technical content and skills is goal-oriented in order to successfully maintain the systems. Students gain experience in engineering, system design and maintenance; become proficient in performing scientific tasks; and extend their understanding of the scientific research process upon conclusion of the project. Hence, the project strived to strengthen the student learning experience by using authentic aquaculture/aquaponics intervention models (e.g., physical objects rearing living and moving things) to foster their native interests while learning by doing via hands-on experiences in the classroom. Overall, the study examined if students' inquiry-based experiences in a "real-life" situation fosters positive learning outcomes based on evidence. Student participation in real-world phenomena and their authentic research-engagement experiences in the classroom may serve as a vehicle for learning as they transition through high school and beyond. Thus, effects or consequences (i.e., student learning outcomes) may happen as a result of participation in the project and meaningful learning may occur as students will be able to connect the basic concepts to their prior knowledge and real-life experiences. As a result, those areas become more relevant for them (i.e., contextualized instruction) and students' real-world investigations in the classroom is meaningful outside of school and thereby developing long-lasting interests toward aquaculture and aquaponics or other STEM-related pursuits.

As mentioned previously, other long-term overarching goals of the project that is not connected to the research questions, is that numerous science and agriculture teachers may implement this curricula unit at their respective high schools and potentially be offered as a dual-credit college course for 9-12th grade secondary students in the future. Further, participating teachers in the project will continue to use their aquaponics systems in their classrooms to teach biology, sustainable foods, and inquiry instruction for years to come.

2.13 Personal Comments by the Researcher

It is my hope that the benchmark lessons/activities used to scaffold understanding and the authentic, hands-on experiential learning experiences students take part in will *stick* with them for years to come and they get involved in science and agriculture throughout high school and beyond. This aquaculture project allowed students to gain knowledge and experience that will hopefully be valuable to them for the rest of their life. It would be exciting to become aware of a number of students that go on to pursue higher education and careers in STEM such as aquaculture and feel that this project helped foster their interest. Further, it would be really rewarding to hear later down the road that those students who participated in this short-term project-based unit became interested in engaging in their food through and persuading their families and friends into raising fish and plants in their local communities. Further, some interested and motivated students may be offered an opportunity to stay in the community and find employment that connects to a STEM-related field. This is especially important considering our world is increasing in population making food scarcity a real issue. Thus, students learning about aquaculture, aquaponics, and “living” aquatic ecosystems may help address food insecurity and thereby provide solutions to the problem and they are also more sensitive to environmental issues within their community. Further, it would be exciting to know that teachers develop an after-school aquaponics club, for example, with their students that grows food for local community organizations. A longitudinal study would be interesting to explore later down the road.

CHAPTER 3. METHODOLOGY

This chapter provides detailed information on how the research questions associated with this study were investigated. The first sections of this chapter elaborate on the research design, a thorough description of this study's population and sample, and an outline of the instruments that were utilized to collect data, the data collection, and the data analysis. The later sections elaborate on the authentic, hands-on intervention (unit) design and concludes with reflections by the researcher.

3.1 Research Questions

Three (3) central research questions guide this quantitative methods inquiry in an effort to examine how experiences with the aquaponics project might affect participants' attitudes, interests, and knowledge transfer of ecosystems. These questions follow:

1. How does participation in the aquaponics project-based unit affect high school students' attitudes toward STEM in general, and aquaculture in particular, as a result of their direct experiences in the project? (e.g., self-reported engagement, interest, attention, curiosity, drive, passion, and enjoyment)
2. How does participation in the aquaponics project-based unit affect high school students' interest toward a STEM-related discipline and/or career pathway as a result of their direct experiences in the project? (e.g., short-term academic and career aspirations, decisions, actions, choices)
3. How does participation in the aquaponics project-based unit affect high school students' understanding of standard-based ecological relationships and concepts as a result of their direct experiences in the project? (e.g., knowledge of

ecosystem processes and their interactions among biotic and abiotic factors, bacterial nitrification process, carrying capacity)

The central questions focused on three aspects of the aquaponics experience. These included: 1) attitudes (e.g., feelings/emotions/opinions); 2) future career pathways (e.g., interest, actions, career choices); 3) understanding of interdependent relationships in ecosystems (e.g., knowledge of ecosystems and their interactions, bacterial nitrification process, and the concept carrying capacity). The *single concept* explored was students' perceptions and experiences in whether meaningful learning occurred after their participation in the project.

3.2 Research Design

Specific research designs focus on data collection, analysis, and writing and the possibilities for researchers may include case study. Creswell (2014) states that case study involves a detailed description of the setting or individuals, followed by analysis of the data. He goes on to say that, "case studies are a design of inquiry found in many fields in which the researcher develops an in-depth analysis of a case, often a program, event, activity, process, on one or more individuals" (p. 14). As mentioned previously, data were collected by means of a pre- and post-survey questionnaire containing 12 response items and pre- and post-content-aligned response assessment to test the research questions associated with this study quantitatively and thereby measured the outcomes (i.e., dependent variables).

A multiple case study was employed in the present study, since the goal was to compare the independent variable student groups across different school environments. It is important to note that the unit of analysis was at the level of *the student* and not the teacher or school even though teachers are factors that can affect student outcomes. Likewise, the school environment is another important factor to consider concerning the school demographics, administration (supportive or not supportive), class schedules, class frameworks, etc. which can also affect how the unit is implemented. Overall, different groups of students across separate school classrooms were analyzed (i.e., independent variables in the experiment) creating a multiple case study as described by Stake (2005). Each school was a case when assessing the effects of APBI on student learning and their attitudes and interests toward STEM and aquaculture.

However, it is important to note that the selection process for student participants were nonrandom (e.g., conveniently selected). Since the students in this study were not randomly assigned, the procedure is commonly called a *quasi-experiment*. Creswell (2014) states that, "In many experiments, only a convenience sample is possible because the investigator must use naturally formed groups (e.g., a classroom, and organization, a family unit) or volunteers" (p. 168). Therefore, the specific type of experiment in the present study was a *quasi-experimental design*. The researcher used naturally formed student groups who met in four different learning spaces (i.e., classroom) and they were in separate schools. Thus, there were multiple cases in this study containing three independent variable student groups that were engaged in the APBI intervention (i.e., treatment groups) and one independent variable student group that did not engage in the APBI intervention (i.e., control group).

In summary, this study completed a cross case, quantitative comparison of similarities and differences amongst the school groups and the participants within these groups were conveniently selected (e.g., quasi-experiment). The outcomes in the study were first examined by themselves (per class/group in each school) and then a cross case comparison amongst the groups in that order. The specific experimental design procedures used in this study was a quasi-experiment that typically compares two or more groups (i.e., between-subject design). The researcher used a control and three experimental groups, but did not randomly assign participants to groups. They were intact classroom groups available to the researcher prior to the study which makes this study a quasi-experimental design.

3.3 Population and Sample

The students described in this study were ninth and tenth graders from four different mid-south United States public high schools and they were not from the same school district. As mentioned previously, there were three different classrooms that represented the treatment groups (Groups 2, 3, and 4) and these students participated in the ten-week APBI unit in their science classrooms. It is important to note that the APBI intervention was part of their science classroom instruction and all students participated. The study also employed an outside control group of students (Group 1) who had no exposure to the APBI intervention. The selection process for participants in this study was nonrandom (i.e., conveniently selected) and the researcher used naturally intact classroom groups.

3.3.1 **Starting Population**. There were 109 students at the beginning of the study, 40 students total in the control group and 69 students total within the three treatment groups (i.e., full student population). To clarify the starting population of each group, Teacher A (Group 1) began with 40 tenth graders contained within this control group; Teacher B (Group 2) began with 22 tenth graders and two ninth graders (same age group as the 10th graders) to round out a class of 24 contained within this treatment group; Teacher C (Group 3) started with 18 ninth graders contained within this treatment group; and Teacher D (Group 4) started with 27 ninth graders contained within this treatment group. It is important to note that attrition occurred in all groups as some students were absent, switched classes, withdrew from their school, or did not consent to have their data used for research. Hence, the number of students completing the entire intervention that are the focus of this study (i.e., student population studied) is smaller than the starting full student population. A few examples include (but not limited to): some of students in the control group (Group 1) were absent during the pre and post content assessment and therefore were not accounted for in the sample population. Treatment group students (Group 2) had two female students and one male student moved to another school during implementation of the project. Likewise, several were absent when the pre and post assessments were administered by the teacher. Subsequently, these students were not included in the sampled population. Treatment group students (Group 3) had a student move to another school, one who did not complete the consent form, another who was absent during the pre-survey interest/attitude assessment, and another who was absent towards the end of the unit due to a chronic illness issue. Consequently, these individuals were not included in the sampled population within this treatment group. Treatment group students (Group 4) had one female student transfer to another school at the beginning of the project.

3.3.2 **Actual number of students participating in the study**. The researcher included only those groups of students in the population who took the pre and post assessments and completed the parent consent and student assent forms and they represent the total number in the study. There were 88 students who completed the pre-and post-content-aligned assessment which included the three treatment groups and the control group. Likewise, there were 55 students who completed the pre-and post-survey questionnaire which included only the three treatment groups. Summary of the student population studied who completed both assessments and returned consent forms are provided in Table 3.1.

Table 3.1 Number of Participants who Completed the Pre and Post Assessments

Instrument	Group 1 Students (Control; Teacher A)	Group 2 Students (Treatment; Teacher B)	Group 3 Students (Treatment; Teacher C)	Group 4 Students (Treatment; Teacher D)
Content-Aligned Assessment (*N*=88)	31	20	15	22
Survey Questionnaire (*N*=55)	*0	15	14	26

**Note*. Students in the control group were not included when assessing the pre- and post-attitude/interest survey instrument in this study.

3.3.3 ***Students' demographics***. In regards to overall ethnicity and gender, the *student population studied* who completed the pre-and-post content-aligned assessment (*N* = 88) included: a combination of White (47.7%), African American (15.9%), mixed ethnicity (15.9%), and other (20.5%). In addition, all students attended a rural school in the mid-south region of the United States and mostly come from low socioeconomic backgrounds. Further, there was a relatively high number of females (61.4%) compared to males (38.6%) within all four student groups (includes the control group). Summary of the student study demographic population who *completed* the pre- and-post content assessment is provided in Table 3.2. In regards to overall ethnicity and gender, the *student population studied* who completed the pre-and-post interest/attitude survey questionnaire (*N* = 55) included: a combination of White (74.5%), mixed ethnicity (9.1%), African American (7.3%), American Indian (1.8%), and other (7.3%). In addition, all students attended a rural school in the mid-south region of the United States and mostly come from low socioeconomic backgrounds. Further, there was a relatively high number of females (65.5%) compared to males (34.5%) within the three treatment groups who participated in the authentic, hands-on intervention in the classroom. Summary of the student study demographic population who *completed* the pre- and-post interest/attitude survey instrument is provided in Table 3.3. Further, in terms of ethnicity when comparing samples across groups, Group 1 (control group) contained a larger population of underrepresented students compared to the number of White students (14 total) represented in the samples who took the pre- and post-content assessment. Group 2 contained a slightly larger population of White students (11 total) compared to underrepresented students (9 total) in the samples who took the pre- and post-content assessment. Further, there were 8 White students and 7 underrepresented students in the samples who took the pre- and post-intervention survey instrument in treatment group 2. Group 4 contained a relatively high population of White students (17 total) compared to underrepresented students (5 total) in the samples who took the pre- and post-content assessment. Further, there were 19 White students and 7 underrepresented students in the samples who took the pre- and post-intervention survey instrument in treatment group 4. Group 3 contained the fewest populations of underrepresented students (1 total) compared to 14 White students in the samples who took the pre- and post-content assessment. Further, there were 0 underrepresented students and 14 White students in the samples who took the pre- and post-intervention survey instrument in treatment group 3.

Table 3.2 Demographic Data from Participating Students in the Project who completed the Pre-and-Post Content Assessment (i.e., the population studied)

Student Groups	School Setting	School Level	Ethnicity and number of students	Gender and number of students	Economically disadvantaged
Group 1 Control	Rural schools	High School	14 White 17 Underrepresented *N* = 31	15 Male 16 Female *N* = 31	67.3%
Group 2 Treatment	Rural schools	High School	11 White 9 Underrepresented *N* = 20	11 Male 9 Female *N* = 20	64.4%
Group 3 Treatment	Rural schools	High School	14 White 1 Underrepresented *N* = 15	6 Male 9 Female *N* = 15	63%
Group 4 Treatment	Rural schools	High School	17 White 5 Underrepresented *N* = 22	2 Male 20 Female *N* = 22	73%

Table 3.3 Demographic Data from Participating Students in the Project who completed the Pre-and-Post Interest/Attitude Survey Instrument (i.e., the population studied)

Student Groups	School Setting	School Level	Ethnicity and number of students	Gender and number of students	Economically disadvantaged
Group 2 Treatment	Rural schools	High School	8 White 7 Underrepresented *N* = 15	8 Male 7 Female *N* = 15	64.4%
Group 3 Treatment	Rural schools	High School	14 White 0 Underrepresented *N* = 14	6 Male 8 Female *N* = 14	63%
Group 4 Treatment	Rural schools	High School	19 White 7 Underrepresented *N* = 26	5 Male 21 Female *N* = 26	73%

3.3.4 *Summary of student population in each sample demarcating educational differences*. The teachers participating in the project provided descriptive insights about their students' characteristics pertaining to interest level, abilities, and academic history. This information is important to obtain when differentiating the groups, making claims about their growth, and identifying any marked differences across groups.

Teacher A described her Group 1 students' characteristics as follows: "*This was a required general Biology course and the student interest level varied from highly interested to highly reluctant learner. They are a very diverse group in terms of their interest and academic abilities. There is an AP Biology option at their level, so these are students who chose not to take AP. There are still several students who are academically advanced, the majority are of average ability, and a few perform below average. These students have limited understanding of ecosystems and their ecology background is pretty weak. Three students in the population have IEP's (Individual education plans – special education accommodations) and one has a 504 Plan (classroom accommodations)*".

Teacher B described her Group 2 students' characteristics as follows: "In this class, students were mostly poor to middle-class households. Three students have IEP's and one student has a 504 plan. Fourteen students come from homes without two biological parents. Four students live in household with guardians (not biological parents). Approximately 5-7 students have good home lives. Approximately 6-8 have good study habits. The students with good home lives are not necessarily the same ones with good study habits. Students were put into mixed-ability groups by teacher. A student with leadership skills was included in each group. In the beginning, all group members supported the others. Toward the end of the project, several groups had students that tended to gravitate toward friends (cliques) instead of staying with the working group". Teacher B continued to say, "These students are comparable to the students in the other biology class this year. However, the school has separated some of the higher-achieving students (self-selected) who are possible interested in attending college classes during their high school year into one class. This pushes the population of students with special considerations and challenges into fewer classes. This year, those higher-achieving students are not in biology". Teacher B continued to say, "Students were mostly engaged in the first few weeks of the project. However, as time progressed, it became evident that the instructor (me) needed to put in place more learning checks and accountability measures into the lessons. Also, the time spent working directly with the recirculating tank system should have been streamlined as students wasted time instead of being proactive in their work habits. Our school has implemented a new academic conduct grade reporting category to all classes. The state of Kentucky is moving forward with initiatives to improve work ready skills education in schools (for example, see the Kentucky Work Ready Skills Initiative)".

Teacher C described her Group 3 students' characteristics as follows: "The student population is mostly lower and middle class households. The majority of our students qualify for free/reduced lunch. My 5th period is mostly White and the girls in my class outnumber the boys. Students got along quite well with each other and worked well in their groups. Some of the stereotypical groups they represent include: football players, band students, bowling team members, girls basketball, and FFA members. AP Environmental Science is a class offered to 9th graders in place of Integrated Science for their 9th grade science credit. Because they have chosen to take an AP class, these are students who typically perform higher academically compared to their class as a whole. These students all chose to be in this class and for the most part are very motivated students. However, for many of them, this is their first AP class, and may not fully reach the rigor expected of them in an AP course and not all of them are ready for the rigor of an AP class. Most of them have decent study skills and are supported at home by their families. They all really enjoyed the real world aspect of the aquaponics unit and were all confident in different aspects of the project. They are typically highly motivated students who are hoping to gain college credit at the end of our course".

Teacher D described her Group 4 students' characteristics as follows: "The student population mostly comes from lower-class households with a few middle-class ones mixed in. My 5th period students in particular are White, African American, Latino, and mixed races, with girls outnumbering boys 5:1. Students get along well with each other. Cliques represented are boy's football and basketball, girl basketball, soccer, and fast pitch softball, band students, academics, and those that aren't as easily grouped into social stereotypes. Biology is a required course for all freshmen. Compared to my other classes, the 5th period students are motivated learners. Half of them are quite engaged, with a supportive home life and several helpful habits (good study skills, willingness to ask for help, proactive with class discussion). The other half lack these support structures, and require more encouragement to perform at their full potential. My girls tend to be more diligent and cautious, but that's not the case for all of them. There are a few that are confident risk takers. Other classes don't demonstrate the same level of academic success as 5th period does, although there are always some students who are academically gifted and willing to put in the work. The class loved the real world science opportunity given through the aquaponics unit".

3.3.5 *Description of the four participating schools*. The four schools that participated in this study were purposefully selected. The researcher first identified teachers in the project, since he needed to study teachers involved in aquaponics. Second, the researcher narrowed the participating teachers to those that were in the first cohort because of their collaborative work on creating the final unit, their implementation of the unit at least twice, and their expertise in teaching secondary life science and ecology specifically. Thus, participants engaged in the APBI intervention were taught by the three experienced biology teachers who had taught the hands-on curriculum prior to this study. In the present study, Teacher B (Group 2) taught a General Biology 10th grade class; Teacher C (Group 3) taught an AP Environmental Science 9th grade class; and Teacher D (Group 4) taught a General Biology 9th grade class; the control group (Group 1) were comprised of 10th graders who were taught general Biology by a highly trained teacher. The control group (Group 1) matched the three student treatment groups in terms of school setting (i.e., rural), school level (i.e., high school), class size, and their economically disadvantaged status. A summary of this information is provided in Table 3.4

3.3.6 *Description of the intervention implemented in each class*. This section describes the intervention implemented in each class in terms of the number of minutes (class time) and designated class period when students met with the teacher. Group 1 students (control group) in which the aquaculture/aquaponics PBI intervention was *not* implemented, had two separate general Biology classes in first period (MWF 8:30-9:30; T/R 8:30-9:25 – class 1) and third period (MWF 10:40-11:40 and T/R 11:10-11:40, lunch, then 12:05-12:30 – class 2) that were equally divided (i.e., 19 students class 1; 21 students class 2). It is important to note that the teacher in the control group (Teacher A) did addresses the concept *carrying capacity* in their general biology class. Likewise, students were involved in nitrogen testing of water and learned about the nitrification process (via nitrogen cycle). Teacher A stated, "*Students and I discussed the rising ammonia levels and why they went down when we added fresh water*". Notably, the control group students were to learn these concepts to avoid any bias with the standard-based pre- and- post content-aligned assessment utilized in the present study. The next three student groups that will be described in this section implemented the aquaculture/aquaponics PBI intervention in the classroom (via referred to as the treatment groups). Group 2 students were in class for 61 minutes and met every day during the week at the designated 4th class period right before lunch; Group 3 students were in class for 54 minutes and met every day during the week at the designated 5th class period; and Group 4 students had 45 minutes each day to facilitate the unit in the classroom and met every day during the week at the designated 5th class period. A summary of this information is provided in Table 3.4. More detail information about the intervention is provided later on in this chapter. As mentioned previously, teacher selection in this dissertation study was on the basis of consistency as they met the following criteria: 1) their comparable expertise and similar times teaching the aquaponics unit; 2) their comparable expertise in teaching biology; 3) similar educational backgrounds; 4) the variety of school settings in which they worked, and still do, which also meets the criteria of the sites selected constitutes a good representative sample of students outside this population frame; 5) comparable experience and expertise implementing the aquaponics job rotations; and lastly 6) there willingness (volunteering) to participate in the study.

Table 3.4 Illustration of the Different Student Population Groups in the Study

	Group 1	Group 2	Group 3	Group 4
Grade Levels	Grade 10	Grade 10	Grade 9	Grade 9
Class Time[a]	55-60	61	54	45
Class Period	MWF 8:30-9:30; T/R 8:30-9:25	11:15-12:16	12:22-1:16	12:47-1:32
Course	General Biology	General Biology	AP Environ. Science	General Biology

[a]Classes met daily.

3.3.7 *Description of the three biology teachers who facilitated the aquaponics intervention*. The three biology teachers in this study who participated in the APBI unit along with several other secondary teachers were originally selected by the researcher during the summer of 2017 as part of a United States Department of Agriculture/National Institute of Food and Agriculture (USDA/NIFA) 1890 Institution Teaching, Research, and Extension Capacity Building Grant (CBG) program. It should be noted that the present study was building on a larger federally funded project under the researcher's direction that has been ongoing for approximately two years with the same biology teachers and other secondary teachers from different Kentucky public high schools. Hence, this research study is a very small focus of the grant project. As mentioned previously, the reason why the three biology teachers were selected in this study was largely due to the fact that they had taught the aquaponics unit twice to two different groups of students during the 2018-2019 academic year. As a result, they were knowledgeable about the unit content, benchmark lessons, and had experience facilitating their students' own aquaponics investigations in the classroom. Further, these three teachers also addressed challenges when integrating agriculture in science classrooms discussed in Chapter 2. In summary, there were commonalities across the teachers who participated in the APBI intervention in this study including: they all taught the aquaponics unit under the researcher's guidance and thus, each teacher had awareness and knowledge of the curriculum. Likewise, all three schools had administrative support, adequate funding, appropriate facilities, and utilized the same equipment which could have affected how the unit was implemented. Likewise, the teachers were committed to the project and demonstrated their willingness to collaborate with the researcher and each other from start to finish. Hence, these factors are noteworthy to mention to help establish consistency for the comparison. However, there were limiting factors that should be summarized relating to the teachers participating in the project and the school environment which includes: 1) the three teachers participating in the project did not have the same daily workload, common preparation time, class schedule, class time, and class frameworks; 2) they did not have the same level of experience in PBI prior to participating in this project; 3) nor did teachers have the same student demographics within their classes; 4) and student class size differed slightly across the three school environments.

3.3.8 *Training of Teachers*. Teachers participating in this study completed training on the aquaponics PBI unit in the summer and fall 2018. Prior to project implementation, they did not have professional training or background in teaching aquaculture or aquaponics. The researcher worked closely with the teachers in the summer to review the outline and goals of the aquaponics unit. The researcher provided the teachers with information about closed aquaponics ecosystems in the form of written lay publications, educational resources on-line, and education video-based training modules taught by aquaculture experts in the field. Likewise, the researcher made numerous on-site visits at their school with the purpose to share his knowledge and develop teachers' expertise in aquaculture and aquaponics. Further, the researcher invited teachers to visit his workplace and conducted a guided demonstration tour of a state-of-the art Aquaculture Research Center on several occasions. These opportunities also developed teachers' knowledge of aquaponics, aquaponics systems, and fish recirculating aquaculture systems (RAS) in particular. It should also be noted that teachers were trained by the researcher to manage their RAS (excluding hydroponics) in fall 2017 in preparation for the 2018 spring unit which focused solely on aquaculture. They developed their expertise in assembly and management of their RAS, performing water quality analysis using various scientific tools, feeding schedules, troubleshooting their water recycle systems, facilitate their student investigations, and other information was shared between teachers and the researcher during this time. The three teachers were also instrumental training the researcher in the unit's design for secondary students as they offered their expertise and ideas throughout the process. The teachers communicated with each other and the researcher while creating some of the benchmark lessons and student assessment activities aligned with NGSS that were used in this dissertation study. During the 2018 fall semester, the researcher and team of teachers continued to collaborate to create the complete aquaponics curriculum in situ as each of the teachers taught the unit to one group of students. They regularly consulted with each other, learning through trial and error. The hydroponics content was added to the curriculum in fall 2018 and continued spring 2019 with a new group of students to create the full unit with a complete producer-consumer aquaponics system. These three teachers, therefore, were considered experts of the unit's design and implementation. The summer collaborative meetings and year-long classroom implementation of the unit comprised training for the three teachers selected for the dissertation study. Other teachers joined the project throughout the 2018-2019 academic year, but they did not develop the level of expertise demonstrated by the three biology teachers and therefore, were not asked to participate in the study. Hence, the three biology teachers implemented the aquaponics unit intervention in the fall semester of 2019 which represented the dissertation study. They also again implemented rotating jobs assigned to individual students within each group to promote experience in different facets common to aquaculture, hydroponics, and other ag-STEM-related fields of study such as engineering and design.

3.4 School Demographics and Teachers' Educational Background

The next section describes the school demographics and the teachers' educational background (undergraduate and graduate degrees and year completed), areas of certification to teach biology, responsibilities in their current positions, signifying if they teach any honors level biology students and/or AP biology, years of experience teaching, and experience teaching secondary biology in particular.

3.4.1 **School Demographics**. Control Group 1 students attend a small independent school serving grades 9-12. It is located within the city limits of a small town with the population of 16,735 (2017). It serves a diverse population of 517 students (2018-2019 school year; grades 9-12th). Demographically, the school serves a diverse student population composed of 59.3% White (non-Hispanic), 16.9% African American, 12.2% two or more races, and 11.6% who identify as "other". Over half of the student population (67.3%) are economically disadvantaged and qualifies for free or reduced lunch (Kentucky Department of Education website, Kentucky School Report Card, 2018-2019 School Year).

3.4.2 **Teacher A demographics**. Teacher A in the control group (Group 1) works in a public secondary school (grades 9-12) located in a small town *surrounded* by farmland. She is White and earned a Bachelor of Science in Microbiology and a Master of Science in Education from the same public University in Kentucky. She has 29 years of experience teaching high school science (mainly chemistry, general biology, and AP Biology) and is a National Board Certified Teacher. She has had some training in project-based instruction and has implemented some project-based experiences with her students prior to the present dissertation project.

3.4.3 ***School demographics***. Treatment Group 2 students attend a small independent school serving grades Pre-K-12. It is located within the city limits of a small town with the population of 2,569 (2017). It serves a diverse student population of 958 students (2017-2018 school year; grades preschool-12th). Demographically, the school serves a diverse student population composed of 72% White (non-Hispanic), 11% African American, 9% Hispanic/Latino, and 8% multiracial. Over half of the student population (64.4%) are economically disadvantaged and qualifies for free or reduced lunch (Kentucky Department of Education website, Kentucky School Report Card, 2017-2018 School Year).

3.4.4 *Teacher B demographics*. Teacher B in the treatment group (Group 2) works in a public secondary school (grades Pre-K-12) that is located in a small town surrounded by farmland. She is White and earned a Bachelor of Arts in Secondary Education from a public University in Indiana focusing on biological science with a minor in general science. She has a Bachelor of Science in General Studies from the same public University and a Master of Arts in Teaching from a public University in Kansas. She has 18 years of experience teaching high school science (mainly general biology, Integrated Science, and Forensics), 16 of which she completed in another secondary school in a nearby county, and is a National Board Certified Teacher; Level 1 Google Certified Educator. Further, for the past 5 years she has served as a council member for the Kentucky Environmental Education Committee. She has worked at her current school for three years and her current appointed job title is Biology Teacher. Before teaching, she was a certified professional secretary for 10 years. In 2018-19 school year, she taught Biology, Forensics (10-12th), and Integrated Science (9th). Notably, she has never implemented project-based instruction prior to participating in this aquaculture project.

3.4.5 *School demographics*. Treatment Group 3 students attend a small county school serving grades 9-12th. It is located within the city limits of a small town with the population of 2,827 (2017). It serves a moderately diverse population of 708 students (2017-2018 school year; grades 9-12th). Demographically, the school serves a moderately diverse student population composed of 95% White (non-Hispanic), 2% Hispanic/Latino, 2% other, and 1% African American. Over half of the student population (63%) are economically disadvantaged and qualifies for free or reduced lunch (Kentucky Department of Education website, Kentucky School Report Card, 2017-2018 School Year).

3.4.6 *Teacher C demographics*. Teacher C in the treatment group (Group 3) works in a public secondary school (grades 9-12) that is located in a small town surrounded by farmland. She is White and earned a Bachelor of Science degree in Biology Education (grades 8-12) from a public University in Kentucky. She is currently working on her Master's Degree in Biology Teacher Leadership and does not have National Board Certification. She has 5 years of teaching experience. Her current appointed job title is Biology Teacher/AP Science Coordinator. In 2018-19 school year, she taught secondary Biology, AP Biology 10th grade, and AP Environmental Science 9th grade. Notably, she has never implemented project-based instruction prior to participating in this aquaculture project.

3.4.7 *School demographics*. Treatment Group 4 students attend a small independent school serving grades 6-12th. It is located within the city limits of a small town with the population of 7,073 (2017). It serves a diverse population of 523 students (2017-2018 school year; grades 6-12th). Demographically, the school serves a diverse student population composed of 55% White (non-Hispanic), 24% African American, 10% two or more races, 11% who identify as "other". Over half of the student population (73%) are economically disadvantaged and qualifies for free or reduced lunch (Kentucky Department of Education website, Kentucky School Report Card, 2017-2018 School Year).

3.4.8 *Teacher D demographics*. Teacher D in the treatment group (Group 4) works in a public secondary school (grades 9-12) that is located in a small town surrounded by farmland. She is White and earned a Bachelor's Degree and Master's Degree in Biology from a public University from Kentucky. She worked in a microbiology lab for a short time before receiving her teaching certification at a public University from Tennessee. She has 9.5 years of experience, 3.5 of which she completed in another secondary school in the Tennessee school systems. She took off 16 years to raise her children and has worked at her current school for 6 years. Her current appointed job title is Biology/AP Biology Teacher. In 2018-19 school year, she taught Dual Credit Biology, AP Biology, General Biology, Integrated Science, and Aquaponics. Teacher D incorporates an enthusiastic teaching style coupled with inquiry based instruction that meets the needs of her student population. Her students have worked alongside the town's local government to effect change in the community's awareness of the historical PCB contamination of Town Branch Creek. Students conducted water quality testing, wrote letters to the mayor, and created and posted warning signs. Students also conduct water quality tests on the Red River. 2018-2019 was the first year for the school to offer a completely hands-on aquaponics course of study. Notably, this teacher has had experience implementing instruction that incorporated student projects outside the classroom as a culminating experience from a traditional teacher-led instructional unit prior to participating in this aquaculture project.

3.5 Ensuring Fidelity of Unit

In preparation for this study, the researcher met with the three biology teachers in the summer of 2019 for the purposes of developing and making small improvements to the fidelity of the APBI unit implementation. The teachers and the researcher devised a plan to improve fidelity of the unit's implementation across the three teachers' classrooms. The plan integrated tools already in place for the project, including: (1) weekly teacher reflection log submissions through the Google Docs Classroom platform already established for the project, (2) collaboration across teachers and the researcher through the Google Docs discussion platform and/or emails, (3) one-on-one discussions between researcher and teachers during school classroom visits, and (4) submission of a check list at the end of the unit detailing dates teachers implemented the specific lesson plans and other activities. This check list was incorporated in the teacher logs. These tools are further described in the paragraphs that follow along with additional checkpoints created by the researcher after suggestions and directions to ensure fidelity were made by his doctoral committee during face-to-face group meetings.

Reflection logs and other teaching records were used to assess fidelity of the intervention. During the first year of the project, teachers periodically submitted journal entries to document their planning and instruction of the aquaponics unit and shared in Google Docs for others to view as well. In this study, the teachers completed weekly reflection log entries demarcating how they followed the unit, documenting their progress and any problems that might arise during the week. Further, teachers documented student work, took pictures of students doing benchmark and other activities and included these in their weekly logs and shared in Google Docs for others to view as well. Such information could then also serve as data to substantiate fidelity.

Teachers also followed a tentative schedule that outlined when they planned to begin the unit, identified key benchmark lessons, and the end of the unit (see Table 3.12). Similar to the weekly logs, this information was posted in Google Docs Classroom platform for others to view as well. This schedule was also helpful for the researcher when planning visits to the classroom. This allowed the researcher to confirm with the teachers the dates of implementation of key lesson plans. While the researcher could not be there regularly, he recorded what was implemented during these dates of observation as well as engaged in informal conversations with the three teachers participating in the project.

3.6 Quantitative Methods Approach

3.6.1 Instrumentation: Pre- and Post-Survey (e.g., student attitudes and interests).

This project measured students' attitudes and opinions toward STEM and aquaculture and their interests towards a STEM-related discipline and/or career pathway using a quantitative descriptive survey methodology. Thus, a quantitative methods, quasi-experimental research design for data collection and its analysis were employed as the survey instrument provided quantitative-based evidence. The population consisted of all student participants *who participated in the authentic, hands-on intervention* (via treatment groups; *N*=55). Respondents were offered a choice of several responses from particular statements that connected to research questions 1 and 2. They responded to statements utilizing 5-point summated scale scores with a 1 representing strongly disagree, 2 for disagree, 3 for neutral, 4 for agree, and 5 for strongly agree. Nardi (2014) asserted that these are technically discrete ordinal measures in which the numerical values are assigned in order from strongly disagree category to strongly agree category (i.e., represent the increase in opinions) with the three answers in between (p. 59). In this study, respondents took the same questionnaire before and after the intervention. However, the researcher did not analyze data to compare the aquaculture treatment groups and the control group. It was thought that the control group students would not reveal any genuine changes, since they did not participate in the authentic, hands-on intervention. Thus, only those students who participated in the aquaponics intervention were measured in the present study (See Appendix A and B). The survey instrument was converted and taken on a computerized Google Form platform. The survey was administered at the beginning and at the end of the project during school as part of instruction. The researcher acknowledges that a limitation exists in that the sample may not represent a larger population of students who might be exposed to the same intervention. Thus, caution is warranted in generalizing the results beyond the sample. The survey instrument utilized in this study was entitled “Students Attitudes toward Aquaculture (Aquaponics) Project.” The instrument was developed by the researcher and the first 12 survey items were rated by a Likert scale that reflect an element relating to the research questions in the study: 1) how the aquaculture project affects students’ interest in STEM; 2) their interest in attaining a STEM career pathway; 3) interest in STEM courses; 4) or interest in aquaculture courses are among a few examples. In addition, the survey included a profile of the respondents with the demographic items. Nardi (2014) expressed that a researcher needs to be clear about their conceptualizations which means that the ideas and terms used in the study should be explicitly stated and the set of questions composed of concepts should be connected to the topic. The researcher then takes the concepts of the research topic and translates them into something measurable called variables which signifies the variation that might exist in the concept. These measurable variables form the basis of the questionnaire items that guide the collection of data and represents what the researcher believes are good indicators of the concept (p. 46-47). In this study, exactly half of the variables connected to research question number one, while the remaining six connected with research question two. Hence, the assessment was designed to measure two main constructs which included students’ attitudes toward STEM and aquaculture and student' interest in future STEM career pathways that were equally divided. A descriptive univariate (one variable at a time) analysis of the variables was performed in this study which also included a profile of the respondents with the demographic items. The objective was to look at every item in the survey to get a sense of the variability of responses. The study employed several ways of presenting the univariate information about the variables in the study which included frequency distributions, statistical measures (i.e., means and standard deviations), and visual representations using graphs. Thus, the data analysis in this study used descriptive statistics which included frequencies, percentages, means, and standard deviations for each of the twelve items within the survey. Nardi (2014) reported that calculating the mean for some ordinal scales such as Likert ones is acceptable (p. 143). Hence, this was implemented in this study. The literature identified no survey instrument that suitability matched the objectives of the study. Hence, to ensure that every participant would accurately interpret and willingly respond, wording for each statement was adjusted specifically for participants by pilot testing the questionnaire with a pool of pilot testers who were representative of the participants in the present study and who were of similar age. The researcher decided to use participants from the same three schools that were taught by the same biology teacher who participated in the present study and another student group (a total of four student groups) from another school during the 2018-2019 academic school year. Pilot testing is considered a good approach to help validate a survey (Nardi, 2014).

3.6.2 **Content-aligned assessment.** An original content-aligned pre- and post-assessment instrument was developed for this study in July 2019 by the researcher and participating biology teachers to measure changes in students' understanding of the target concepts (see Appendix C). It is important to note that all four student groups (includes the control group; *N*=88) completed the content test. A science education researcher with expertise in ecology education also provided guidance during test construction and had recommendations which were applied to ensure that it connected to the standard-based concepts addressed in the unit. The focus of the assessment is on the concepts that can be learned through participating in an aquaponics project based on current NGGS standards, while some of the cognitive tasks are specific to aquatic ecosystems. The goal is that these tasks may reveal growth in learning (i.e., evidence of a change in scores by individual) between the pre and post assessments. However, it is important to note that the assessment was created to be applicable to *all* students, whether or not they completed the aquaponics project. The original assessment consisted of three main learning parts and goals which includes *ecosystems*, *carrying capacity*, and *scientific argument* in which students had to apply their knowledge and problem solve and use science inquiry process skills to identify the best response. A format that is similar to characteristics of an ACT college-entrance exam. An outline of each of the three main parts in the original assessment are identified below.

1. **Ecosystems (Part A)**
    a. Biotic Factors
    b. Abiotic Factors
        i. Nitrogen Cycle
            1. Ammonia
            2. Nitrite
            3. Nitrate
            4. Water Temperature
            5. Dissolved Oxygen
            6. Alkalinity
            7. pH

2. **Carrying Capacity (Part B)**
    a. Population Growth Patterns
        i. Logistical
        ii. Exponential
    b. Limiting Factors
        i. Independent
        ii. Dependent

3. **Scientific Argument (Part C)**
    a. Investigation Question
    b. Claim: A statement that is the answer to the investigation question.
    c. Evidence
        i. Experimental Design
            1. Independent Variable
            2. Dependent Variable
        ii. Data Gathering and Graphing
    d. Reasoning
        i. Data Interpretation
        ii. Connection to Scientific Concepts
        iii. Explain how the Evidence supports the Claim

This data collection tool connects to research question 3 and incorporates multiple-choice items, short answer questions, and several open response tasks. Items were created to measure both content and process understanding such as interpreting graphs, describing and analyzing data, drawing conclusions, and use aquaponics concepts to explain real-world phenomena. It is important to note that only twelve questions from the original assessment were selected by the researcher, science education researcher, and a participating teacher in the project. The objective was to narrow the focus towards the key concepts (carrying capacity and nitrogen cycle) that connects directly with research question 3. For example, the first question (Part A: Ecosystems) participants had to show their understanding of the nitrogen cycle in an aquatic ecosystem (i.e., pond) by matching the correct description with the correct location in the image provided. In question number twelve, participants also had to interpret a graph that illustrated cycling of a new tank. Other questions focused on factors that might limit a population of organisms' ability to survive in a particular environment (i.e., limiting factors). Likewise, questions were developed to assess student understanding of the concept *carrying capacity*. For example, participants examined a graph depicting populations of organisms (i.e., bacterial and elephant) and determined if they reached carrying capacity and why or why not did organisms keep increasing or decreasing (questions 2-7). Lastly, vocabulary-based or questions that were too aquaponics-specific were omitted from the content assessment used in this study. It was believed that the control group students would be at a disadvantage since they did not participate in the aquaponics project. The developers of this assessment wanted to ensure that there was no bias towards students completing the project. The study wanted to find out whether the project would enhance treatment students' understanding of the standard-based concepts and the content-aligned assessment was delivered in both the control and treatment group interventions. It is important to note that other researchers have used a similar approach in their pre/posttest assessments measuring inquiry science process skills (Marx et al., 2004; Rivet & Krajcik 2008). Each cognitive task was also tied to one or more of the current standards utilized in the intervention. Responses to the eight short answer questions in part A (e.g., ecosystems and carrying capacity) and the four open response tasks in part B (e.g., scientific argument) were coded on a 5-point scoring rubric scale which can be found in Appendix C. It is important to note that the science education researcher provided the initial rubric template, while the researcher and participating teachers incorporated the criteria descriptions for each scale and question. Likewise, three (3) different scorers assessed student responses independently to establish interrater reliability. Nardi (2014) stated that content analysis requires some degree of agreement among those who are scoring the data. If those scoring the data agree, then we can claim there is interrater reliability. The interpretations of the qualitative responses are consistent among various scorers (p. 65). The researcher selected two experienced high school teachers who were not connected with the project. The criteria for selection included: 1) the graders had an ecological science education background; 2) knowledge and experience incorporating aquaculture in the classroom; 3) and experience creating and scoring rubrics for open-ended items at the secondary level. Hence, the rubrics in this study were scored separately by two teachers who were not involved in the project and third scorer was the researcher. This study determined if interrater reliability was established at 90% or better between scores as described by Rivet and Krajcik (2008). Results indicate that the percentage of agreement between the three scorers in this study was 92.6%.

3.6.3 ***Description of outside teachers who graded content assessment***. A brief descriptive summary of the two teachers experience and background who were selected to grade the individual pre- and post-tests are provided below. This information from their voice is provided to demonstrate how they are good candidates for analysis of test results. It should be noted the two teachers were paid $300 per day for their services from USDA/NIFA grant funds and it took them three days to complete. Likewise, they were added to the IRB since they would be considered researchers on the project. Teacher grader 1 stated, "*I taught biological sciences for 29 years. During that time, I taught basic biology, Advanced Placement Biology, human genetics, anatomy and physiology, environmental science, and aquaculture. Throughout my years at the same high school, I had extensive experience developing tests and rubrics and using rubrics for scoring. Our aquaculture program was taught collaboratively with the agriculture teacher and was strongly supported by a nearby University. The nearby University provided us equipment and materials as well as having staff readily available for consultation and hands-on help. After I retired, I had the honor of teaching environmental science and river history aboard a University led houseboat, through my association with Canoe Kentucky. For that, I designed and delivered curriculum and maintained supplies and equipment"*. Teacher grader 2 stated, "*I have taught agriculture science for 6 years in both the middle and high school settings. I cover basic topics of ecology and have used small counter-top aquaponics systems to help my students understand the concepts better. As a classroom educator, I have created numerous assessments and* *rubrics to assist my students in understanding their own achievement with learning the standards we cover in class*". The pre-intervention and post-intervention content assessment were taken on the computer in the classroom by those participants actively engaged in the project and the control group students using a Google Forms platform. For those students without access to Google Forms, or that preferred to take the assessment with paper/pencil, paper forms were provided. The scorers for the assessments analyzed student written pre-test and post-test responses and inputted data (via using the research rubric) into an Excel spreadsheet provided by the researcher.

3.7 Overview of Data Collection

The researcher sought permission from the University of Kentucky Institutional Review Board (IRB) and Kentucky State University Institutional Review Board (Office of the Deputy Provost, Research and Sponsored Programs) to collect data from the participants in the project. The researcher received approval of an Institutional Authorization Agreement (IAA; IRB Reliance Authorization Agreement) in which the University of Kentucky (Office of Research Integrity) agreed to rely on Kentucky State University's IRB review and oversight.

Consent was obtained from students' parents or legal guardian and assent was obtained from the students themselves. As mentioned previously, if these forms were not collected from both the parents and youth then that student was not included in this research project. Thus, this study encompassed all of the participants that the researcher had finalized parental consent forms and youth assent forms for. All of the participants who completed the consent and assent forms were asked to volunteer in the study and complete the pre- and post-survey questionnaire and pre- and post-content assessments. It should be noted that every participant was made aware that although their parents or legal guardian had consented to the study and they had assented to it that they still had the right to discontinue at any time. From here on out in this chapter, the word *participants* refer to the students who completed adult consent and youth consent forms that partook in the hands-on project-based activities consented and assented to.

As mentioned previously, 31 participants comprised the control group, while 57 participants comprised the treatment groups (88 total) for the pre- and post-content-aligned assessment. Further, 55 participants comprised the treatment groups and 0 participants comprised the control group (55 total) for the pre- and post-survey instrument. Summary of this data is provided in Table 3.1.

As mentioned previously, this study utilized a quantitative methods approach to examine how the intervention might promote interest and improve attitudes towards aquaculture and STEM and develop participants understanding of key concepts relating to carrying capacity and the nitrification process in aquatic ecosystems. This study also measured changes in participants' understanding of ecological relationships and ecosystem concepts using a standard-based content-aligned instrument. It should also be mentioned that the same data collection tools were used across all cases (student groups) to maintain consistency and instruments used were connected to the central research questions.

When explaining how testing was conducted for the purposes of identifying assumptions, data were analyzed to confirm normality (via normally distributed) using

Shapiro-Wilk Test and assumptions of equal variances of the dependent variable across groups using Levene's Test. An overview of the data collection, justifications, and details of the analysis process before and after the short-term APBI unit are provided in Tables 3.5 and 3.6.

Table 3.5 Overview of the Data Collection and Analysis Process Before and After the Unit for Content Test

*Pre- and Post-Content Assessment	
Procedure	Product
Paired-samples *t*-test (within subject design) comparison between the pretest and posttest scores across all four student groups (*N*=88)	*t*-statistic and its probability value
Tests of normality using Shapiro-Wilk of mean difference (improvement) variable AND mean pretest and posttest score distribution across all four student groups (*N*=88); histogram distribution and mean profile plots; Levene's test of equality of variances; descriptive statistics	*SW*-statistic, Levene's test, and descriptive statistics
Comparative analysis (between subject design) Mann-Whitney test of mean difference (improvement) between all groups (*N*=88); mean profile plots	*MW*-statistic and its probability value;
Kruskal-Wallis test of significance of pretest and posttest mean rank score comparison between all four groups; A Mann-Whitney test if there were significant differences; mean plot profiles	*KW* rank test statistic; comparison test if different using *MW*-test statistic

*All four student groups (includes the control).

Table 3.6 Overview of the Data Collection and Analysis Process for the Unit for Survey

*Pre- and Post-Survey Instrument	
Procedure	Product
Descriptive statistics (univariate analysis) across the three treatment groups	Descriptive
Frequency distributions	Frequencies
Demographic items across all three treatment groups	Descriptive
Kruskal-Wallis test of pretest and posttest mean rank score comparison between the three treatment groups; A Mann-Whitney test if there were significant differences	*KW* rank test statistic; comparison test if different using *MW*-test statistic
Exploratory factor analysis and survey instrument assessed for reliability	Cronbach's α-statistic

*Treatment groups only.

3.8 Quantitative Data Analysis

3.8.1 **Content Assessment.**

The researcher sought to find whether there was a statistical significant difference between the pre- and the post-content scores. To address this objective, the researcher used a paired-samples *t*-test (within subject design) on the pre-and post-content test scores. The paired-samples *t*-test was used to compare the pretest to the posttest scores across *all 88 participants* (subjects) in the study by means of the statistical analysis software SPSS (Version 22). Basically, there were two measurements from the same individual (subject) at different times in the intervention which eliminated the error of it being a different person or between subjects. A *t*-test formula is designed to assess the difference in means while taking into account the connection or correlation between the two measures (i.e., paired samples *t*-test). Likewise, *t*-test is a statistical technique commonly used to compare the means of two populations when the sample size is small similar to this study. Comparable methods were performed by Rivet and Krajcik (2008) and Marx et al. (2004) as a *t*-test analyses was conducted to compare their pretest and posttest results in terms of overall improvement and gains for each of the science learning goals of the project. A summary of the present study data are provided below in Table 3.7.

Table 3.7 Paired-Samples t-test Comparison Between the Pre- and Posttest Scores with Respect to All Four Student Group Populations

	Paired Differences			
	M	*SD*	*df*	p^a
Posttest score – Pretest score	13.52	13.41	87	.000

$^a p < 0.05$. (significant difference)

Results of the paired-samples *t*-test showed that there was a statistically significant difference between the pre- and post-content test scores across *all 88 participants* among the four student group populations. It is important to note that these results do not make comparisons or show which student groups had better improvement in scores. Likewise, it is important to note that these findings and what follows below were analyzed and presented in this chapter for the purposes of identifying assumptions.

The one assumption underpinning the paired-samples *t*-test was that the differences between the mean scores are normally distributed (Aron, Aron, & Coups, 2005). Hence, prior to *t*-test analysis, the researcher sought to find whether or not the data was normally distributed. To test this assumption, the researcher employed the Shapiro-Wilk test, which is suited for sample sizes similar to the present study (N=88). The Shapiro-Wilk test is a numerical means of assessing normality. A summary of this data of the difference (improvement) variable are provided in Table 3.8. Results showed that the data was statistically significantly different from a normal distribution. Results revealed a skewness of .561 and kurtosis of negative .662 indicating that the difference (improvement) data did not have a normal distribution. The researcher also created a histogram in SPSS which displays the frequency of difference (improvement), created a normal Q-Q Plot of difference (improvement) looking to see if the points were fairly close on the line, and a Box Plot of difference (improvement) to see if there were any outliers in the distribution. The three figures below (Figures 3.1, 3.2, and 3.3) provide a visual representation of the difference (improvement) between the pre- and post-content scores. These representations indicate that the assumption of normality is not satisfied and we are not working with normally distributed differences.

Table 3.8 Shapiro-Wilk Test of Normality for Differences Between the Pre- and Post-Content Scores with Respect to All Four Student Groups

	SW value[a]	*df*	*p**
Difference (Improvement)	.938	88	.000

[a]SW value stands for Shapiro-Wilk statistic.

*$p < 0.05$. (significant difference); Skewness = .561; Kurtosis = -.662

Figure 3.1 Histogram of Difference (Improvement)

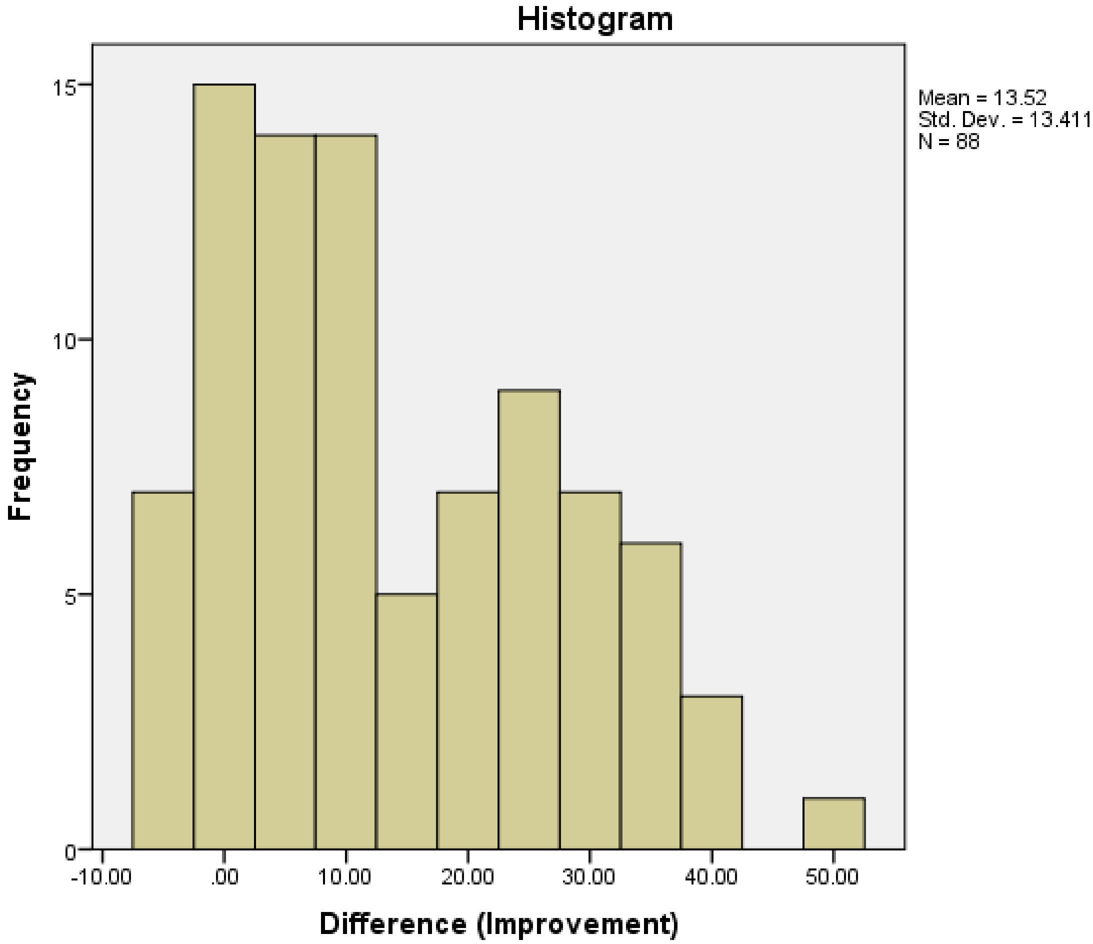


Figure 3.2 Normal Q-Q Plot of Difference (Improvement)

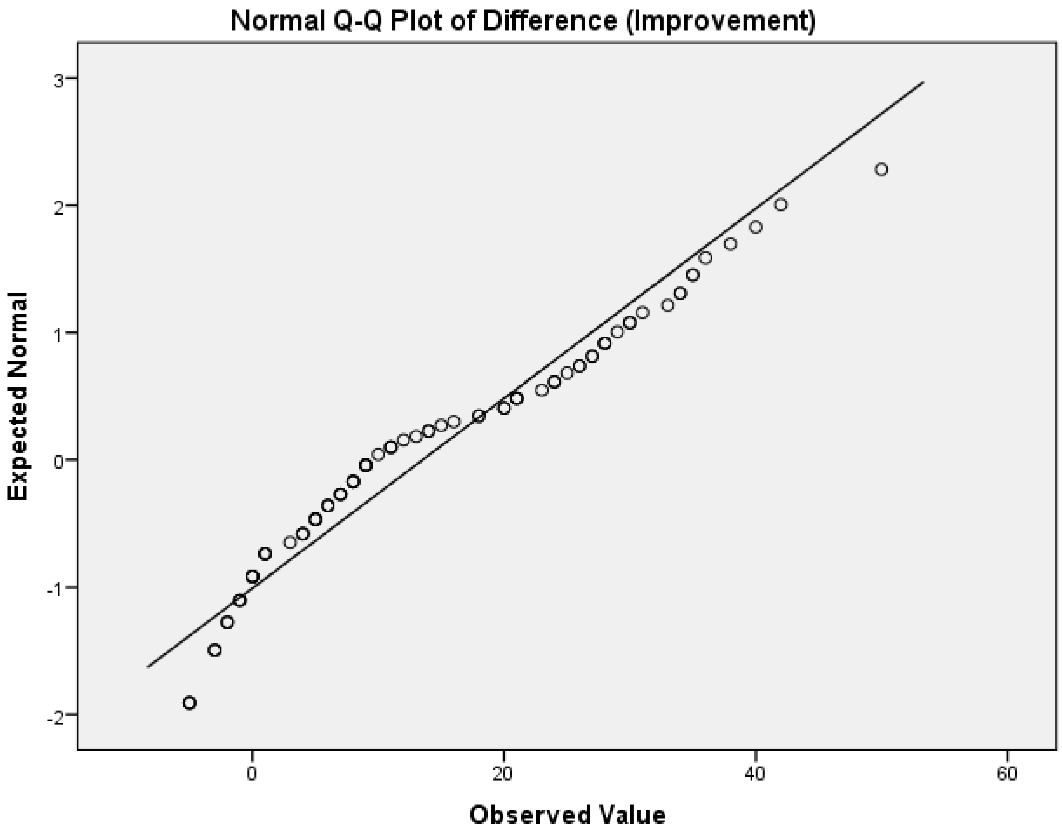
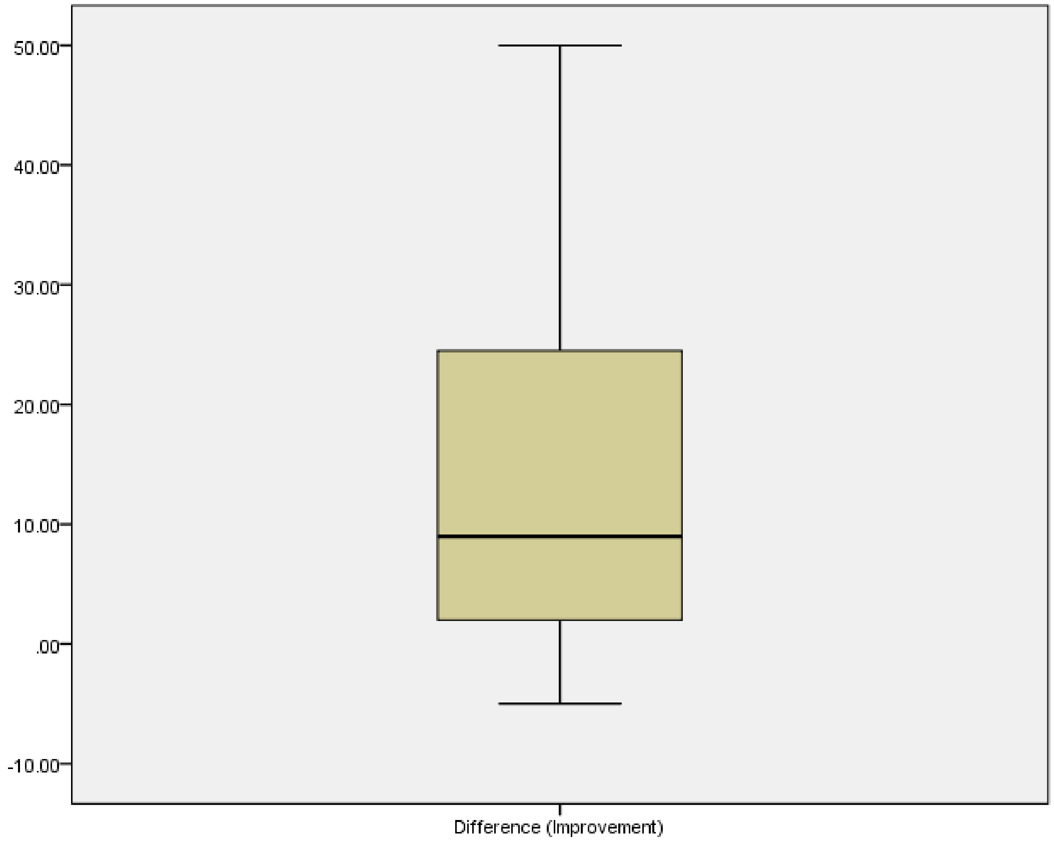


Figure 3.3 Box Plot of Difference (Improvement)



Likewise, the researcher employed the Shapiro-Wilk test to see if the mean pretest score and mean posttest score distribution across all 88 participants was normally distributed or not. Similarly, the p-values are less than the significance level (α= .05) and they give significant results, indicating these data are also not normally distributed. Hence, the assumption of normality was not satisfied in either case and a conclusion was made that the researcher was not working with normally distributed differences. Similarly, it is important to note that these data and what follows below were analyzed and presented in this chapter for the purposes of identifying assumptions. A summary of this data are provided in Table 3.9 (pretest score) and Table 3.10 (posttest score). Figures 3.4, 3.5, and 3.6 provide a visual representation of the pretest scores, while Figures 3.7, 3.8, and 3.9 provide a visual representation of the posttest scores.

Table 3.9 Shapiro-Wilk Test of Normality for Mean Pretest Score with Respect to All Four Student Groups

	SW value[a]	*df*	*p**
Pretest score	.868	88	.000

[a]SW value stands for Shapiro-Wilk statistic.

**p* < 0.05. (significant difference); Skewness = 1.368; Kurtosis = 1.864

Figure 3.4 Histogram of Pretest Score

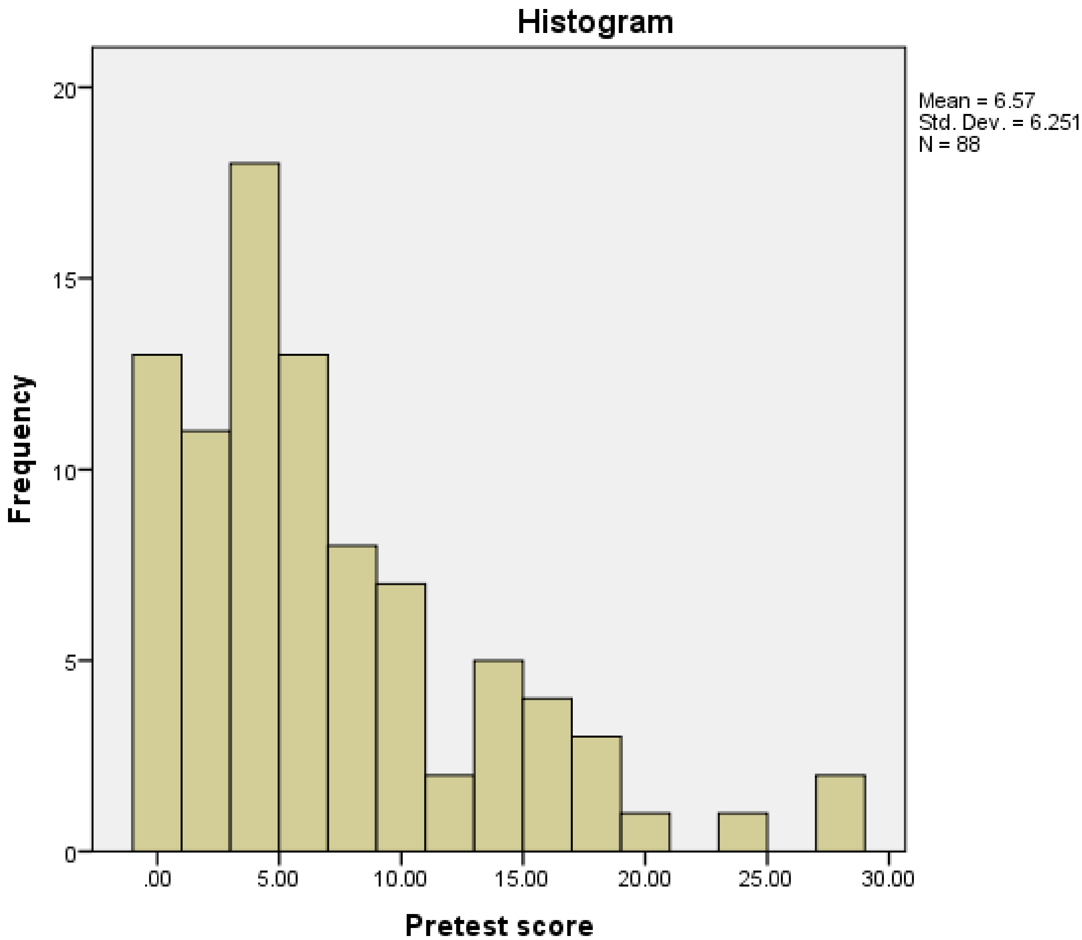


Figure 3.5 Normal Q-Q Plot of Pretest Score

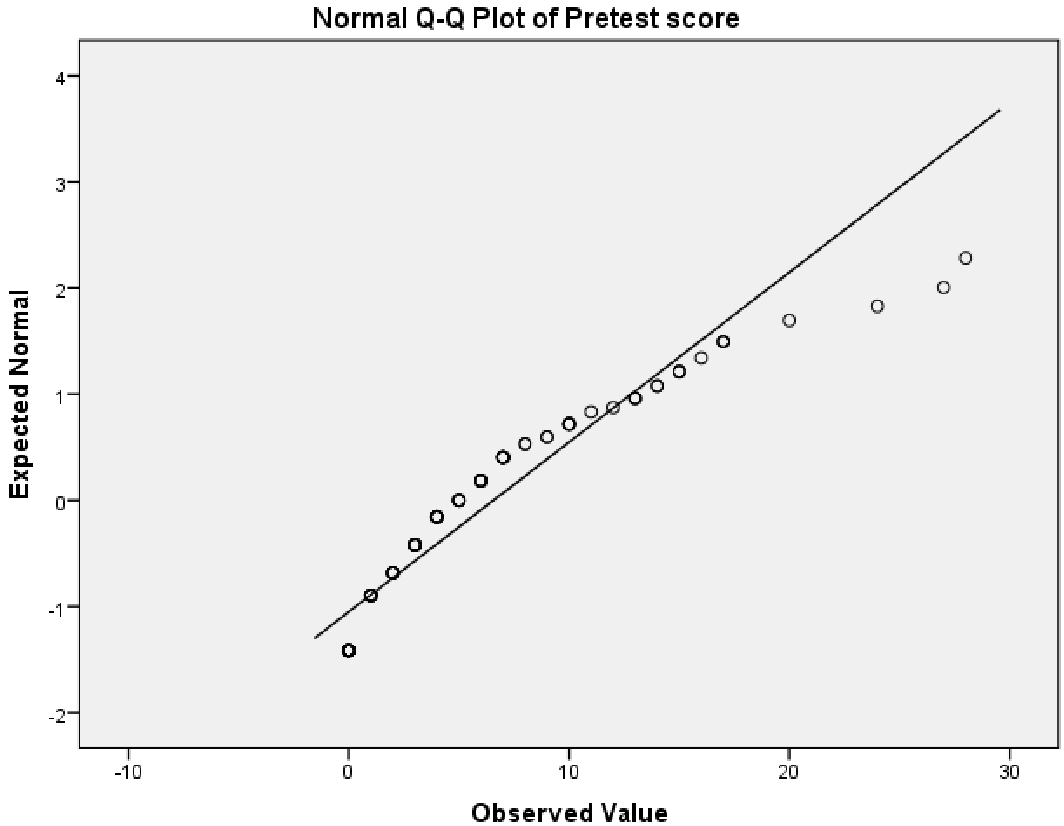


Figure 3.6 Box Plot of Pretest Score

Table 3.10 Shapiro-Wilk Test of Normality for Mean Posttest Score with Respect to All Four Student Groups

	SW value[a]	*df*	*p**
Posttest score	.957	88	.005

[a]SW value stands for Shapiro-Wilk statistic.

**p* < 0.05. (significant difference); Skewness = .212; Kurtosis = -1.023

Figure 3.7 Histogram of Posttest Score

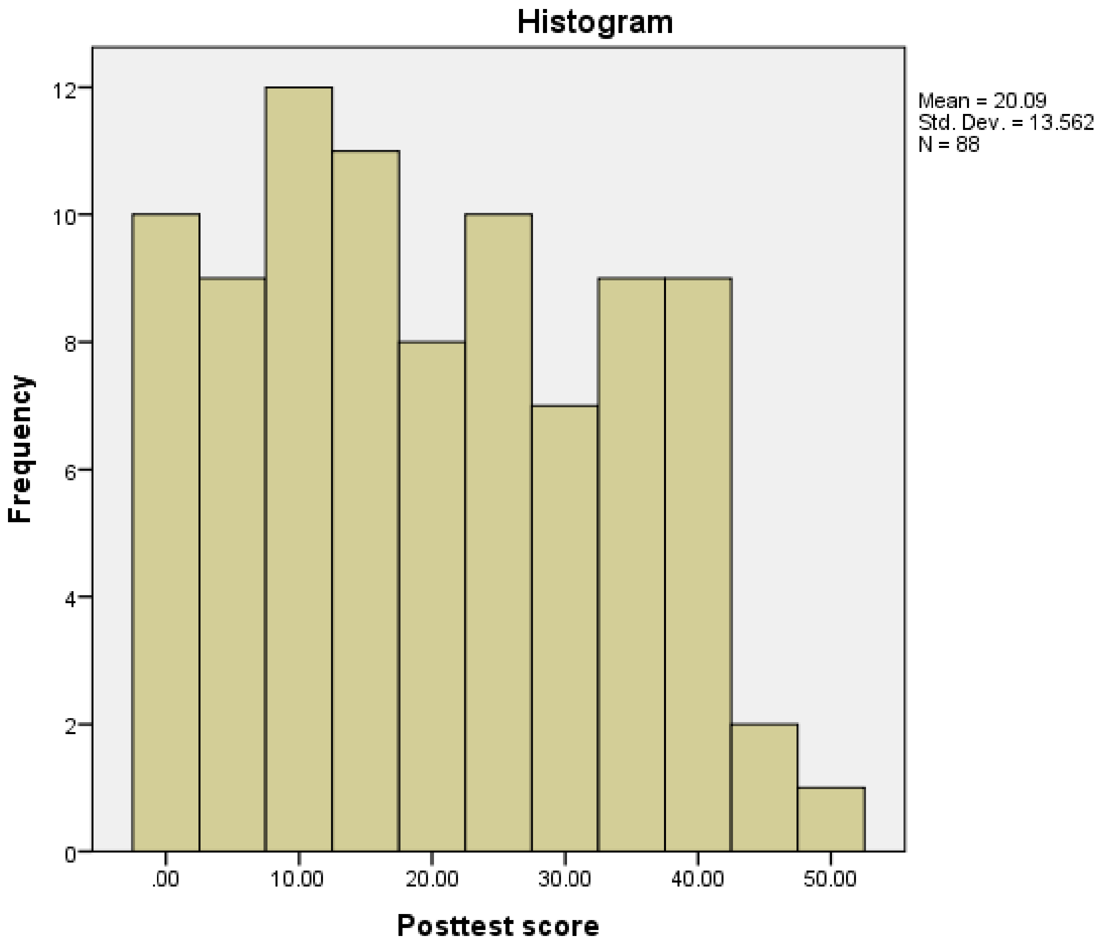


Figure 3.8 Normal Q-Q Plot of Posttest Score

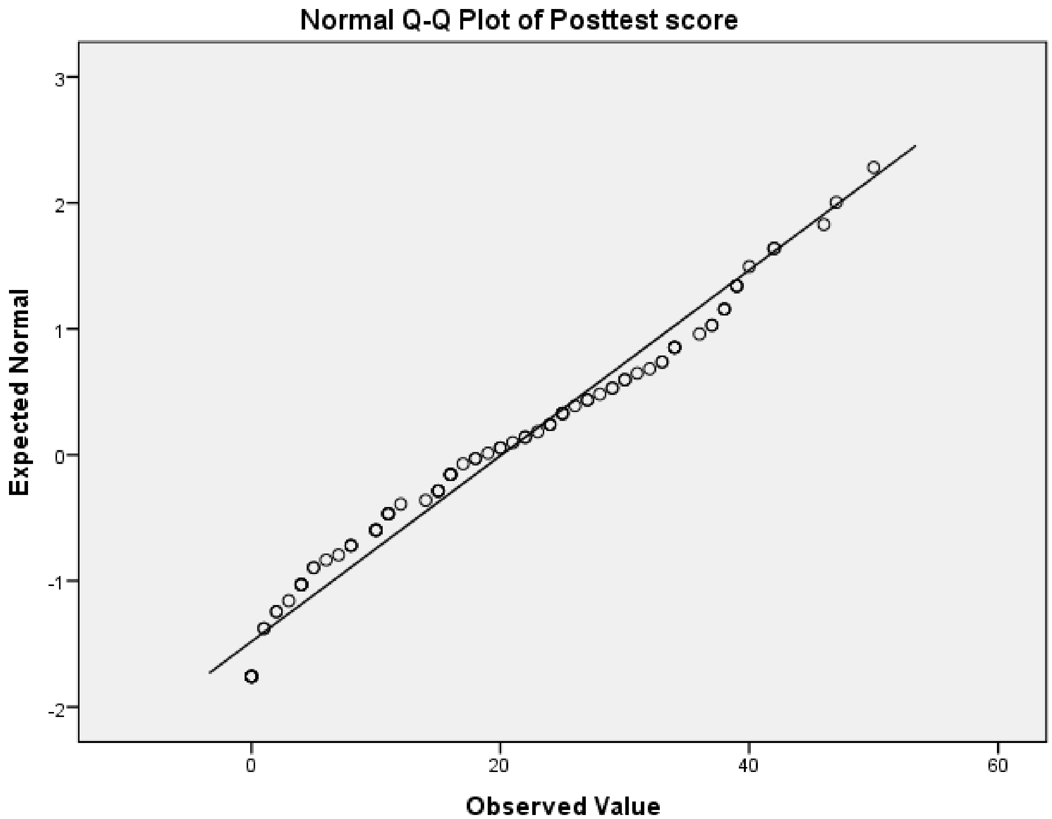


Figure 3.9 Box Plot of Posttest Score

In addition, to test the assumption of equal variances of the dependent variable, the researcher employed the Levene's test for homogeneity of variances. Levene's test is an inferential statistic used to assess the equality of variances for a variable calculated for two or more groups. The researcher did not want to automatically assume that variances of the populations were equal so Levene's test was employed to assess this assumption. Results indicated that the assumption of homogeneity of variance were not met as the error variance of the dependent variable is not equal across groups. As mentioned previously, these data and what follows below were analyzed and included in this chapter for the purposes of identifying assumptions. An overview of the results are provided in Table 3.11.

Table 3.11 Levene's Test for Homogeneity of Variance with Respect to All Four Student Groups

Mean difference (improvement)[a]	Levene's statistic	*p**
Student Groups (all four)	3.013 (F)	.035

[a]($df1$, $df2$) = (3, 84)
[*]$p < 0.05$. (significant difference)

For the comparative analysis, the researcher sought to find whether there was a statistical significant difference between all four student groups (N=88; between subject design) and data were analyzed on the *mean difference (improvement)* after participants took the pre-and post-content assessment by means of the SPSS. To address this objective, the researcher decided to use *Mann-Whitney U test* (a non-parametric statistic) which is the non-parametric alternative to the univariate ANOVA independent t-test. The Mann-Whitney U test is used to compare differences between two independent groups when the dependent variable is either ordinal or continuous, but not normally distributed. The test compares the number of times a score from one sample is ranked higher than a score from another sample. In the present study, the Mann-Whitney test was used to compare two populations (student groups) at a time and provided mean ranks for each, with a Bonferroni correction to control for type 1 errors. The statistical significance level for the Bonferroni correction was $\alpha = .05/6 = 0.008$. The series of comparisons included: a) 1 vs 2; b) 1 vs 3; c) 1 vs 4; d) 2 vs 3; e) 2 vs 4; and f) 3 vs 4, respectively. The objective of this test was to see if the mean difference (improvement) between student groups was significantly different or not. Results are presented in Chapter 4.

The researcher also sought to find whether or not there was a statistical difference between the *pre- and post-content mean scores* between all student groups (N=88). To address this objective, instead of using a one-way between-group analysis of variance (ANOVA), the researcher employed the corresponding non-parametric statistic *Kruskal-Wallis* by means of the SPSS on specifically the mean pretest score and posttest scores to look at the four independent variable student groups to see if there were any differences between them. The Kruskal-Wallis test is a rank-based non-parametric test that can be used to determine if there are statistically significant difference between two or more groups of an independent variable on a continuous or ordinal dependent variable. Further, this test compares two or more independent samples of equal or different sample sizes. Results indicated that there were highly significant differences for both the pre and posttest, so the researcher employed a series of *Mann-Whitney tests* and compared two populations (student groups) at a time which provided mean ranks for each, with a *Bonferroni* correction to control for type 1 errors. Similarly, the researcher divided alpha by the number of comparisons, which was six total. Hence, the statistical significance level for the *Bonferroni* correction was $\alpha = .05/6 = 0.008$. The final sample size was N = 88 (Group 1 = 31; Group 2 = 20; Group 3 = 15; and Group 4 = 22) and shown in Table 3.1. Results are reported in Chapter 4 of this paper.

It is important to reiterate that the assumptions for the one-way ANOVA: (a) normally distributed mean scores and (b) equal variances of scores between groups (Aron et al., 2005; Warner, 2008) were not met when comparing between all (N=88) four student groups. The assumption of normality was tested using the Shapiro-Wilk test and the assumption of equal variances was tested using Levene's test for homogeneity of variances. Hence, this was the reason why the researcher decided use non-parametric models in this study.

However, the researcher did employ a univariate parametric ANOVA to identify statistically significant differences between group mean difference (improvement) sum scores (Tables 4.23 and 4.24). These results were used to compare with the alternative non-parametric models. Likewise, the researcher did find if comparing "only" the three treatment groups (N=57), excluding the control group, data were normally distributed and no outliers in the distribution. Likewise, there was homogeneity such that the error variance of the dependent variable was equal across groups. In this case, parametric tests could have been employed which includes: independent samples t-test (i.e., univariate ANOVA) to compare the mean difference between student groups (e.g., corresponds to Mann-Whitney non-parametric test) and a one-way ANOVA to compare pretest scores and posttest scores between student groups (e.g., corresponds to Kruskal-Wallis non-parametric test).

3.8.2 Survey instrument. The study examined student responses to an attitudinal/interest survey before and after the authentic, hands-on intervention. As mentioned previously, the questionnaire contained closed, Likert-response questions that ask participants about their opinions towards STEM disciplines, careers, and aquaculture. In addition, the survey instrument contained basic demographic information (see Appendix A and B). An attitudinal/interest questionnaire was employed in order to examine whether participation in the APBI unit had an effect in the participants' attitude/interest scores or not. To address this objective, the researcher used a univariate descriptive survey methodology as described in the previous section. The researcher received consultation from a coworker with experience and training in statistics and employed an exploratory factor analysis of the pilot 2018 survey data to see how many factors emerged from the dataset and to evaluate the nature of the factors. Construct validity was verified and the assessment was designed to measure two constructs (e.g., interest in STEM and future in STEM). The goal was to confirm to what extent items seem to be targeted at the same underlying construct. Two factors emerged that explained 63% of the variance and results revealed items associated with their construct in the pilot questionnaire did indeed load upon the intended construct having a factor loading criterion of above 0.3 coefficient. Thus, this process was carried out to validate that the instrument was functioning as intended. The researcher then employed a reliability function which reveals the questionnaire's reliability values in terms of Cronbach's alpha (α). This is a statistic to estimate reliability of the pre- and post-survey instrument used in the present study. The survey data analyzed from the pilot test represented a total of 95 participants who took the interest/attitude assessment during the 2018-2019 academic school year. Cronbach's alpha is often used to assess internal consistency: and this statistic reflects how closely related a set of items are as a group. Internal consistency is used to evaluate the extent to which items on a scale relate to one another. Taber (2018) stated that Cronbach's alpha is commonly used in science education studies as an indicator of instrument or scale reliability or internal consistency and reflects the extent to which different subsets of test items would produce similar measures. Taber (2018) also stated that it remains common practice in science education to consider alpha reaching value of 0.70 as a sufficient measure of reliability or internal consistency of an instrument. Nardi (2014) stated that an internal consistency reliability coefficient of 0.92 reflects a very strong relationship between the items on the test. The closer the correlation coefficient is to 1.0, the more reliable it is. Thus, it is considered to be a measure of scale reliability and allows the researcher to determine if the 5-point Likert scale is reliable or not (p. 65). For the pilot-survey responses, $\alpha = .832$. The pre- and post-survey used in this study was also assessed for reliability using Cronbach's alpha. The pre- and post-survey used in this study was also assessed for reliability using Cronbach's alpha. For the pre-survey responses, $\alpha = .863$. For the post-survey responses, $\alpha = .894$. The researcher employed pre and post-intervention descriptive statistics as well as the Kruskal-Wallis mean rank test to compare between the three groups for each item to reveal any significant differences between them. Results indicated that there were significant differences within some of the respective items, so the researcher employed a series of *Mann-Whitney tests* and compared two populations (student groups) at a time which provided mean ranks for each, with a *Bonferroni* correction to control for type 1 errors. Similarly, the researcher divided alpha by the number of comparisons, which was three total. Hence, the statistical significance level for the *Bonferroni* correction was $\alpha = .05/3 = 0.017$. The final sample size was N = 55. Results are reported in Chapter 4 of this paper. Further, the pre-intervention and post-intervention closed-survey quantitative instrument in this study was taken by participants using Google Forms Platform in the classroom similar to the content assessment described previously. For those participants without access to the computerized Google Forms, or preferred to take the survey with paper/pencil, the paper survey forms were later inputted by the researcher. Google Forms allows student responses to automatically end up in a spreadsheet format that is updated as new submissions are received. Likewise, graphs can then be easily created based on data in the spreadsheet.

3.9 Classroom Visits to Establish Fidelity of Unit

The researcher was present in teachers' classrooms to observe participants during specific anchoring events in the classroom. The specific anchoring events in the classroom included: engineering and constructing closed recirculating systems, fish and plant stocking, water quality testing, weekly or bi-weekly fish sampling, harvesting, data collection, calculations, and participants' oral presentations at the conclusion of the unit. These frequent visits thereby helped establish and confirm fidelity of the intervention implementations. The researcher collected checklists of specific lessons to confirm the formative activities, videos, and classroom discussions were implemented in a manner consistent with the ideals and goals of the project and unit. However, there was variance across teachers because of their expertise, time, teaching situations, and other factors described previously. The researcher stayed in contact with each teacher on a weekly basis through email and/or text messages to help establish fidelity of the unit.

3.10 Intervention (Unit) Design

3.10.1 Carrying Capacity Key Concepts. Ecosystems have *carrying capacities,* which can be explained as the maximum number of species the ecosystem can support (Monte-Luna et al. 2004). The authors conveyed that any given ecosystem is capable of sustaining organism populations based on the limiting factors of food, water, shelter, and space. However, as for populations and communities, an ecosystem presents a finite resource base for its constituent. Participants learned in this study the concept that quantity can affect these capacities relating to feed input. Menczer (1998) suggested that carrying capacities is a two-fold notion: the individuals (or biomass) and the factors that control their growth performance. Hence, the author asserted that combining both elements would reflect more completely what the concept really represents, while Paine (1966) asserted that in certain environments, space is the main determinant of carrying capacity. However, within the aquaponics system in the present investigation, the carrying capacity was dependent primarily upon the quantity of feed entering the environment at a particular fish density or biomass. During the large tank project-based investigation, participants learned through their real-world, hands-on experiences that feeding is the most important daily activity and feeding rates may need to be adjusted to fit a recirculating water system according to *capacity* of the biological and mechanical filters and the availability of nitrifying beneficial bacteria present in an aquaponics ecosystem. Participants while working in groups explored in their investigation(s) how the abundance of feed input at a maximum inclusion rate may change and influence the availability of the bacteria compared to a lower inclusion rate over time.

3.10.2 **Aquaponics key concepts**. Fox et al. (2010) stated that the *aquaponics* concept involves integrating aquaculture and hydroponics, where fish wastewater is utilized as a nutrient source for the plants grown in soilless culture. Aquaponics is considered an efficient sustainable method of growing plants and fish together in a closed recirculating system. Schneller et al. (2015) stated that because aquaponics simultaneously grows edible plants and raises fish in a closed-loop system, the technology can increase the availability of food, thus addressing food security.

3.10.3 ***Project-based investigation (PBI) model***. The intervention in the present project was designed around a project-based investigation (PBI) model that is well documented in the literature (Wilhelm & Confrey 2005; Wilhelm et al., 2008; Krajcik & Blumenfeld 2006; Singer et al., 2000; & Polman, 2000). A definitive component of PBI is to identify the driving research question (Krajcik & Blumenfeld, 2006). It guides the intervention design and is a driver for learning. Other necessary criteria for a project classroom is benchmark lessons to scaffold understanding (Singer et al. 2000) and milestones to give participants feedback and time for revisions (Polman, 2000). Wilhelm and Confrey (2005) reported this project criteria design which followed a student-driven research question, benchmark lessons to build on content understanding, and gave students feedback and time for revisions. Edelson et al. (1999) stated that project-based instruction that embraces driving research questions, benchmark lessons, and milestones can provide opportunities for participants to improve their understanding of scientific and mathematical practices by problematizing various situations, placing a demand for knowledge, discovering new principles, refining preexisting understanding, and applying understanding while pursing answers to research questions. Wilhelm et al. (2008) found that environments rich in projects allow participants to (a) engage in contextualized problem solving, (b) make connections within and across disciplines, (c) develop reasoning skills, and (d) accurately represent and communicate concepts. Student-driven investigations were the focus of the project-based model utilized in the present study. This section explains how these emerge and incorporated in the intervention model.

The PBI unit was designed to lead participants through an inquiry into aquaculture (i.e., fish farming) and hydroponics (i.e. growing plants in nutrient-rich water) and the underlying concepts were centered on the specific phenomenon - *carrying capacity*. The PBI intervention model first emerged as "whole-class" group investigation project of an aquaponics system in the classroom. The student-driven research question was: *How does nutrient input affect the carrying capacity of our aquaponics ecosystem*? The teachers and researcher selected the driving question prior to the study. This 8-week investigation was the classroom model used for to anchor the benchmark lessons and other learning experiences. Participants investigated how the amount of feed (i.e., nutrient input or feeding rate) in an aquatic ecosystem can influence water quality parameters and the productivity of fish and plants over time (i.e., as a measure of carrying capacity). Focus of benchmark lessons to scaffold understanding, formative assessments in which some were used as milestones, and contextualized classroom experiences was on the role of nutrients (i.e., amount of feed input) introduced into the aquaponics system. Thus, the 8-week whole-class investigation provided participants opportunities to think about the aquaponics system's response to nutrient input and how added nutrients can challenge the functioning of the ecosystem. Through collaborative experiences with the whole-class aquaponics system, participants were to learn that there are limits and boundaries limited the productivity these models can support. Furthermore, these experiences led to the incorporation of 4-week student-driven investigations (e.g., mini-tank group projects) that emerged from the whole-class project which fits a project-based model. Hence, the 4-week model was the student-driven investigation portion of the project.

3.10.4 *Major objectives of unit*. The major objective of the unit was to build student understanding of standard-based concepts regarding *carrying capacity* through investigating a real-world aquaponics ecosystem in the classroom. Participants worked through their large tank carrying capacity investigation (e.g., classroom model project) and were to think about the importance of identifying patterns and trends, how their aquaponics recirculating system can be used as a model to study natural phenomena, how living things or ecosystems go through periods of stability and change, and the different types of investigations that can be designed and carried out by scientists as it relates to aquaculture and aquaponics which led to their mini-ecosystem small group investigations. Another major objective of the unit was to develop participants' scientific and mathematical practices and reasoning skills in the classroom. An example of the scientific practices involved measuring important abiotic water quality parameters such as total ammonia nitrogen (TAN), nitrite, nitrate, total alkalinity, pH, dissolved oxygen, and temperature. Participants were also exposed to the basic concept of the nitrification process whereby nitrifying bacteria convert ammonia to nitrite-nitrogen and then to less toxic nitrate-nitrogen. This aligns with NGSS HS-LS2-4 as participants used mathematical representations to support claims for the cycling of matter and flow of energy among organisms in an ecosystem. The unit also provided participants opportunities to practice engineering design. They developed and used models, defined problems, and designed solutions for engineering their recirculating aquaponics system. They collaboratively designed, setup, and integrated their aquaponics system that rested above a fiberglass tank where the fish resided. The teacher's had participants work in small groups and create a written and/or physical model of their proposed aquaponics system early on in the unit. Participants in the classroom were responsible for maintaining their aquaponics system and problem solve to come up with solutions throughout the project-based unit similar to a real-world engineer. A third major objective of the unit was to create and authentic scientific community through which they worked and investigated interactions within the closed aquaponics ecosystem. The intervention incorporated collaborating learning through roles (i.e., rotating jobs), each member delivered different information to provide a comprehensive view of the environment under study. Participants learned the relationship between the parameter change at different scales and the *carrying capacity* of the ecosystem based on evidence (i.e., claim, evidence, and reasoning). The intervention also developed participants' basic applied scientific knowledge commonly associated with aquaculture research. The student tasks to investigate interactions within their closed aquaponics systems included: 1) investigate growth performance of fish and plants; 2) monitor the nitrogen cycle; 3) analyze and interpret quantitative data; 4) compare relationships among interdependent factors in ecosystems (i.e., ecological relationships); 5) and use mathematical representations to support and revise explanations based on evidence about factors affecting populations in ecosystems of different scales. In the case of the latter, the purpose was to find the average; identify the trends; utilize graphical comparisons of multiple sets of data (i.e., mathematical representations) gathered from each participating school; and they acquired STEM-related skills to make graphs and charts from these investigative experiences.

3.10.5 *Benchmark lessons and activities in unit*. Benchmark lessons in this unit were developed by outside aquaculture/aquaponics experts (The Aquaponics Source Inc., Boulder, CO), the three biology teachers who participated in the project, and researcher who had knowledge of available aquaculture education resources. It should be noted that Teacher B was instrumental in designing many of benchmark lessons and activities in this unit. The whole-classroom model project was integrated in the unit and used as an anchor around which to build benchmark lessons and develop participants' background knowledge, science and engineering skills, and introduce fundamental ideas needed to conduct their own mini-research, student-centered investigations (via group project work). Wilhelm and Confrey (2005) found in their design the need for enacting the benchmark activities and group project implementation features simultaneously. As a result, the authors discovered a notable phenomenon that emerged during their study as the participants (who had a driving research focus) thought about and connected their group project work with benchmark activities, which led to conceptual understanding. Participants in this project began asking their own questions and ultimately decided upon one question to research and pursue early on in the curriculum while engaged in the whole-class project. They started their own group projects at week six of the unit. Multiple formative assessment activities were integrated throughout the APBI unit. Formative assessment activities are considered a key component of PBI designed to provide participants immediate feedback. These activities not only developed participants' knowledge and skills, but also prepared them for their group oral presentations (i.e., large tank investigation and mini-system investigation) at the end of the unit (i.e., culminating event). The benchmark lessons and formative assessment activities within the APBI unit are summarized below and provided in Table 3.12 (see below).

Benchmark lesson 1 (week 1): Controlled Experiment. In this lesson the learning outcome targets pertained to the elements of a controlled experiment (i.e., investigation question, control group, independent variable, dependent variables, and constant variables). Likewise, participants watched a video*, Ants That Count – Research Study Analysis* on YouTube to gain more knowledge in this lesson. Lastly, a formative assessment activity had participants draw a simple comic strip that showed an experiment without a control that does not properly plan for the element of a controlled experiment (15 min time limit), and then make connections to their upcoming experimental design investigation using their newly assembled aquaponics system in the classroom.

Benchmark lesson 2 (week 1): Aquaponics System Engineering and Design. In this lesson participants were introduced to the concept aquaponics. They were to observe a basic aquaponics diagram, ponder how their aquaponics system needed to be constructed to optimize fish growth, and become aware and knowledgeable of the different components they have to build the system (i.e., submersible water pumps of different sizes and function, filters and function, biofilter media and function, air pump and function, and water heater and function). Participants were to submit a proposal of how should the biofilter media be arranged with the goal of maximizing the growth of beneficial bacteria while minimizing the chance of water overflow; and they listed project goals, criteria, and constraints. Formative Assessment Activity: *Building an Aquaponics System Student Plan*. Participants designed a proposal about what configuration of bio media did they propose for the filter box.

Benchmark lesson 3 (week 1): Adding Bacteria. In this lesson participants learned why bacteria are important in aquaponics, focused on the two types of bacteria, where they think these nitrifying bacteria will grow in the system, the role of the bacteria within the ecosystem, learned about the nitrogen cycle, and what happens when an aquaponics system is cycled. Formative Assessment Activity: *Drawing Picture of the Nitrogen cycle*. Participants participating in the project annotated their chart and cycle drawing to show their understanding.

Benchmark lesson 4 (week 2): Koi Carp Introduction. In this lesson participants obtained a general overview of Koi carp as they were used in the large tank investigation.

Benchmark lesson 5 (week 2): Introduction to Aquaponics. In this lesson participants learned more about what aquaponics is, how it works, and why it is a valuable source of food. Participants were to learn that aquaponics is an ecosystem in which plants and fish are grown together. They learned that an ecosystem is a system where living things depend on one another and their environment to grow and flourish. Formative Assessment Activity: *Drawing Picture of an Aquaponics System*. Participants drew an image of what *their* aquaponics system would look like if you could set it up anywhere. They had to include the components required to keep the system going.

Benchmark lesson 6 (week 2): Introduction to Aquaculture. In this lesson participants became aware of over-fishing the oceans which has become an important problem, they learned about aquaculture as a solution to the problem, they learned about recirculating aquaculture systems (RAS), and understanding how the aquaponics cycle works to benefit both the fish and the plants. Formative Assessment Activity: *Fish in a Bucket Whole Class Investigation*. Participants investigated the question, "how do ammonia levels change if fish water is not allowed to mix with plants?" and identified the independent variable, dependent variable, constants, described a control situation (normal conditions), described experiment situation (experiment conditions), hypothesis (what do you think will happen based on what you know right now?), reported evidence, claim, and reasoning.

Benchmark lesson 7 (week 3): Koi Spawning, Growth, and Feeding Video. In this lesson participants watched an education YouTube video taught by Dr. Boris Gomelsky who is a Professor at Kentucky State University and learned about why Koi are good fish for raising in recirculating and aquaponics systems.

Benchmark lesson 8 (week 3): Advanced Aquaponics Lesson. In this lesson participants learned the benefits to using an aquaponics system. The lesson was designed to help participants understand why anyone would take on the project of aquaponics, and especially in their own classroom. Participants learned a few benefits: an aquaponics system necessarily produces food that is free of chemicals (necessarily organic produce), uses far less water than traditional soil-based gardening (1/10 the water of dirt gardening), treats waste as valuable input into the plant growing part of the system (turning a waste disposal problem into a valuable input), growing your own food in your own backyard no fossil fuel is used to transport it, free from deer, dogs and bunnies (no pesky herbivores to get the pick of your garden), weed free (no weeds to pull), no dirt, no watering, no fertilizing (nature of the system, fertilization happens automatically), fish are safe to eat since you have complete control over every factor and they are fresh, and the fish are ecological such as you are lessening the demand for fish from our oceans and you are not using energy to ship frozen fish from faraway lands.

Benchmark lesson 9 (week 3): Human Impact on Biodiversity. In this lesson participants learned about designing, evaluating, and refining solutions for reducing the impacts of human activities on the environment and biodiversity. Formative Assessment Activity: *Investigate Best Solution for Farming/Fishing*. They prepared a presentation of their choice to compare and communicate the difference between traditional farming/fishing and aquaponics farming/fishing. They included scientific argument (claim, evidence, and reasoning), bibliography, presentation and self-evaluation.

Benchmark lesson 10 (week 4): Advanced Bacteria Lesson. In this lesson the learning targets were to understand, in a very general sense, what bacteria are, realize that not all bacteria are bad, understand that bacteria can be helpful to humans and plants, understand that the nitrogen plants come indirectly from the waste of the fish, and learn more about the two critical types of bacteria in the aquaponics system and that each plays a role in converting toxic ammonia to helpful nitrates. Formative Assessment Activity: *Drawing Diagram of the Nitrogen Cycle in the Aquaponics System*.

Benchmark lesson 11 (week 4): Ecological Succession. In this lesson the learning targets were to differentiate between primary and secondary ecological succession, identify pioneer species and describe their importance in ecosystem succession, predict the progression of organisms as an ecosystem undergoes succession, differentiate between aerobic and anaerobic processes, and apply understanding of ecological succession to the cycling of a new aquarium.

Benchmark lesson 12 (week 5): Carrying Capacity. This was a primary lesson of the unit. The learning targets were describing how populations change over time using the concepts of birth rate, death rate, immigration, and emigration; differentiate between exponential and logistical growth patterns in populations; explain factors that affect population growth patterns; identify carrying capacity for a population given a set of parameters; and predict future population growth patterns based on changes to limiting factors in an ecosystem. Formative Assessment Simulation Activity: *Carrying Capacity Formative Assessments (2 total)*. Participants were given data from a simulation computer-based program provided by the teacher. Participants working in small groups were to identify the independent variable, dependent variable, and name three constants present in the data. They were to answer how does decreasing the grass growth rate affect the carrying capacity of the rabbit population in the simulation? They were to answer how is the carrying capacity of rabbits affected by an increase in available grass energy?

Benchmark lesson 13 (week 6): Group Behavior. In this lesson the learning targets were to distinguish between group and individual behavior, identify examples of group behavior in several different animal groups, and evaluate how group behavior increases the chance of survival for both the individual and the species. Formative Assessment Activity: *Group Behavior Assessment*. Participants were to answer what is the purpose of an animal to survive. Is it better to be alone or to be part of a group? After watching multiple videos in class, they were to answer questions using a chart on group behaviors. They then identified group behaviors within the aquaponics system.

Benchmark lesson 14 (week 7): Carbon Cycle. In this lesson the learning targets were to identify the atomic structure of carbon, identify where carbon atoms are part of each system (atmosphere, geosphere, hydrosphere, and biosphere), explain how carbon atoms moves from one system to another, identify how rates of photosynthesis and cellular respiration affect the carbon movement within these systems, and identify and propose a solution for a closed aquaponics system with high CO_2 in the hydrosphere. Formative Assessment Activity: *Carbon Cycle Assessment*. Participants took an assessment on carbon cycle and identified what carbon is, how carbon moves through plants and through animals, where carbon atoms are located on earth, how carbon atoms move through Earth's systems, and how carbon atoms move through an aquaponics system.

Benchmark lesson 15 (week 8): Ecosystems. This was also a primary lesson of the unit. The learning targets were to understand that ecosystems can take-on a number of different forms and appearances, to understand that organisms within an ecosystem interact with their environment and each other, to understand that species are interdependent, to understand that the loss of one species may affect another, even if those species do not interact directly, and to understand that ecosystems are fragile.

Benchmark lesson 16 (week 8): Energy in Ecosystems. In this lesson the learning targets were to differentiate between energy and matter, differentiate between autotrophs and the different types of heterotrophs, construct a food web representing at least four trophic levels, identify the energy conversions within an aquaponics system, identify how the law of conservation of energy is upheld within an aquaponics system (ecological pyramids, what happens to the energy not passed on to the next level? where is the original source of energy for aquaponics systems?), and identify how the law of conservation of matter is upheld with an aquaponics system (referencing carbon and nitrogen cycles). Formative Assessment Activity: *Energy in Ecosystems Assessment*. Participants were to draw/describe representations of energy in an ecosystem of their choice (food web, pyramid of numbers, energy pyramid, or biomass pyramid). They were asked specific questions regarding biomass pyramids for their aquaponics system, and other tasks related to the subject.

Benchmark lesson 17 (week 9): Biodiversity. In this lesson the learning targets were to design or simulate a population growth model by manipulating environmental conditions given population graphs or charts containing data, analyzing the history or predict the future of an ecosystem, interpret population graphs or charts containing authentic, real-world data about changes in biodiversity, and explain the importance of biodiversity using a scientifically accurate definition. Formative Assessment Simulation Activity: *Biodiversity Impact on Carrying Capacity Assessment*. Participants were engaged in an ecology lab simulation which allowed them to create different food chains and webs within a model ecosystem. They reported observations (what they saw) and made inferences (what it might mean). After they were comfortable with using the simulation, they gathered data to answer the investigative question.

Table 3.12 Specific Components of the APBI unit

Unit Lesson Plans Outline

FOCUS: Carrying Capacity

Week	Benchmark Lesson	Assessment
1	Prior to starting the unit: • Controlled Experiment Lesson Slides • Table Top Twitter • Ants That Count Video • Aquaponics System Engineering & Design • Adding Bacteria Teacher Guide & Lesson Slides • Researcher transported fish and plants to each class	Ants That Count Research Summary GO HS-ETS1-2 Filter Design Proposal Nitrogen Cycle Annotation
2	Introduction to Aquaponics & LARGE TANK INVESTIGATION • KOI INTRODUCTION - Lesson (incorporated first 20 minutes of education video). • Aquaponics Jobs Introduction • Introduction to Aquaponics Teacher Guide & Slides • Aquaculture Lesson Teacher Guide & Slides	Koi Carp Intro Example Draw an Aquaponics System Fish in a Bucket CER (Whole class investigation) CER Research Summary GO
3	Aquaponics Benefits • Advanced Aquaponics Teacher Guide (HS-LS2-7 & HS-ETS1-1) & Lesson Slides • Human Impact on Biodiversity (HS-LS2-7) • Researcher visited each classroom	HS-ETS1-1 Global Challenge & HS-LS2-7 Human Impact
4	Aquaponics - Nitrogen Cycle & Ecological Succession • Set up small tank systems • Advanced Bacteria Teacher Guide (HS-LS2-3) & Lesson Slides • Ecological Succession Lesson (HS-LS2-6)	HS-LS2-3 Nitrogen Cycle Diagram HS-LS2-6 Ecological Succession

<table>
<tr><td>5</td><td>Carrying Capacity Lecture (HS-LS2-1)
Back to the Roots Teacher Guide (Resource)</td><td>HS-LS2-1 Carrying Capacity</td></tr>
<tr><td>6</td><td>SMALL TANK INVESTIGATION
Group Behavior
HS-LS2-8 Group Behavior Lesson
Start Small Mini-Tank Investigation this week
First Plant Harvest & Rotation
Researcher transported red claw crayfish and plants to each classroom</td><td>HS-LS2-8</td></tr>
<tr><td>7</td><td>Carbon Cycle
Carbon Cycle Lesson (HS-LS2-5)
Fish Pond Interactions Article
Table Top Twitter
Researcher visited each classroom</td><td>HS-LS2-5 Carbon Cycle
Fish Pond Assessment</td></tr>
<tr><td>8

Fall Break</td><td>Energy Transfer
Aquaponics - Energy Transfers
Ecosystems Teacher Guide & Lesson Slides
Energy in Ecosystems (HS-LS2-4)</td><td>HS-LS2-4 Energy in Ecosystems</td></tr>
<tr><td>9</td><td>Biodiversity
Biodiversity Lecture (HS-LS2-2)
Aquaponics Group Summary Template
End 4-week small tank investigation
Researcher visited each classroom
The final presentation of learning should include elements from all of the standards explored in this unit.</td><td>HS-LS2-2 Biodiversity impact on Carrying Capacity</td></tr>
<tr><td>10</td><td>Classroom final presentations

The opportunity to present learning to an authentic audience is an essential component of project based learning.</td><td>Teacher Presentation Rubric</td></tr>
</table>

3.10.6 *Description of unit connections to current NGSS standards*. Student tasks in the APBI unit were designed to connect to current NGSS standards (see Appendix D) and support participants' interest. The various activities participants were engaged in may not only improve and promote their interest and attitudes toward aquaculture, aquaponics, and STEM, but also build their content knowledge in the selected content areas. As mentioned in Chapter 2, *carrying capacity* was the phenomenon under study in the APBI unit and is the central concept of the NGSS life science core idea Ecosystems: Interactions, Energy, and Dynamics (NGSS for Lead States, 2013), heretofore referred to as the core idea of Ecosystems. The unit addresses ecosystem performance expectations HS-LS2-1 through HS-LS2-4 and HS-LS2-6. See Appendix D for a delineation of these selected performance expectations. To elaborate, these target performance expectations draw upon practices of mathematical and computational representations to support explanations of factors that affect *carrying capacity* of ecosystems at different scales. Notably, the boundary clarification statement explains that emphasis is on quantitative analysis and comparison of the relationships among interdependent factors including boundaries, resources, climate, and competition. Mathematical comparisons may include graphs, charts, histograms, and population changes gathered from various data sets. The unit addressed three of the disciplinary core ideas (DCI) contained within the core idea of Ecosystems. The first DCI is LS2.A: Interdependent Relationships in Ecosystems, which states: Ecosystems have carrying capacities, which are limits to the numbers of organisms and populations they can support. These limits result from such factors as the availability of living and nonliving resources and from such challenges such as predation, competition, and disease. Organisms would have the capacity to produce populations of great size were it not for the fact that environments and resources are finite. This fundamental tension affects the abundance (number of individuals) of species in any given ecosystem (NGSS for Lead States, 2013). The crosscutting concepts of HS-LS2-1 indicates that the significance of a phenomenon is dependent on the scale, proportion, and quantity at which it occurs. The science and engineering practices of this NGSS-HS-LS2-1 involves using mathematics and computational thinking such as using representations of phenomenon or design solutions to support explanations. Another NGSS that addressed the phenomenon under study includes HS-LS2-2, which described in the student performance expectation, the usage of mathematical representations to support and revise explanations based on evidence about factors affecting biodiversity and populations in ecosystems of different scales. Notably, the clarification statement states that examples of mathematical representations include finding the average, determining trends, and using graphical comparisons of multiple sets of data. The disciplinary core ideas of HS-LS2-2 states the following: A complex set of interactions within an ecosystem can keep its numbers and types of organisms relatively constant over long periods of time under stable conditions. If a modest biological or physical disturbance to an ecosystem occurs, it may return to its more or less original status (e.g., the ecosystem is resilient) as opposed to becoming a very different ecosystem. Extreme fluctuations in conditions or the size of any population, however, can challenge the functioning of ecosystems in terms of resources and habitat availability (LS2.C, Ecosystem Dynamics, Functioning, and Resilience). Particularly, the disciplinary core ideas aligned well with the intervention. The crosscutting concepts indicate that using the concept of orders of magnitude allow one to understand how a model at one scale relates to a model at another scale. The science and engineering practices of HS-LS2-2 involve using mathematical representations of phenomenon or design solutions to support and revise explanations. Participants in the project were asked to make claims from evidence and reasoning as the complex interactions in aquaponics ecosystems maintain relatively consistent numbers and types of organisms in stable conditions, but changing conditions may result in a new ecosystem which connects with HS-LS2-6. Likewise, there are connections to nature and science as scientific knowledge is open to revision in light of new evidence. Most scientific knowledge is quite durable, but is, in principle, subject to change based on new evidence and/or reinterpretation of existing evidence (HS-LS2-2). Participants was also exposed to the basic concept of the nitrification process (i.e., nitrogen cycle) whereby nitrifying bacteria convert ammonia to nitrite and then to less toxic nitrate. This aligns with NGSS HS-LS2-4 as participants used mathematical representations to support claims for the cycling of matter and flow of energy among organisms in an ecosystem. The engineering practices in the project aligns with the Engineering, Technology, and Applications of Science (ETS) domain. High school participants were engaged in Engineering Design as the primary fundamental concept. Analyzing a major global challenge to specify quantitative and qualitative criteria and constraints for solutions to account for societal needs and wants is a student performance expectation of NGSS-HS-ETS1-1. Participants analyze complex real-world problems by specifying criteria and constraints for successful solutions (HS-ETS-1, Science and Engineering Practices). The disciplinary core ideas state that humanity faces major global challenges today, such as the need for supplies of clean water, food, and energy sources that minimize pollution, which can be addressed through engineering. These global challenges also may have manifestations in local communities. The crosscutting concepts indicate that new technologies can have deep impacts on society and the environment, including some that were not anticipated. Further, analysis of costs and benefits is a critical aspect of decisions about technology. The engineering practices also aligns with HS-ETS1-2 as participants were to design a solution to a complex real-world problem by breaking it down into smaller, more manageable problems that can be solved through engineering. The engineering practices in the classroom also aligns with HS-ESS3-4: Evaluate or refine a technological solution that reduces impacts of human activities on natural systems (HS. Human Sustainability; Earth and Space Sciences). The disciplinary core ideas state that scientists and engineers can make major contributions by developing technologies that produce less pollution and waste and that preclude ecosystem degradation. The crosscutting concepts state that engineers continuously modify these technological systems by applying scientific knowledge and engineering design practices to increase benefits while decreasing costs and risks. The engineering practices also align with NGSS HS-LS2-7 as participants were to design, evaluate, and refine a solution for reducing the impacts of human activities on the environment and biodiversity. Participants in the project developed a small-scale indoor (classroom) aquaponics system which they designed, engineered, and managed. The aquaponics systems operated at each participating school represents a small model of large-scale aquaponics systems used currently in aquaculture for farm-raised fish, shrimp, and other organisms. The use of aquaculture systems is a new technology that can reduce impacts of pollutants and waste released to the environment, thus providing sustaining and environmentally friendly farming practices to sustain an ever-growing human population. Through experience of managing their own aquaponics systems, participants were to learn how closed recirculating systems such as this are designed to raise large quantities of fish in relatively small volumes of water. The water is treated to remove toxic waste products and so it can be continually reused. Participants were to learn the concept that these new technological systems (e.g., aquaponics) can minimize costs, since closed recirculating systems have very little daily water exchange (less than 2 percent) and use 90% less water compared to traditional farming practices of plants grown in soil. It is important to note that the curriculum topics and content also aligns well with the eight science and engineering practices (National Research Council [NRC], 2011) which includes: 1) Asking questions and defining problems; 2) Developing and using models; 3) Planning and carrying out investigations; 4) Analyzing and interpreting data; 5) Using mathematics and computational thinking; 6) Constructing explanations and designing solutions; 7) Engaging in arguments from evidence; 8) Obtaining, evaluating, and communicating information.

3.10.7 *Student-designed investigations*. As mentioned previously, there were two investigation models in the project that offered teachers opportunities to get their participants involved in collaborative, inquiry-based group activities in the classroom that aligns to the driving question. First, there was an 8-week investigation as the *classroom model* that began at the beginning of the unit involving a large aquaponics system and used to anchor the benchmark lessons, develop student knowledge and skills needed to conduct their own investigations, and *guide the classroom study* that connected to the driving question and most utilized aspects of the anchoring events. Second, the 4-week model was the student-driven investigation portion of the project. This model was essentially mini models to the larger whole-class aquaponics ecosystem whereby student participants designed their own small group experiments. Both were designed to engage participants in active investigation (e.g., research-engagements) as they learned by applying science and engineering practices as they gathered and analyzed data, share, and support conclusions. Participants in the project, while working in small groups, came up with their own sub-driving investigative questions (e.g., student-driven investigation portion of the project) that related to the phenomenon *carrying capacity*. Participants developed driving questions early on during their classroom model investigation while working in small groups. Milestones were incorporated by the teacher to provide participants' feedback on research design, data collection/analysis methods, and initial findings concerning their mini-research projects. The researcher stayed in communication and provided support with each participating teacher regarding students own investigations. Wilhelm and Confrey (2005) stated that in a project-enhanced environment, the project begins on the first day of the unit and continues throughout the unit. The project component is used as driving tool that assists with students' learning and connection-making where the students become experts of their particular project piece (pp. 44-45). After the participants completed their research, the project-based unit concluded with a final presentation (i.e., tangible product or artifact) by participants to their peers, teachers, school administrators, and researcher. Likewise, their parents and community members were invited to this culminating event. The final group presentations allowed participants to share their learned expertise, activities, anchoring events, and communicate the results of the experiments conducted during the unit and bring closure the project. Prince and Felder (2006) explained that project-based instruction centers on an authentic task, but is distinguished from other forms of inductive learning by its focus on the creation of a product – often a report or visualization presentation(s) detailing the participants' response to a driving question, as a driver for learning.

3.10.8 *Collaborative tasks with peers during the 8-week large tank (whole-class) investigation*. Participants from each school in the project while working collaboratively in small groups (2-4 total) were assigned one of eight (8) job descriptions each week which included: 1) *Research Supervisor*, 2) *Social Media Specialist - Agriculture Communications*, 3) *Veterinarian*, 4) *Ichthyologist – Biomass*, 5) *Environmental Scientist – Water Quality (Ammonia, Nitrite, and pH)*, 6) *Environmental Scientist – Water Quality (Alkalinity, Dissolved Oxygen, and Nitrate)*, 7) *Systems Engineer*, or 8) *Botanist – Lighting and Biomass*, respectively. Thus, each group was able to participate in all jobs by the time the intervention ended, since the large tank (whole class) investigation had a duration of eight weeks. These tasks assigned to participants in the classroom while engaged in the large tank investigation promoted a team work approach and encouraged them to take ownership throughout their direct learning experience. As mentioned previously, incorporating collaborative learning through roles (rotating jobs) creates and authentic scientific community through which they will work. Rotating jobs provided participants' opportunities to investigate interactions within their large tank aquaponics system as each member collected different information to provide a comprehensive view of the environment under study. Pea and Gomez (1992) stated that project involve conversations that have two-way transformational communication, whereas the standard one-way (teacher to student) transmission. Incorporating specific rotating roles (jobs) each week in the present study intervention allowed learners to encompass both each other (participants) and their teacher as they worked through their scientific group project work.

3.10.9 *The eight week classroom model investigation*. Teacher D participants were to discover if the maximum nutrient (feed) input level (3% of body weight per day) challenge the functioning of their aquaponics system and ultimately cause water pollution. Teacher B participants explored a moderate nutrient (feed) input level (2% of body weight per day), while Teacher C participants determined whether the low nutrient inclusion level (1% of body weight per day) created stable conditions over time. In this scenario, the nitrifying bacteria may be able to keep up with the nutrient input entering into the ecosystem. Participants were to discover that there may be limits in their ecosystem at each respective school. Overall, emphasis was on "evidence-based" quantitative analysis and comparison of the relationships among interdependent factors and the factors that affect *carrying capacity* of ecosystems at different scales. In terms of the potential outcomes, the lower nutrient input level may have resulted in poorer lettuce growth and reduced growth performance of fish, but more stable water quality conditions may have occurred compared to the higher nutrient inclusion levels. Conversely, the higher nutrient level explored by Teacher D participants may have affected the carrying capacity of the ecosystem and cause water pollution over time. Several focal students (2-4 total) were selected to orally present the outcomes of the class system to the representative group of the focal students from each school at the conclusion of the project (i.e., culminating product). They were live presentations and the audience was their teacher and classmates. It should be noted that the oral presentations were video-recorded by the researcher and/or teacher. Likewise, all participating students in the project from each school were actively involved in organizing, creating graphs and charts, and preparing the oral presentation regardless if they were chosen to actually orally present it or not. Therefore, the focal students did not do all of the work prior to the final group presentations.

3.10.10 *The four week mini-ecosystems investigation*. The 4-week student-driven model systems (Water Garden; Back to the Roots, Inc.) were introduced into each classroom at week six of the intervention. The 3-gallon scaled-down, interactive mini-fish tanks with above grow-bed for plants allowed participants the freedom to study in depth and to set up small group experiments in the classroom and see changes day to day. Notably, these mini-water garden tanks used the same nutrient film technique and are essentially mini models of the class system designed and constructed in each classroom. The nutrient rich water from the mini-fish tank flows over the roots in the grow-bed tray. Participants were to learn the basic concepts that fish provide the *fuel*, plants provide the *filter*, and the nitrifying bacteria serve as the *engine* for their miniature ecosystems. The purpose behind the mini-ecosystems was to give participants additional opportunities to do investigations in the classroom that are particularly meaningful and interesting to them. Notably, the central driving research question in PBI provides opportunities for participants to conduct their own investigations and thereby create sub-driving investigative questions. Forbes and Davis (2009) stated the following: One way to help participants make connections with individual experiences given the overall focus of the unit is to employ investigation questions. They are similar to driving questions, but are used with individual lessons or investigations, often serving as sub-questions to driving questions (p. 368). Notably, the investigative questions connect to the engineering, scientific, and mathematics practices in addition to the Next Generation Science Standards (NGSS) to promote student learning. In the present project, each participating high school received four (4) to six (6) mini ecosystems which allowed participants to break up into smaller groups (3-5 total) and further investigate the phenomenon under study - *carrying capacity*. It should be noted that each school received juvenile Australian red claw crayfish (*Cherax quadricarinatus*) that were available for their group studies. As mentioned previously, these mini ecosystems were used as models to their larger tank carrying capacity (whole class) investigation. Student participants in the previous 2018-2019 academic year discovered that both red claw and Koi were highly suitable to study when designing their mini model studies. Likewise, the teachers and researcher found that participants participating in the previous projects were eager to conduct their own group investigations in the classroom. A list of student-generated questions below are similar to what was explored during the 2018-2019 academic year. These questions provided options/ideas for the present study participants which included: Water quality (i.e., abiotic factor) as a measure of *carrying capacity*: What is the effect on the water quality of the small tank system as the number of crayfish increases? (Density of 1-2-3-4 crayfish); How is the water quality of the small tank system affected as the type of organism is changed? (i.e. crayfish vs bony fish; control for animal mass & feed in each tank); How does increasing the biodiversity in a small tank affect carrying capacity (measured by water quality)? (i.e., add a water plant to the tank); How does the amount of light affect carrying capacity (measured by water quality)? (i.e., change the amount of light given to tanks - energy input for photosynthesis).

3.10.11 *Student oral group presentations protocol*. Participants were asked to reflect upon their learning and present their 4-week mini-ecosystem group investigations in multiple ways of their choosing such as PowerPoint, Prezi, other presentation software, or even poster presentation (i.e., culminating product). Notably, group presentations were shared and critiqued by those in the classroom similar to the way scientists share their work within research communities. It should be noted that the focal students selected to orally present findings of the 8-week class system investigation followed a similar protocol as participants working in groups informed their audience the following information (but not limited to):

Section 1: What question were you trying to answer and why?

The guiding investigative question:

A. What is your independent variable?
B. What are your dependent variables?

Section 2: What did you do during your investigation and why did you conduct your investigation in this way?

A. Describe how the experiment was conducted.
B. What data did you collect?
C. How did you analyze the data? Why did you decide to do it this way?
    a) Include diagrams, figures, charts, graphs, tables, etc.
    b) Did you check your calculations?
    c) Include one or two images featuring the group at work.

Section 3: What is your argument?

A. Claim (Your answer to the investigation question)

a) What other claims did you discuss before deciding this claim?

B. Evidence (Data)

a) Our justification of the evidence?

b) How was the data collected?

C. Reasoning

a) Convince the audience that your claim is scientifically valid.

b) Explain how their interpretation of the analysis is appropriate.

c) Why they decided to present their evidence in that manner.

d) How confident are you that your claim is valid?

e) What could you do to increase your confidence?

Section 4: How did what you learned relate to the real word?

Overall, the culminating events (i.e., group presentations) in the present project would be considered a tangible, real world outcome (e.g., learner product). This is in agreement with Marshall et al. (2010) who reported that a recent development in PBI is a shift in focus from students' immediate interests toward supporting long-term learning goals. Barron et al. (1998) presented four design principles of PBI that reflect this emphasis on broader learning goals which include: defining learning appropriate goals that lead to deep understandings, providing scaffolding, providing opportunities for self-assessment and revision, and developing social structures that promote participation and sense of agency. The authors explained that the first two are aimed primarily at developing content knowledge, the second two at general educational skills.

CHAPTER 4. RESULTS

The objective of this study was to examine how participation in an authentic, hands-on aquaculture project-based intervention affects the STEM attitudes and short-term interests in STEM disciplines and/or STEM career aspirations of the student participants who were high school level from rural schools in Kentucky. Likewise, this study examined how participation in the project affects students' understanding of the target concepts and the interdependent relationships when studying real-world aquatic ecosystems in the classroom. The goal was to have participants' gain conceptual understanding of the targeted concepts and increase existing positive attitudes toward STEM disciplines and STEM career pursuits.

This chapter provides an in-depth look into the results (via the outcomes) of this investigation. First, this chapter provides the content-aligned assessment outcomes and interpretations of the quantitative objectives which connects to research question 3. This is discussed first because it establishes statistically significant positive changes in students' understanding of targeted concepts. Second, this chapter provides the survey outcomes and the interpretations of the quantitative objectives which connects with research questions 1 and 2, respectively.

4.1 Content-Aligned Assessment Findings (e.g., Research Question 3)

In order to specifically investigate high school level students' understanding of standard-based ecological relationships and concepts as a result of their direct experiences in the project, quantitative data from the pre- and post-intervention content-aligned assessment were utilized which aligns with research question 3. How participation in the aquaponics project-based unit affect high school students' understanding of standard-based ecological relationships and concepts as a result of their direct experiences in the project?

The study examined the "raw" pre and posttest content sum mean scores and 60 being the total possible points. Results revealed that Group 3 students had numerically the highest average *pretest sum score* (12.13) compared to the other three groups. Group 1 students had numerically the second highest average pretest sum score (6.19), while Groups 4 (5.31) and 2 (4.35) were numerically the lowest at the beginning of the authentic, hands-on PBI intervention (unit). A summary of the descriptive statistics when comparing between the four student groups of the *pretest content mean scores* are provided in Tables 4.13 and 4.14.

Table 4.13 Descriptive Statistics for Pretest Content Sum Score Comparison with Respect to the Four Student Groups

	Dependent Variable: Pretest Score		
	M	*SD*	*N*
Group 1 Students (control)	6.19	7.30	31
Group 2 Students	4.35	4.14	20
Group 3 Students	12.13	5.79	15
Group 4 Students	5.31	4.38	22
Total	6.57	6.35	88

Table 4.14 Descriptive Statistics for Pretest Content Sum Score Comparison with Respect to the Four Student Groups (Cont.)

		95% CI	
	SE	*LL*	*UL*
Group 1 Students (control)	1.31	3.51	8.87
Group 2 Students	.93	2.41	6.29
Group 3 Students	1.50	8.93	15.34
Group 4 Students	.93	3.38	7.26

Results revealed that Group 4 students had numerically the highest average *posttest sum score* (37.27) compared to the other three groups. Group 3 students had numerically the second highest average posttest sum score (22.20), while Group 2 students were slightly lower (16.30) and the control group students had numerically the lowest (9.32) average posttest sum score. A summary of the descriptive statistics when comparing between the four student groups of the *posttest content mean scores* are provided in Tables 4.15 and 4.16.

Table 4.15 Descriptive Statistics for Posttest Content Sum Score Comparison with Respect to the Four Student Groups

	Dependent Variable: Posttest score		
	M	*SD*	*N*
Group 1 Students (control)	9.32	7.39	31
Group 2 Students	16.30	11.18	20
Group 3 Students	22.20	7.70	15
Group 4 Students	37.27	5.82	22
Total	20.09	13.56	88

Table 4.16 Descriptive Statistics for Posttest Content Sum Score Comparison with Respect to the Four Student Groups (Cont.)

		95% CI	
	SE	*LL*	*UL*
Group 1 Students (control)	1.33	6.61	12.03
Group 2 Students	2.50	11.07	21.53
Group 3 Students	1.99	17.94	26.47
Group 4 Students	1.24	34.69	39.86

The study also examined the mean difference (improvement) after students took the pre- and post-content-aligned assessment from each school group. Overall, Group 4 students had numerically the highest mean difference (improvement) sum scores at 31.95 when compared to all other student groups. The mean improvement sum scores for Groups 2 and 3 students were numerically similar at 11.95 and 10.07, while the control group students (Group 1) had numerically the lowest mean difference (improvement) sum score at only 3.13 between the pre- and post-content-aligned assessment.

A summary of the descriptive statistics which includes the mean, standard deviation, number of participants who took the pre and post assessment, standard error, and lower and upper bound for overall difference (improvement) sum score comparison with respect to the four student groups are presented in the Tables 4.17 and 4.18. Likewise, a profile plot visual representation showing the estimated marginal means of difference (improvement) of each school is provided in Figure 4.10.

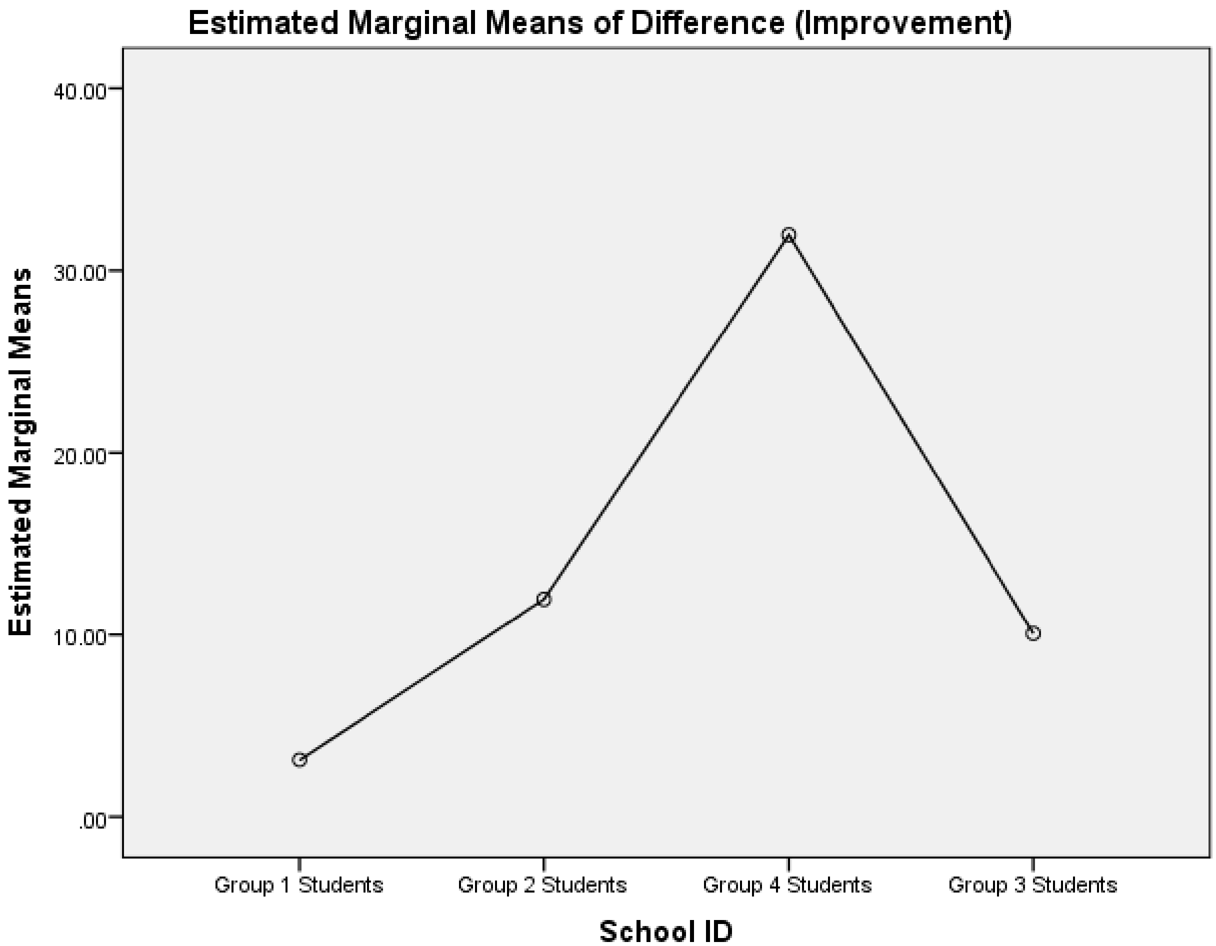
Table 4.17 Descriptive Statistics for Overall Mean Difference (Improvement) Sum Score Comparison with Respect to the Four Student Groups

	Dependent Variable: Difference (Improvement)		
	M	*SD*	*N*
Group 1 Students (control)	3.13	6.05	31
Group 2 Students	11.95	9.57	20
Group 3 Students	10.07	7.61	15
Group 4 Students	31.95	6.72	22
Total	13.52	13.41	88

Table 4.18 Descriptive Statistics for Overall Mean Difference (Improvement) Sum Score Comparison with Respect to the Four Student Groups (Cont.)

		95% CI	
	SE	*LL*	*UL*
Group 1 Students (control)	1.33	.487	5.77
Group 2 Students	1.65	8.66	15.24
Group 3 Students	1.91	6.27	13.87
Group 4 Students	1.57	28.82	35.09

Figure 4.10 Means of Difference (Improvement) Across the Four Groups



For the comparative analysis (between subject design), the researcher sought to find whether there was a difference statistically between the four student group populations. The researcher looked at the *mean difference (improvement)* sum scores between all groups (*N*=88) after participants took the pre-and post-content assessment and data was analyzed by means of the SPSS. To address this objective, instead of using an independent samples t-test, the researcher employed the corresponding non-parametric statistic *Mann-Whitney U and used a series of mean rank tests* to test whether the mean difference (improvement) sum scores between student groups were significantly different or not. As explained previously in Chapter 3, a Mann-Whitney Test Statistic was selected since the assumptions of normal distribution and equal variances of the dependent variable across groups were not met. This procedure compared two populations (student groups) at a time which provided mean ranks for each, with a *Bonferroni* correction to control for type 1 errors. The researcher divided alpha by the number of comparisons, which was six in total. The statistical significance level for the total comparison and then divided across the six comparisons (via *Bonferroni* correction) was $\alpha = .05/6 = 0.008$. It is important to note that Mann-Whitney test puts everything in terms of rank rather than in terms of raw values.

Results from this study revealed a statistically significant difference ($P < 0.008$) when comparing between Group 1 students (mean rank of 20.34) and Group 2 students (mean rank of 34.78) (.001 statistical significance); Group 1 students (mean rank of 19.39) and Group 3 students (mean rank of 32.0) (.003 statistical significance); and Group 1 students (mean rank of 16.0) and Group 4 students (mean rank of 42.5) (.001 statistical significance), respectively. These results demonstrate that the control group students (Group 1) had significantly ($P < 0.008$) lower mean difference (improvement) scores compared to all other student group populations. Likewise, results demonstrate that there was a statistically significant difference ($P < 0.008$) when comparing between Group 2 students (mean rank of 11.23) and Group 4 students (mean rank of 30.84), (.001 statistical significance), and with Groups 3 students (mean rank of 8.13) and Group 4 students (mean rank of 26.41), (.001 statistical significance), respectively. These results demonstrate that Group 4 students had a significantly higher mean difference (improvement) score compared to all other student groups. However, no statistically significant differences ($P > 0.008$) were found when comparing between Group 2 students (mean rank of 18.40) and Group 3 students (mean rank of 17.47) (.805 statistical significance), respectively.

Overall, to summarize, these findings reveal that Group 4 students had a significantly higher ($P < 0.008$) mean difference (improvement) score when compared to all other groups. Hence, data suggests that students from this population (Group 4) had the highest knowledge increase between the pre-and post-content assessment. Likewise, student populations from (Groups 2 and 3 were similar statistically) with respect to mean difference (improvement) scores. However, it is important to note that students' knowledge improved in all three treatment groups and was significantly ($P < 0.008$) higher compared to the control group (Group 1). Clearly, this is a positive outcome in the present study as it was expected that the three treatment groups would have a greater improvement in scores compared to the control group (Group 1), since they participated in the authentic, hands-on intervention in the classroom. Results are provided in Table 4.19.

Table 4.19 Mann-Whitney Rank Test of Mean Difference (Improvement) Between the Pre- and Post-Content Scores with Respect to the Four Student Groups (N = 88)

		Dependent Variable: Difference (Improvement)		
School ID	Two Pop.	Mean Rank	*MW*-test Statistic[a]	Sig.[b]
Group 1	Group 1	20.34	134.500	.001
	Group 2	34.78		
Group 1	Group 1	19.39	105.00	.003
	Group 3	32.00		
Group 1	Group 1	16.00	.000	.001
	Group 4	42.50		
Group 2	Group 2	18.40	142.00	.805
	Group 3	17.47		
Group 2	Group 2	11.23	14.500	.001
	Group 4	30.84		
Group 3	Group 3	8.13	2.000	.001
	Group 4	26.41		

[a]Mann-Whitney U Test Statistic.

[b]Mean difference is significant at the 0.008 level.

Additionally, the researcher sought to find whether or not there was a statistical difference of the *pre- and post-content mean scores* between the four student groups (*N*=88). To address this objective, instead of using a one-way independent, between-group analysis of variance (ANOVA), the researcher employed the corresponding non-parametric statistic *Independent-Samples Kruskal-Wallis Test* by means of the SPSS on specifically the pretest mean rank score and posttest mean rank score (i.e., dependent variables) to determine if there was statistical significance between the four student groups (i.e., independent variables). As explained previously in Chapter 3, a Kruskal-Wallis Test Statistic was selected since the assumptions of normal distribution and equal variances of the dependent variable across groups were not met. As a reminder, the Kruskal-Wallis test (sometimes also called the one-way ANOVA on ranks) is a rank-based non-parametric test that can be used to determine if there are statistically significant differences between two or more groups of an independent variable on a continuous or ordinal dependent variable. Results showed that there were highly statistically significant differences ($P < 0.05$) in both the pretest score and posttest score between the four student groups. For the pretest score, the significance level between groups was .001, while the posttest score significance level between groups was .001, respectively. Results are presented in Table 4.20.

Table 4.20 Kruskal-Wallis Mean Rank Test for the Pretest and Posttest Content Assessment with Respect to the Four Student Groups

Pretest score[a]	School ID	*N*	Mean Rank	Test Statistic[c]
	Group 1 Students	31	40.40	
	Group 2 Students	20	35.73	
	Group 3 Students	15	68.83	
	Group 4 Students	22	41.66	
	Total	88		17.172
Posttest score[b]	Group 1 Students	31	24.18	
	Group 2 Students	20	37.60	
	Group 3 Students	15	49.67	
	Group 4 Students	22	75.89	
	Total	88		54.961

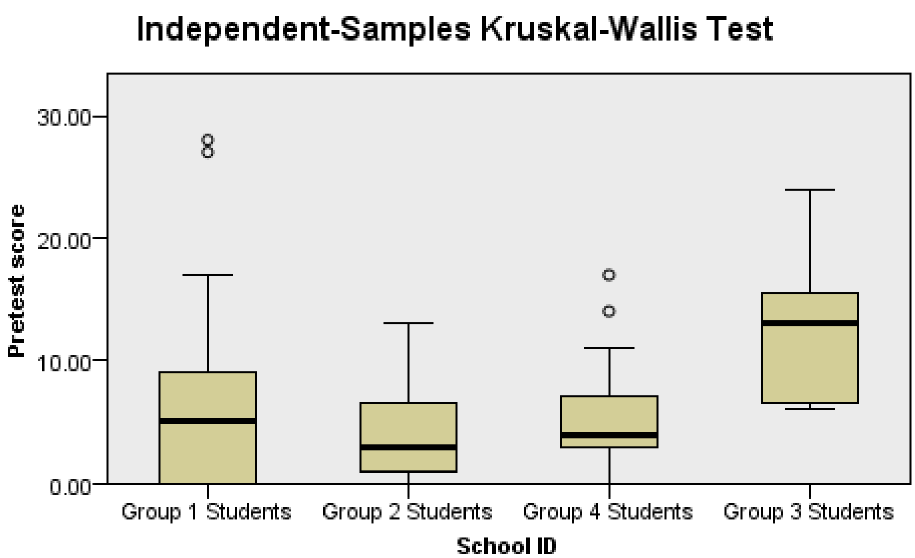
[a]Pretest score $p < 0.05$. (significant difference) between groups = .001

[b]Posttest score $p < 0.05$. (significant difference) between groups = .000

[a](df) = (3)

The Independent-Samples Kruskal-Wallis Test of significance of the *pretest mean rank score* comparison revealed a statistically significant difference ($P < 0.05$) between the four student group populations which includes: Interestingly, Group 3 students had numerically the highest pretest mean rank score (68.83) compared to the other three groups; Group 4 students had numerically the second highest pretest mean rank score (41.66); the control group students (Group 1) had numerically the third highest pretest mean rank score (40.40); and Group 2 students proved to have numerically the lowest pretest mean rank score (35.73) compared to the other student populations, respectively. A visual representation of the pretest mean rank score distribution is provided in Figure 4.11.

Figure 4.11 Independent-Samples Kruskal-Wallis Test of Pretest Score

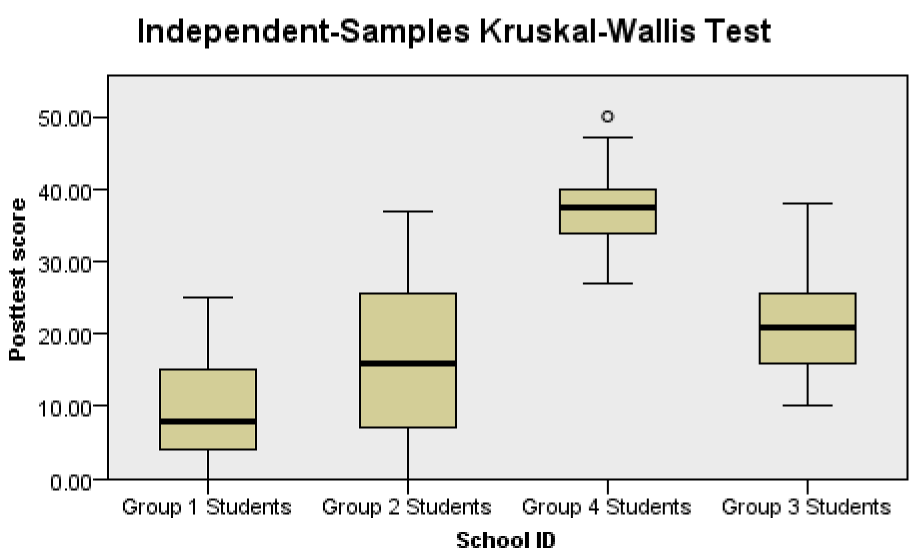


Total N	88
Test Statistic	17.172
Degrees of Freedom	3
Asymptotic Sig. (2-sided test)	.001

1. The test statistic is adjusted for ties.

Similarly, the Independent-Samples Kruskal-Wallis Test of significance of the *posttest mean rank score* comparison also revealed a statistically significant difference (*P* < 0.05) between the four student group populations which includes: Group 4 students numerically had the highest posttest mean rank score (75.89); Group 3 students had numerically the second highest posttest mean rank score (49.67); Group 2 students had numerically the third highest posttest mean rank score (37.60); and the control group (Group 1) students had numerically the lowest posttest mean rank score (24.18), respectively. A visual representation of the posttest means rank score distribution is provided in Figure 4.12.

Figure 4.12 Independent-Samples Kruskal-Wallis Test of Posttest Score



Total N	88
Test Statistic	54.961
Degrees of Freedom	3
Asymptotic Sig. (2-sided test)	.000

1. The test statistic is adjusted for ties.

Since there were statistically significant differences (*P* < 0.05) in the pretest scores and posttest mean rank scores between groups, the researcher employed a series of *Mann-Whitney tests* and compared two populations (student groups) at a time which provided mean ranks for each, with a *Bonferroni* correction to control for type 1 errors. Similarly, the researcher divided alpha by the number of comparisons, which was six in total. The statistical significance for the total comparison and then divided across the six comparisons (via *Bonferroni* correction) was $\alpha = .05/6 = 0.008$. The final sample size was $N = 88$ (Group 1 = 31; Group 2 = 20; Group 3 = 15; and Group 4 = 22).

The Mann-Whitney test, comparing two populations at a time and providing a *pretest mean rank* for each, showed a statistically significant difference ($P < 0.008$) between several of the student group populations which includes: In particular, Group 3 students had a significantly ($P < 0.008$) higher pretest mean rank content score compared to all other groups which included Group 1 students, the control (mean rank of 19.16 versus 32.47) (.002 statistical significance), Group 2 students (mean rank of 12.25 versus 25.67) (.001 statistical significance), and Group 4 students (mean rank of 13.75 versus 26.70) (.001 statistical significance), respectively.

However, the Mann-Whitney test also revealed no statistically significant differences ($P > 0.008$) between the pretest scores of other groups. For example, the control group (Group 1 students) did not have a statistically significant ($P > 0.008$) pretest content mean rank score (mean rank of 26.55) compared to Group 2 students (mean rank of 25.15) (.741 statistical significance); Group 4 students (mean rank of 27.43) compared to Group 1 students (mean rank of 26.69) (.863 statistical significance);

and Group 2 students (mean rank of 19.33) compared to Group 4 students (mean rank of 23.48) (.269 statistical significance), respectively. Results are shown in Table 4.21.

Table 4.21 Mann-Whitney Comparison Mean Rank Test for the Pretest Content Assessment

Pretest score	School ID	*N*	Mean Rank	Sig[a]	Test Statistic[b]
Group 1 vs 2	Group 1 Students	31	26.55	.741	293.0
	Group 2 Students	20	25.15		
Group 1 vs 3	Group 1 Students	31	19.16	.002	98.0
	Group 3 Students	15	32.47		
Group 1 vs 4	Group 1 Students	31	26.69	.863	331.5
	Group 4 Students	22	27.43		
Group 2 vs 3	Group 2 Students	20	12.25	.000	35.0
	Group 3 Students	15	25.67		
Group 2 vs 4	Group 2 Students	20	19.33	.269	176.5
	Group 4 Students	22	23.48		
Group 3 vs 4	Group 3 Students	15	26.70	.000	49.5
	Group 4 Students	22	13.75		

[a]Significance is below .008.

[b]Mann-Whitney U

The Mann-Whitney test, comparing two populations at a time and providing a *posttest mean rank* for each also showed a statistically significant difference ($P < 0.008$) between several of the student group populations. In particular, Group 4 students had a significantly (*P* < 0.008) higher posttest mean rank content score compared to all other groups which included Group 1 students, the control (mean rank of 16.00 versus 42.50) (.001 statistical significance), Group 2 students (mean rank of 11.30 versus 30.77) (.001 statistical significance), and Group 3 students (mean rank of 9.30 versus 35.61) (.001 statistical significance), respectively.

However, the Mann-Whitney test also revealed no statistically significant differences between the posttest scores of other groups. For example, the control group (Group 1 students) did not have a statistically significantly (*P* > 0.008) lower posttest content mean rank score (mean rank of 22.37) when compared to Group 2 students (mean rank of 31.63) (.030 statistical significance). It is important to note that the control group (Group 1 students) did have a numerically higher average pretest score (6.19) compared to Group 2 students (4.35). Considering this comparison and that of the posttest mean ranks scores, Group 1 students showed very little growth in learning and had a significantly (*P* < 0.008) lower mean difference between the pre-and posttest scores compared to Group 2 students (.001 statistical significance). Likewise, no statistically significant differences (*P* > 0.008) were found between the posttest mean rank of Group 2 students (mean rank of 15.68) and Group 3 students (mean rank of 21.10) (.122 statistical significance), respectively. Results are shown in Table 4.22.

Table 4.22 Mann-Whitney Comparison Mean Rank Test for the Posttest Content Assessment

Posttest Score	School ID	*N*	Mean Rank	Sig[a]	Test Statistic[b]
Group 1 vs 2	Group 1 Students	31	22.37	.030	197.5
	Group 2 Students	20	31.63		
Group 1 vs 3	Group 1 Students	31	17.81	.000	56.0
	Group 3 Students	15	35.27		
Group 1 vs 4	Group 1 Students	31	16.00	.000	.000
	Group 4 Students	22	42.50		
Group 2 vs 3	Group 2 Students	20	15.68	.122	103.5
	Group 3 Students	15	21.10		
Group 2 vs 4	Group 2 Students	20	11.30	.000	16.0
	Group 4 Students	22	30.77		
Group 3 vs 4	Group 3 Students	15	9.30	.000	19.5
	Group 4 Students	22	25.61		

[a]Significance is below .008.

[b]Mann-Whitney U

Further, the researcher also employed a univariate analysis of variance (ANOVA) multiple comparison parametric test to identify any potential effects the intervention had on student learning. This approach was performed while recognizing that the data in the present study did not fit a normal distribution nor having homogeneity of variance across the four different student groups. As described previously in Chapter 3, the researcher sought to find whether or not the data was normally distributed. To test this assumption, the researcher employed the Shapiro-Wilk test, which is suited for sample sizes similar to the present study. The Shapiro-Wilk test is a numerical means of assessing normality. Further, to test the assumption of equal variances of the dependent variable, the researcher employed the Levene's test for homogeneity of variances. Levene's test is an inferential statistic used to assess the equality of variances for a variable calculated for two or more groups. The researcher did not want to automatically assume that variances of the populations were equal so Levene's test was employed to assess this assumption.

The mean difference (improvement) dependent variable across the four student groups were compared statistically (via parametric test ANOVA) after taking the pre- and- post content-aligned test at the $\alpha = 0.05$ level. A Tukey's multiple range test was conducted if the researcher found statistically significant differences between the four student groups. Results indicate similar patterns and trends emerged across the four different student groups when comparing the parametric and non-parametric statistical methods. The parametric ANOVA and subsequent Tukey's test revealed that Group 4 students had statistically significantly higher ($P < 0.05$) mean difference (improvement) sum scores compared to all other student groups. A difference of 28.83 for Group 1, 20.0 for Group 2, and 21.89 for Group 3 when comparing Group 4 students to these three groups, respectively. Likewise, the control group (via Group 1 students) had significantly lower ($P < 0.05$) improvement sum scores compared to all other student groups. A difference of -8.82 for Group 2, -28.83 for Group 4, and -6.94 for Group 3 when comparing Group 1 students to these three groups, respectively. However, there were no significant differences ($P > 0.05$) found between student Groups 2 and 3, respectively. Results revealed only a difference of 1.88 between Groups 2 and 3, respectively. A summary of this data are shown in Tables 4.23 and 4.24.

Table 4.23 Univariate Analysis of Variance (ANOVA) Multiple Comparison Test for Mean Difference (Improvement) Sum Scores with Respect to the Four Student Groups

School ID (I)	Student Group (J)	*N*	Mean Difference (I-J)	Std. Error	Sig.[a]
Group 1	Group 2 Students	20	-8.82	2.12	.001
	Group 4 Students	22	-28.83	2.06	.001
	Group 3 Students	15	-6.94	2.32	.019
Group 2	Group 1 Students	31	8.82	2.12	.001
	Group 4 Students	22	-20.00	2.29	.001
	Group 3 Students	15	1.88	2.53	.878
Group 4	Group 1 Students	31	28.83	2.06	.001
	Group 2 Students	20	20.00	2.29	.001
	Group 3 Students	15	21.89	2.48	.001
Group 3	Group 1 Students	31	6.94	2.33	.019
	Group 2 Students	20	-1.88	2.53	.878
	Group 4 Students	22	-21.89	2.48	.001

[a]Mean difference (improvement) is significant at the .05 level.

Table 4.24 Univariate Analysis of Variance (ANOVA) Multiple Comparison Test for Mean Difference (Improvement) Sum Scores with Respect to the Four Student Groups (Cont.)

			95% CI	
School ID (I)	Student Group (J)	*N*	*LL*	*UL*
Group 1	Group 2 Students	20	-14.38	-3.26
	Group 4 Students	22	-34.23	-23.42
	Group 3 Students	15	-13.03	-.84
Group 2	Group 1 Students	31	3.26	14.38
	Group 4 Students	22	-26.00	-14.01
	Group 3 Students	15	-4.74	8.51
Group 4	Group 1 Students	31	23.42	34.23
	Group 2 Students	20	14.01	26.00
	Group 3 Students	15	15.40	28.38
Group 3	Group 1 Students	31	.84	13.04
	Group 2 Students	20	-8.51	4.74
	Group 4 Students	22	-28.38	-15.40

4.2 Attitude/Interest Survey Instrument Findings (e.g., Research Questions 1 and 2)

In order to specifically investigate high school level students' attitudes and opinions toward STEM and aquaculture and their interests toward a STEM-related discipline and/or career pathway, quantitative data from a pre- and post-survey instrument were utilized. The survey instrument asked participants to respond to twelve statements that reflected an element relating to researcher questions 1 and 2. For example, how the aquaculture project affects their interest in STEM, interest in attaining a STEM career pathway, interest in STEM subjects, or interest in aquaculture courses are among a few topics that were addressed in this assessment. The population consisted of only those students who participated in the authentic, hands-on intervention in the classroom. Thus, data were compared across only the three treatment groups. The researcher employed descriptive univariate analysis statistics across all participant groups which included frequency distributions, means, and standard deviations. Descriptive data were also reviewed to determine if students' attitudes toward STEM and aquaculture and their interests toward a STEM-related discipline and/or career pathway changed across pre- and post-responses. An overview of the univariate descriptive statistics results for the pre-intervention survey is presented in Tables 4.25 and 4.26. Likewise, an overview of the univariate descriptive statistics for the post-intervention survey is presented in Tables 4.27 and 4.28.

Table 4.25 Descriptive Statistics for Pre-Intervention Survey Instrument Comparison with Respect to the Treatment Groups (N = 55)

Dependent Variable (item number)	Student Groups	*M**	Std. Dev.	*N*
Aquaculture would be a highly interesting profession	2	3.07	.704	15
	3	3.57	.756	14
	4	2.84	.881	26
	Total	3.10	.845	55
At this time, aquaculture increases my interest in science	2	3.07	.704	15
	3	3.57	.756	14
	4	3.34	.882	26
	Total	3.28	.818	55
At this time, aquaculture increases my interest in engineering	2	2.33	.817	15
	3	3.36	.745	14
	4	3.08	1.02	26
	Total	2.95	.970	55
At this time, aquaculture increases my interest in mathematics	2	2.27	.961	15
	3	2.93	.829	14
	4	2.61	1.27	26
	Total	2.60	1.10	55
My participation in the aquaculture project will increase my interest in a STEM career field	2	2.80	1.01	15
	3	3.43	.756	14
	4	3.11	1.07	26
	Total	3.11	.994	55

My participation in the aquaculture project will increase my desire to take more courses in a STEM-related area	2	2.67	.890	15
	3	3.43	.646	14
	4	3.08	.891	26
	Total	3.05	.870	55
My participation in the project will increase my desire to take courses in aquaculture specifically	2	2.60	1.06	15
	3	2.93	.917	14
	4	2.54	1.17	26
	Total	2.65	1.08	55
When I graduate from high school, I would like to work with people who make discoveries in science	2	2.20	.941	15
	3	3.57	1.09	14
	4	2.61	1.24	26
	Total	2.75	1.22	55
I am interested in future opportunities to study aquaculture and aquatic science subjects for high school and advanced credit	2	2.60	1.06	15
	3	3.57	.852	14
	4	2.46	1.27	26
	Total	2.78	1.20	55
I would encourage my friends (not attending project) to consider courses in aquaculture	2	2.80	.561	15
	3	3.50	.760	14
	4	2.96	.999	26
	Total	3.05	.870	55

At this time, aquaculture increases my curiosity in technology	2	2.87	.915	15
	3	3.14	.663	14
	4	3.15	1.12	26
	Total	3.07	.960	55

I expect to pursue higher education in a STEM-related field	2	2.53	.834	15
	3	3.79	1.12	14
	4	3.04	1.11	26
	Total	3.09	1.13	55

*1= strongly disagree, 2= disagree, 3= neutral, 4= agree, 5= strongly agree.

4.2.1 **Descriptive Statistics Findings of Pre-Intervention Survey Responses**. For the pre-intervention survey instrument, results demonstrate that Group 3 students had numerically the highest mean ordinal Likert scale response (i.e., response options 1=strongly disagree, 2= disagree, 3=neutral, 4=agree, and 5=strongly agree) when comparing between student groups in eleven out of the twelve items within the survey instrument. The only exception was for item 11 (At this time, aquaculture increases my curiosity in technology) as Group 4 had numerically a slightly higher mean Likert scale response (3.15) compared to all other student groups. It should be noted that Group 2 students had numerically the lowest mean scale response for nine out of the twelve items (items 2-6, 8, and 10-12) compared to all other student groups. The next Table illustrates a similar trend as Group 3 students had numerically the highest lower bound (*LL*) and upper bound (*UL*) mean ordinal Likert scale response for all twelve items with the exception of item 11 as Group 4 students had a slightly higher *LL* mean response scale (2.77) compared to all other student groups

Table 4.26 Descriptive Statistics for Pre-Intervention Survey Instrument Comparison with Respect to the Treatment Groups (Cont.)

			95% CI	
Dependent Variable	Groups	*SE*	*LL*	*UL*
1. Aquaculture would be a highly interesting profession	2	.208	2.65	3.48
	3	.215	3.14	4.00
	4	.158	2.53	3.16
2. At this time, aquaculture increases my interest in science	2	.210	2.65	3.50
	3	.217	3.14	4.01
	4	.159	3.03	3.67
3. At this time, aquaculture increases my interest in engineering	2	.233	1.87	2.81
	3	.241	2.87	3.84
	4	.177	2.72	3.43
4. At this time, aquaculture increases my interest in mathematics	2	.282	1.70	2.83
	3	.292	2.34	3.51
	4	.214	2.19	3.05
5. My participation in the aquaculture project will increase my interest in a STEM career field	2	.254	2.29	3.31
	3	.263	2.90	4.00
	4	.193	2.73	3.50
6. My participation in the aquaculture project will increase my desire to take more courses in a STEM-related area	2	.217	2.23	3.10
	3	.224	3.00	3.88
	4	.165	2.75	3.40
7. My participation in the aquaculture project will increase my desire to take courses in aquaculture	2	.280	2.04	3.16
	3	.289	2.35	3.51
	4	.212	2.11	2.97

8. When I graduate from high school, I would like to work with people who make discoveries in science	2	.291	1.62	2.78
	3	.301	2.97	4.18
	4	.221	2.17	3.06
9. I am interested in future opportunities to study aquaculture and aquatic science subjects for high school and advanced credit	2	.290	2.02	3.18
	3	.300	2.97	4.17
	4	.220	2.02	2.90
10. I would encourage my friends (not attending project) to consider courses in aquaculture	2	.217	2.36	3.24
	3	.225	3.05	3.95
	4	.165	2.63	3.29
11. At this time, aquaculture increases my curiosity in technology	2	.250	2.37	3.37
	3	.259	2.62	3.66
	4	.190	2.77	3.54
12. I expect to pursue higher education in a STEM-related field	2	.270	1.99	3.08
	3	.280	3.22	4.34
	4	.205	2.63	3.45

Table 4.27 Descriptive Statistics for Post-Intervention Survey Instrument Comparison with Respect to the Treatment Groups (N = 55)

Dependent Variable (item number)	Student Groups	*M**	Std. Dev.	*N*
Aquaculture would be a highly interesting profession	2	3.07	.961	15
	3	3.21	.802	14
	4	3.23	1.07	26
	Total	3.18	.964	55
Aquaculture activities increased my interest in science	2	3.13	.915	15
	3	3.50	.941	14
	4	3.42	.857	26
	Total	3.36	.890	55
Aquaculture activities increased my interest in engineering	2	2.93	.884	15
	3	3.21	1.19	14
	4	3.00	.938	26
	Total	3.04	.980	55
Aquaculture activities increased my interest in mathematics	2	3.27	1.10	15
	3	2.86	.864	14
	4	2.54	.989	26
	Total	2.81	1.02	55
My participation in the aquaculture project increased my interest in a STEM career field	2	2.93	.799	15
	3	3.43	1.02	14
	4	3.19	1.17	26
	Total	3.18	1.04	55

My participation in the aquaculture project increased my desire to take more courses in a STEM-related area	2	2.93	.704	15
	3	3.64	1.01	14
	4	3.42	.987	26
	Total	3.35	.947	55
My participation in the project increased my desire to take courses in aquaculture specifically	2	2.53	.834	15
	3	3.00	1.18	14
	4	2.81	1.02	26
	Total	2.78	1.01	55
When I graduate from high school, I would like to work with people who make discoveries in science	2	2.80	1.01	15
	3	3.57	1.09	14
	4	2.92	1.16	26
	Total	3.05	1.12	55
I would like future opportunities to study aquaculture and aquatic science subjects for high school and advanced credit	2	2.73	.884	15
	3	3.36	1.01	14
	4	3.08	1.09	26
	Total	3.05	1.03	55
I would encourage my friends (not attending project) to consider courses in aquaculture	2	2.73	.884	15
	3	3.43	1.16	14
	4	3.58	1.07	26
	Total	3.31	1.08	55

Aquaculture activities increased				
my curiosity in technology	2	3.07	.961	15
	3	3.14	.949	14
	4	3.38	.898	26
	Total	3.24	.922	55
I expect to pursue higher education	2	2.87	.834	15
in a STEM-related field	3	3.43	1.01	14
	4	3.12	1.11	26
	Total	3.13	1.04	55

*1= strongly disagree, 2= disagree, 3= neutral, 4= agree, 5= strongly agree.

4.2.2 ***Descriptive statistics findings of post-survey responses***. For the post-intervention survey instrument, results demonstrate that Group 3 students had numerically the highest mean ordinal Likert scale response in eight out of the twelve items when comparing between student groups within the survey instrument. The only exceptions were for questionnaire items 1 (Aquaculture would be a highly interesting profession) 10 (I would encourage my friends not attending project to consider courses in aquaculture), and 11 (Aquaculture activities increased my curiosity in technology) as Group 4 had numerically a higher mean Likert scale response compared to all other student groups. Likewise, Group 2 student had numerically a higher mean Likert scale response for item 4 (Aquaculture activities increased my interest in mathematics) when compared to all other student groups. The next Table illustrates a similar trend relating to the lower bound (*LL*) and upper bound (*UL*) mean ordinal Likert scale student responses between the three different student groups.

Table 4.28 Descriptive Statistics for Post-Intervention Survey Instrument Comparison with Respect to the Treatment Groups (Cont.)

			95% CI	
Dependent Variable	Groups	*SE*	*LL*	*UL*
1. Aquaculture would be a highly interesting profession	2	.253	2.56	3.57
	3	.262	2.69	3.74
	4	.192	2.85	3.62
2. Aquaculture activities increased my interest in science	2	.231	2.67	3.60
	3	.239	3.02	3.98
	4	.175	3.07	3.78
3. Aquaculture activities increased my interest in engineering	2	.256	2.42	2.45
	3	.265	2.68	3.75
	4	.195	2.61	3.39
4. Aquaculture activities increased my interest in mathematics	2	.256	2.75	3.78
	3	.265	2.33	3.40
	4	.194	2.15	2.93
5. My participation in the aquaculture project increased my interest in a STEM career field	2	.269	2.39	3.47
	3	.278	2.87	3.99
	4	.204	2.78	3.60
6. My participation in the aquaculture project increased my desire to take more courses in a STEM-related area	2	.239	2.45	3.41
	3	.247	3.15	4.14
	4	.181	3.06	3.79
7. My participation in the aquaculture project increased my desire to take courses in aquaculture specifically	2	.263	2.01	3.06
	3	.272	2.46	3.55
	4	.199	2.41	3.21

8. When I graduate from high school, I would like to work with people who make discoveries in science	2	.286	2.23	3.37
	3	.296	2.98	4.17
	4	.217	2.49	3.36
9. I would like future opportunities to study aquaculture and aquatic science subjects for high school and advanced credit	2	.263	2.21	3.26
	3	.272	2.81	3.90
	4	.200	2.68	3.48
10. I would encourage my friends (not attending project) to consider courses in aquaculture	2	.270	2.19	3.27
	3	.279	2.87	3.99
	4	.205	3.17	3.99
11. Aquaculture activities increased my curiosity in technology	2	.240	2.59	3.55
	3	.248	2.65	3.64
	4	.182	3.02	3.75
12. I expect to pursue higher education in a STEM-related field	2	.268	2.33	3.40
	3	.277	2.87	3.98
	4	.203	2.71	3.52

4.2.3 *Quantitative descriptive gain and loss in STEM attitudes and interest of the descriptive data*. Table 4.29 reveals the percent change across the pre and post responses with respect to each of the three different student groups (see below). When examining a positive or negative change from the pre- to post-intervention survey, the results revealed the following: Group 4 students had six statements (items 1, 6, 7, 8, 9, and 10) with "increasing" scale responses with a 5% or greater increase (pre to post survey means for item 1, 2.84 to 3.23; item 6, 3.08 to 3.42; item 7, 2.54 to 2.81; item 8, 2.61 to 2.92; item 9, 2.46 to 3.08; and item 10, 2.96 to 3.58). Group 2 students had three statements (items 3, 4, and 12) with "increasing" scale responses with a 5% or greater increase (pre to post survey means for item 3, 2.33 to 2.93; item 4, 2.27 to 3.27; and item 12, 2.53 to 2.87). Group 3 students had one statement (item 6) with a 5% or greater increase (pre to post survey means for item 6, 3.43 to 3.64) and two statements (items 1 and 12) with "decreasing" scale response less than 5% (pre to post survey means for item 1, 3.57 to 3.21 and item 12, 3.79 to 3.43). Overall, specifically there was a 12.4% increase in Group 4 students' interest in future opportunities to study aquaculture subjects for high school and advanced credit (item 9), a 12.4% increase to encourage their friends (not attending project) to consider courses in aquaculture (item 10), and these also correspond with the statement on Group 4 students' desire (5.4% increase) to take courses in aquaculture specifically (item 7). Hence, these descriptive statistics data suggest that when Group 4 students responded to statements on a five-point Likert scale that relates to aquaculture subjects and courses, they tended to have a positive perception to pursue this opportunity in the future when examining the posttest responses. Furthermore, there was a 7.8% increase (gain) in Group 4 students' attitudes toward aquaculture as being a highly interesting profession (item 1). In terms of the desire to take courses in a STEM-related area (item 6), there was a 6.8% increase in Group 4 students on the pre- and post-intervention survey. Lastly, there was a 6.2% increase in Group 4 students' aspirations to work with people who make discoveries in science after high school (item 8). Overall, data reveals that Group 4 students demonstrated positive growth in their interest in learning hands-on science, technology, engineering and math (STEM) and working with people who are immersed in science discovery in the future. This pre- and post-intervention survey data may suggest that these group of students particularly enjoyed learning about the biological and ecological concepts when studying a "living" ecosystem and engaging in real-world research tasks in the classroom. Overall, specifically there was a 12% increase in Group 2 students' interest in specifically engineering (item 3) and a 20% increase in their interest in specifically mathematics (item 4) with the same group of students. Likewise, there was a 6.8% increase on the pre (2.53) and post (2.87) intervention survey with the statement on pursuing higher education in a STEM-related field for item 12 among Group 2 students which is encouraging. The descriptive data suggests that students from this particular group favored more of the hands-on engineering and mathematics aspects of the project and perhaps less the ecological aspects. Further, these same students also had a 4% increase in their curiosity of technology. It could be that students in this group were more interested in the hands-on learning experiences of producing fish and plants, and subsequently, the real-life mathematics calculating growth performance of Koi carp, figuring out water quality averages-patterns-trends, and determining feed conversion ratios; a keen interest in engineering and designing their recirculating aquaculture systems while working in small groups; and more curious to use various technological equipment (i.e., hand-held probe devices) throughout the project. As a result, this may have spark their motivation to pursue a STEM-related field in college related to engineering or mathematics that possibly links to agriculture science studies in the future. Overall, specifically there was a 5.2% moderate gain in Group 3 students' desire to take more courses in a STEM-related area (item 6). However, there was a negative (loss) growth (7.2%) in Group 3 students' attitudes towards aquaculture as a profession (item 1) and 7.2% loss with the statement on expecting to pursue higher education in a STEM-related field (item 12). The descriptive data suggest that Group 3 students had a relatively high perception of aquaculture at the beginning of the project, but decreased after completing the intervention. Likewise, data suggest that Group 3 students appears to have a desire to take STEM-related courses, but may not consider a STEM field after high school.

Table 4.29 Descriptive Statistics for Percentage Change Comparison Across the Pre and Post Responses with Respect to the Treatment Groups (N = 55)

Dependent Variable (item number)	Student Groups	Pre-Survey *M*	Post-Survey *M*	% Change *M*
Aquaculture would be a highly interesting profession	2	3.07	3.07	0%
	3	3.57	3.21	-7.2%
	4	2.84	3.23	+7.8%
	Total	3.10	3.18	+1.6%
At this time, aquaculture increases my interest in science	2	3.07	3.13	+1.2%
	3	3.57	3.50	-1.4%
	4	3.34	3.42	+1.6%
	Total	3.28	3.36	+1.6%
At this time, aquaculture increases my interest in engineering	2	2.33	2.93	+12%
	3	3.36	3.21	-3%
	4	3.08	3.00	-1.6%
	Total	2.95	3.04	+1.8%
At this time, aquaculture increases my interest in mathematics	2	2.27	3.27	+20%
	3	2.93	2.86	-1.4%
	4	2.61	2.54	-1.4%
	Total	2.60	2.81	+4.2%
My participation in the aquaculture project will increase my interest in a STEM career field	2	2.80	2.93	+2.6%
	3	3.43	3.43	0%
	4	3.11	3.19	+1.6
	Total	3.11	3.18	+1.4%
My participation in the aquaculture project will increase my desire to take more courses in a STEM-related area	2	2.67	2.93	+5.2%
	3	3.43	3.64	+4.2%
	4	3.08	3.42	+6.8%
	Total	3.05	3.35	+6%

My participation in the project will increase my desire to take courses in aquaculture specifically	2	2.60	2.53	-1.4%
	3	2.93	3.00	+1.4%
	4	2.54	2.81	+5.4%
	Total	2.65	2.78	+2.6
When I graduate from high school, I would like to work with people who make discoveries in science	2	2.20	2.80	+4%
	3	3.57	3.57	0%
	4	2.61	2.92	+6.2%
	Total	2.75	3.05	+6.0%
I am interested in future opportunities to study aquaculture and aquatic science subjects for high school and advanced credit	2	2.60	2.73	+2.6%
	3	3.57	3.36	-4.2%
	4	2.46	3.08	+12.4%
	Total	2.78	3.05	+5.4%
I would encourage my friends (not attending project) to consider courses in aquaculture	2	2.80	2.73	-1.4%
	3	3.50	3.43	-1.4%
	4	2.96	3.58	+12.4%
	Total	3.05	3.31	+5.2%
At this time, aquaculture increases my curiosity in technology	2	2.87	3.07	+4%
	3	3.14	3.14	0%
	4	3.15	3.38	+4.6%
	Total	3.07	3.24	+3.4%
I expect to pursue higher education in a STEM-related field	2	2.53	2.87	6.8%
	3	3.79	3.43	-7.2%
	4	3.04	3.12	+1.6%
	Total	3.09	3.13	+0.8%

4.2.4 *Findings Comparing the Three Student Groups*. Additionally, the researcher employed a Kruskal-Wallis mean rank test to compare the pretest and posttest mean rank score between the three treatment groups as described in Chapter 3. The Independent-Samples Kruskal-Wallis Test of significance of the *pre-intervention survey instrument* comparison revealed a significant difference ($P < 0.05$) between the three student group populations for the following six statements: 1 (Aquaculture would be a highly interesting profession), 3 (At this time, aquaculture increases my interest in engineering), 8 (When I graduate from high school, I would like to work with people who make discoveries in science), 9 (I am interested in future opportunities to study aquaculture and aquatic science subject for high school and advanced credit), 10 (I would encourage my friends (not attending project) to consider courses in aquaculture), and 12 (I expect to pursue higher education in a STEM-related field), respectively. An overview of this pre-survey data comparison is provided in Table 4.30. A visual representation and the distribution of these items having significant differences among the three different student groups are also provided for the reader and provided in Figures 4.13 to 4.18, respectively.

Table 4.30 Kruskal-Wallis Mean Rank Pre-Intervention Survey Instrument Comparison with Respect to the Treatment Groups

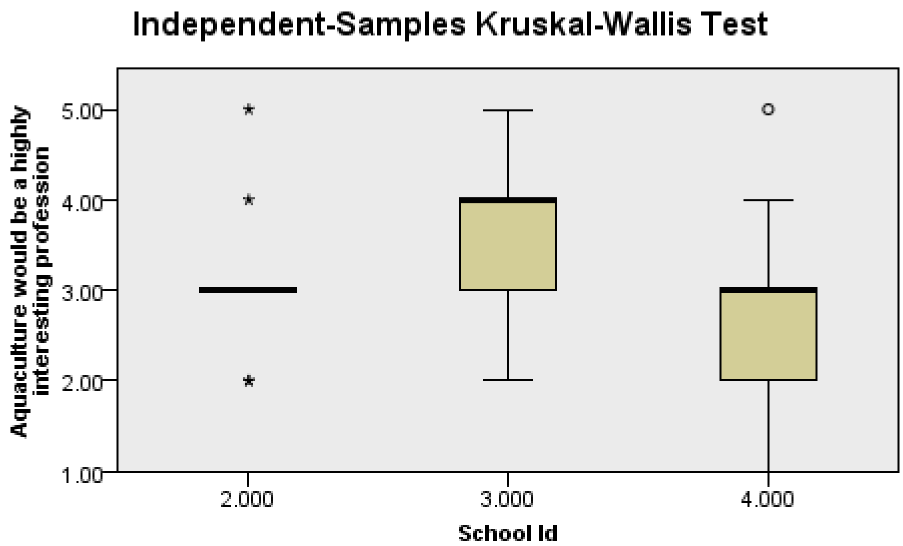
Dependent Variable[a]	Student Groups	*N*	Mean Rank	Sig.[a] (Test-Statistic[b])
Aquaculture would be a highly interesting profession	2	15	26.67	.020[a]
	3	14	37.11	
	4	26	23.87	
	Total	55		(7.852)
At this time, aquaculture increases my interest in science	2	15	22.07	.162
	3	14	31.89	
	4	26	29.33	
	Total	55		(3.639)
At this time, aquaculture increases my interest in engineering	2	15	18.33	.011[a]
	3	14	34.07	
	4	26	30.31	
	Total	55		(9.038)
At this time, aquaculture increases my interest in mathematics	2	15	24.00	.254
	3	14	33.32	
	4	26	27.44	
	Total	55		(2.738)
My participation in the aquaculture project will increase my interest in a STEM career field	2	15	23.77	.302
	3	14	32.57	
	4	26	27.98	
	Total	55		(2.395)
My participation in the aquaculture project will increase my desire to take more courses in a STEM-related area	2	15	21.43	.069
	3	14	34.32	
	4	26	28.38	
	Total	55		(5.359)

My participation in the project will increase my desire to take courses in aquaculture specifically	2	15	26.80	.459
	3	14	32.43	
	4	26	26.31	
	Total	55		(1.555)
When I graduate from high school, I would like to work with people who make discoveries in science	2	15	20.87	.008[a]
	3	14	38.36	
	4	26	26.54	
	Total	55		(9.595)
I am interested in future opportunities to study aquaculture and aquatic science subject for high school and advanced credit	2	15	25.90	.014[a]
	3	14	38.36	
	4	26	23.63	
	Total	55		(8.520)
I would encourage my friends (not attending project) to consider courses in aquaculture	2	15	21.93	.030[a]
	3	14	36.29	
	4	26	27.04	(6.987)
	Total	55		
At this time, aquaculture increases my curiosity in technology	2	15	23.93	.463
	3	14	28.64	
	4	26	30.00	
	Total	55		(1.538)
I expect to pursue higher education in a STEM-related field	2	15	19.97	.013[a]
	3	14	36.96	
	4	26	27.81	
	Total	55		(8.744)

[a]$p < 0.05$. (significant difference)

[b](df) = (2)

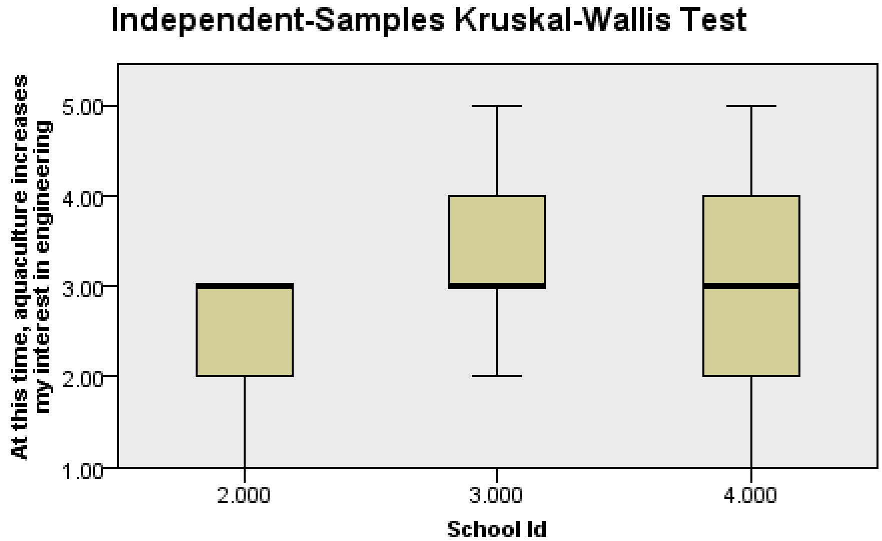
Figure 4.13 Independent-Samples Kruskal-Wallis Test of Pre-Project Survey Item 1



Total N	55
Test Statistic	7.852
Degrees of Freedom	2
Asymptotic Sig. (2-sided test)	.020

1. The test statistic is adjusted for ties.

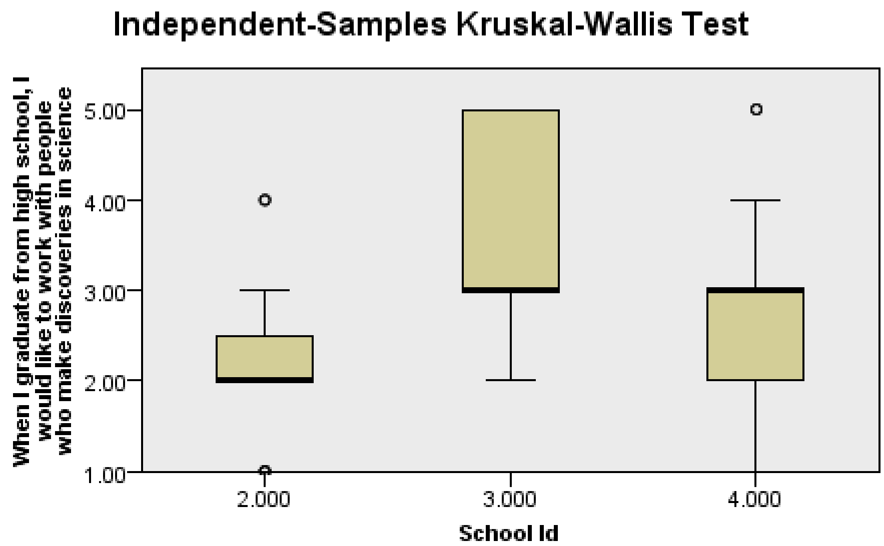
Figure 4.14 Independent-Samples Kruskal-Wallis Test of Pre-Project Survey Item 3



Total N	55
Test Statistic	9.038
Degrees of Freedom	2
Asymptotic Sig. (2-sided test)	.011

1. The test statistic is adjusted for ties.

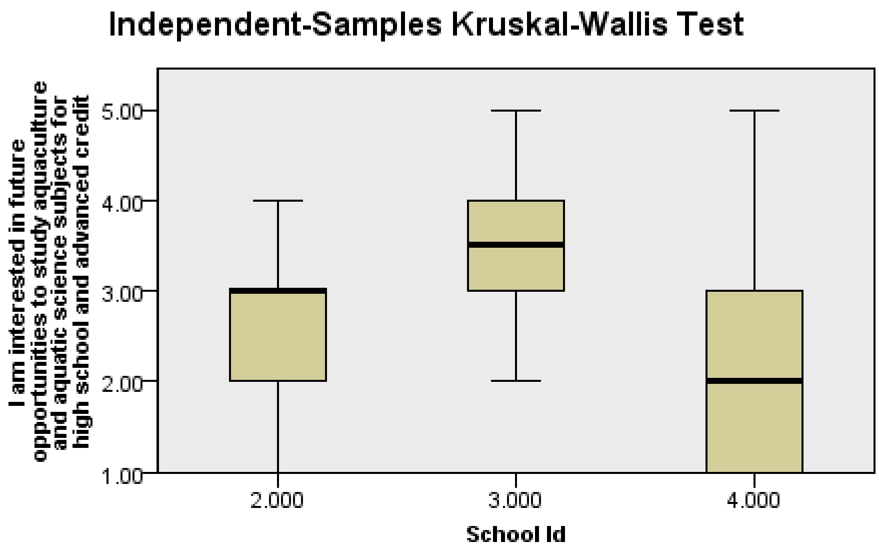
Figure 4.15 Independent-Samples Kruskal-Wallis Test of Pre-Project Survey Item 8



Total N	55
Test Statistic	9.595
Degrees of Freedom	2
Asymptotic Sig. (2-sided test)	.008

1. The test statistic is adjusted for ties.

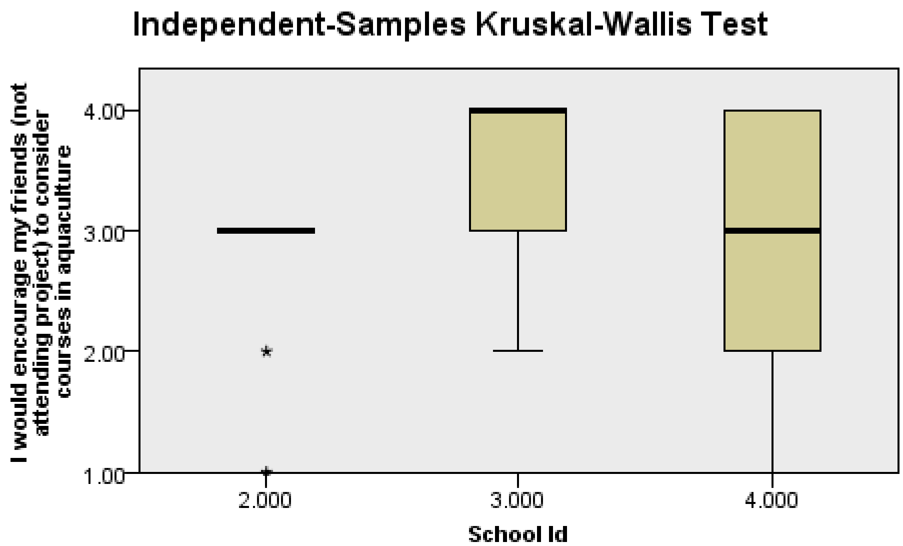
Figure 4.16 Independent-Samples Kruskal-Wallis Test of Pre-Project Survey Item 9



Total N	55
Test Statistic	8.520
Degrees of Freedom	2
Asymptotic Sig. (2-sided test)	.014

1. The test statistic is adjusted for ties.

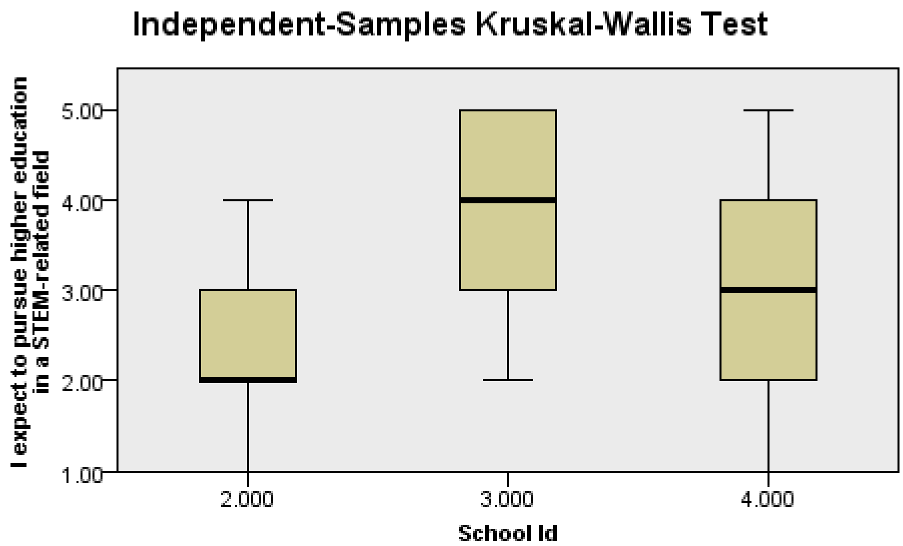
Figure 4.17 Independent-Samples Kruskal-Wallis Test of Pre-Project Survey Item 10



Total N	55
Test Statistic	6.987
Degrees of Freedom	2
Asymptotic Sig. (2-sided test)	.030

1. The test statistic is adjusted for ties.

Figure 4.18 Independent-Samples Kruskal-Wallis Test of Pre-Project Survey Item 12



Total N	55
Test Statistic	8.744
Degrees of Freedom	2
Asymptotic Sig. (2-sided test)	.013

1. The test statistic is adjusted for ties.

Since there were significant differences ($P < 0.05$) in the pre-intervention survey instrument between groups, the researcher employed a series of *Mann-Whitney tests* and compared two populations (student groups) at a time which provided mean ranks for each, with a *Bonferroni* correction to control for type 1 errors. Similarly, the researcher divided alpha by the number of comparisons, which was three in total. Hence, the statistical significance level for the *Bonferroni* correction was $\alpha = .05/3 = 0.017$. The final sample size was $N = 55$ (Group 2 = 15; Group 3 = 14; and Group 4 = 26). Results of the Mann-Whitney U test for the pre-intervention survey are shown in Table 4.31.

Table 4.31 Mann-Whitney Comparison Mean Rank Test for Pre-Intervention Survey Instrument with Respect to the Treatment Groups (N = 55)

Variable	Student Groups	*N*	Mean Rank	Sig[a]	Test Statistic[b]
Aquaculture would be a highly interesting profession	Group 2 Students	15	12.17	.063	62.5
	Group 3 Students	14	18.04		
	Group 2 Students	15	22.50	.547	172.50
	Group 4 Students	26	20.13		
	Group 3 Students	14	26.57	.015	97.0
	Group 4 Students	26	17.23		
At this time, aquaculture increases my interest in engineering	Group 2 Students	15	10.80	.005	42.0
	Group 3 Students	14	19.50		
	Group 2 Students	15	15.53	.026	113.0
	Group 4 Students	26	24.15		
	Group 3 Students	14	22.07	.547	160.0
	Group 4 Students	26	19.65		

When I graduate from high school, I would like to work with people who make discoveries in science	Group 2 Students	15	10.40	.002	36.0
	Group 3 Students	14	19.93		
	Group 2 Students	15	18.47	.314	157.0
	Group 4 Students	26	22.46		
	Group 3 Students	14	25.93	.031	106.0
	Group 4 Students	26	17.58		
I am interested in future opportunities to study aquaculture and aquatic science subject for high school and advanced credit	Group 2 Students	15	11.60	.026	54.0
	Group 3 Students	14	18.64		
	Group 2 Students	15	22.30	.602	175.5
	Group 4 Students	26	20.25		
	Group 3 Students	14	27.21	.007	88.0
	Group 4 Students	26	16.88		
I would encourage my friends (not attending project) to consider courses in aquaculture	Group 2 Students	15	11.10	.009	46.5
	Group 3 Students	14	19.18		
	Group 2 Students	15	18.83	.383	162.5
	Group 4 Students	26	22.25		

	Group 3 Students	14	24.61	.104	124.5
	Group 4 Students	26	18.29		
I expect to pursue higher education in a STEM-related field	Group 2 Students	15	10.80	.005	42.0
	Group 3 Students	14	19.50		
	Group 2 Students	15	17.17	.121	137.5
	Group 4 Students	26	23.21		
	Group 3 Students	14	24.96	.076	119.5
	Group 4 Students	26	18.10		

[a]Significance is below .017.

[b]Mann-Whitney U test statistic

For the *pre-intervention survey*, the Mann-Whitney test comparing two populations at a time and providing a mean rank for each revealed a significant difference ($P < 0.017$) between several of the student group populations among certain items which includes the following:

Group 3 students had a significantly ($P < 0.017$) higher pre-survey mean rank (26.57) compared to Group 4 (mean rank of 17.23) for item 1 (Aquaculture would be a highly interesting profession), while there were no significant differences found when comparing Groups 2 and 3 or comparing Groups 2 and 4 for the same item, respectively.

Group 3 students had a significantly ($P < 0.017$) higher pre-survey mean rank (19.50) compared to Group 2 (mean rank of 10.80) for item 3 (At this time, aquaculture increases my interest in engineering). However, there were no significant differences found when comparing Groups 4 and 2 (i.e., *Bonferroni* correction) or Groups 3 and 4 for the same item 3, respectively.

Group 3 students had a significantly ($P < 0.017$) higher pre-survey mean rank (19.93) compared to Group 2 (mean rank of 10.40) for item 8 (When I graduate from high school, I would like to work with people who make discoveries in science). However, there were no significant differences found when comparing Groups 3 and 4 (i.e., *Bonferroni* correction) or Groups 2 versus 4 for the same item 8, respectively.

Group 3 students had a significantly ($P < 0.017$) higher pre-survey mean rank (25.21) compared to Group 4 (mean rank of 16.88) for item 9. However, there were no significant differences found when comparing Groups 2 and 3 (i.e., *Bonferroni* correction) or Groups 2 and 4 for the same item 9, respectively.

Group 3 students had a significantly ($P < 0.017$) higher pre-survey mean rank (19.18) compared to Group 2 (mean rank of 11.10) for item 10 (I would encourage my friends, not attending project, to consider courses in aquaculture). However, there were no significant differences found when comparing Groups 2 and 4 or Groups 3 and 4 for the same item 10, respectively.

Group 3 students had a significantly ($P < 0.017$) higher pre-survey mean rank (19.50) compared to Group 2 (mean rank of 10.80) for item 12 (I expect to pursue higher education in a STEM-related field). However, there were no significant differences found when comparing Groups 2 and 4 or Groups 3 and 4 for the same item 12, respectively.

The Kruskal-Wallis test of significance of the *post-intervention survey instrument* comparison also revealed a significant difference ($P < 0.05$) between the three student group populations for statements 6 (My participation in the aquaculture project increased my desire to take more course in a STEM-related area) and 10 (I would encourage my friends, not attending project, to consider courses in aquaculture), while there were not significant differences ($P > 0.05$) for the remaining ten survey items. An overview of this post-survey data is provided in Table 4.32. A visual representation and distribution of the two items having significant differences are also presented in Figures 4.19 and 4.20.

Table 4.32 Kruskal-Wallis Mean Rank Post-Intervention Survey Instrument Comparison with Respect to the Treatment Groups

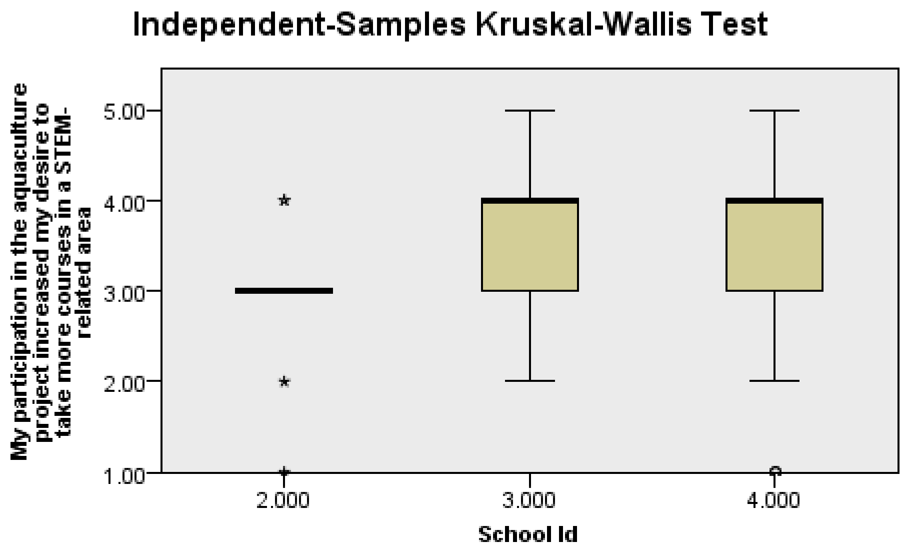
Dependent Variable[a]	Student Groups	*N*	Mean Rank	Sig.[a] (Test Statistic)[b]
Aquaculture would be a highly interesting profession	2	15	25.47	.635
	3	14	27.11	
	4	26	29.94	
	Total	55		(.910)
Aquaculture activities increased my interest in science	2	15	24.10	.487
	3	14	29.36	
	4	26	29.52	
	Total	55		(1.439)
Aquaculture activities increased my interest in engineering	2	15	26.07	.725
	3	14	30.57	
	4	26	27.73	
	Total	55		(.644)
Aquaculture activities increased my interest in mathematics	2	15	34.37	.106
	3	14	28.82	
	4	26	23.88	
	Total	55		(4.497)
My participation in the aquaculture project increased my interest in a STEM career field	2	15	24.47	.523
	3	14	30.79	
	4	26	28.54	
	Total	55		(1.296)
My participation in the aquaculture project increased my desire to take more courses in a STEM-related area	2	15	19.87	.046[a]
	3	14	32.21	
	4	26	30.42	
	Total	55		(6.175)

My participation in the project increased my desire to take courses in aquaculture specifically	2	15	23.70	.386
	3	14	31.25	
	4	26	28.73	
	Total	55		(1.906)
When I graduate from high school, I would like to work with people who make discoveries in science	2	15	24.00	.145
	3	14	34.75	
	4	26	26.67	
	Total	55		(3.866)
I would like future opportunities to study aquaculture and aquatic science subject for high school and advanced credit	2	15	22.87	.268
	3	14	31.82	
	4	26	28.90	
	Total	55		(2.634)
I would encourage my friends (not attending project) to consider courses in aquaculture	2	15	18.73	.020[a]
	3	14	30.07	
	4	26	32.23	(7.780)
	Total	55		
Aquaculture activities increased my curiosity in technology	2	15	24.87	.383
	3	14	25.86	
	4	26	30.96	
	Total	55		(1.920)
I expect to pursue higher education in a STEM-related field	2	15	23.50	.334
	3	14	31.61	
	4	26	28.65	
	Total	55		(2.196)

[a]$p < 0.05$. (significant difference)

[b]$(df) = (2)$

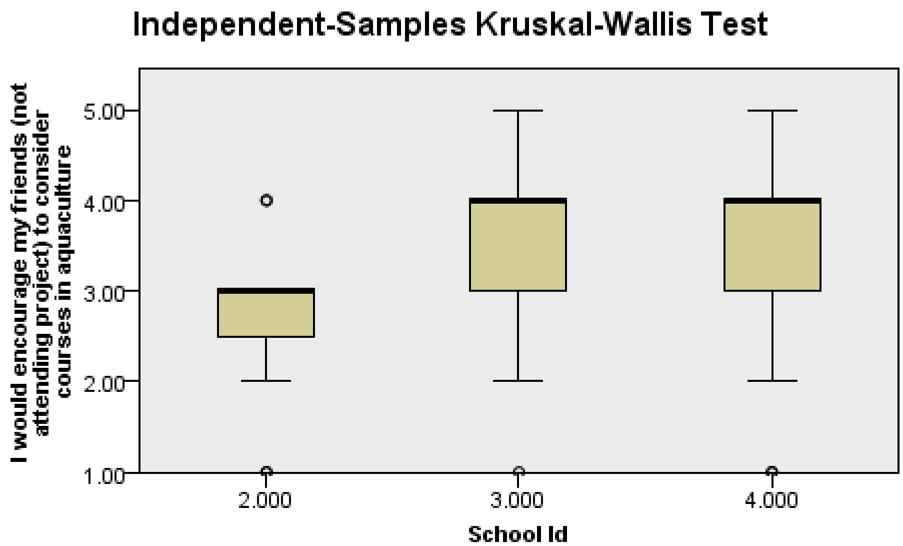
Figure 4.19 Independent-Samples Kruskal-Wallis Test of Post-Project Survey Item 6



Total N	55
Test Statistic	6.175
Degrees of Freedom	2
Asymptotic Sig. (2-sided test)	.046

1. The test statistic is adjusted for ties.

Figure 4.20 Independent-Samples Kruskal-Wallis Test of Post-Project Survey Item 10



Total N	55
Test Statistic	7.780
Degrees of Freedom	2
Asymptotic Sig. (2-sided test)	.020

1. The test statistic is adjusted for ties.

Similarly, since there were significant differences ($P < 0.05$) found in the post-intervention survey instrument between groups for items 6 and 10, the researcher employed a series of *Mann-Whitney tests* and compared two populations (student groups) at a time which provided mean ranks for each, with a *Bonferroni* correction to control for type 1 errors. Additionally, the researcher divided alpha by the number of comparisons, which was three in total. Hence, the statistical significance level for the *Bonferroni* correction was $\alpha = .05/3 = 0.017$. The final sample size was $N = 55$ (Group 2 = 15; Group 3 = 14; and Group 4 = 26). Results of the Mann-Whitney U test for the post-intervention survey are shown in Table 4.33.

Table 4.33 Mann-Whitney Comparison Mean Rank Test for Post-Intervention Survey Instrument with Respect to the Treatment Groups (N = 55)

Variable	Student Groups	*N*	Mean Rank	Sig[a]	Test Statistic[b]
My participation in the aquaculture project increased my desire to take more courses in a STEM-related area	Group 2 Students	15	12.13	.063	62.0
	Group 3 Students	14	18.07		
	Group 2 Students	15	15.73	.032	116.0
	Group 4 Students	26	24.04		
	Group 3 Students	14	21.64	.664	166.0
	Group 4 Students	26	19.88		
I would encourage my friends (not attending project) to consider courses in aquaculture	Group 2 Students	15	12.23	.070	63.50
	Group 3 Students	14	17.96		
	Group 2 Students	15	14.50	.007	97.5
	Group 4 Students	26	24.75		
	Group 3 Students	14	19.61	.726	169.5
	Group 4 Students	26	20.98		

[a]Significance is below .017.

[b]Mann-Whitney U test statistic

Results from the Mann-Whitney mean rank test revealed that there were no significant differences ($P > 0.017$) found when comparing Groups 2 and 3, Groups 2 and 4, and Groups 3 and 4 for item 6, respectively. Relating to item 10, Group 4 students had a significantly ($P < 0.017$) higher post-survey mean rank (24.75) compared to Group 2 (mean rank of 14.50) for item 10 (I would encourage my friends, not attending project, to consider courses in aquaculture). However, there were no significant differences found when comparing Groups 2 and 3 or Groups 3 and 4 for the same item 10, respectively.

CHAPTER 5. DISCUSSION, RECOMMENDATIONS, AND CONCLUSIONS

5.1 A Discussion of the Interpretations of the Findings

The purpose of the present study was to examine the effects of a 10-week long authentic APBI unit on participating high school students' attitudes toward STEM in general, and aquaculture and aquaponics in particular, and interests in future STEM-related disciplines and/or STEM career pathways. The study also measured changes in students' understanding of the phenomena carrying capacity and bacterial nitrification process (via target concepts) and their knowledge of ecosystems and related ecological relationships. Quantitative data were collected and analyzed to determine whether or not students participating in the project improved their thoughtful consideration and knowledge of the delicate nature of ecosystems and their interactions among biotic and abiotic factors when engaged in a contextualized PBI model unit.

The researcher argues that a classroom rich in authentic, hands-on project-based instructional experiences will help participants gain a deeper conceptual understanding of ecosystem processes and their interactions. This agrees with Cetin's (2003) assertion that to provide conceptual change and meaningful learning of science concepts, there is a need for using effective techniques for overcoming those misconceptions in science. The researcher also posits that students' exposure to this intervention will promote positive attitudes toward STEM in general, and aquaculture in particular, as well as positive changes in their short-term interests in STEM disciplines and/or STEM career pathways. Further, a goal of the project was to contribute to the growing body of research on the effects of APBI on student learning.

The study was guided by a situated learning theoretical framework which encompasses a constructivist theoretical framework, but specifically integrates the environmental factors present in the space where the study occurred (e.g., teacher's instructional styles, class environments, and student demographics). Thus, the researcher utilized this framework as a lens when discussing the outcomes.

Results from this study revealed that an authentic, hands-on APBI intervention contributed to students' content understanding of ecological relationships and concepts. Specifically, the treatment group students who participated in the aquaculture project improved their content understanding of carrying capacity and nitrogen cycle. A statistically significant difference ($P < 0.008$) was found when comparing between Group 1 students (mean rank of 20.34) and Group 2 students (mean rank of 34.78) (.001 statistical significance); Group 1 students (mean rank of 19.39) and Group 3 students (mean rank of 32.0) (.003 statistical significance); and Groups 1 students (mean rank of 16.0) and Group 4 students (mean rank of 42.5) (.001 statistical significance), respectively. Hence, these results demonstrate that the control group students (Group 1) had significantly ($P < 0.008$) lower mean difference (improvement) sum scores after taking the pre- and post-content-aligned assessment when compared to the treatment groups (Groups 2, 3 and 4). As mentioned previously, Teacher A addressed the target concepts in their general biology class, but the control group students purposefully did not receive opportunities to engage in the authentic, hands-on APBI intervention. Hence, the evidence from this study suggest that the authentic APBI instructional experiences facilitated students' understanding of the target concepts. Overall, results demonstrate that the project-based intervention, utilizing a real-life aquaculture/aquaponics context, was an effective method to provide meaningful learning and content understanding of standard-based ecological concepts and relationships.

Likewise, results demonstrate that there was a statistically significant difference ($P < 0.008$) when comparing between Group 2 students (mean rank of 11.23) and Group 4 students (mean rank of 30.84), (.001 statistical significance), and with Groups 3 students (mean rank of 8.13) and Group 4 students (mean rank of 26.41), (.001 statistical significance), respectively. These results demonstrate that Group 4 students had a significantly higher mean difference (improvement) score compared to all other student groups. However, no statistically significant differences ($P > 0.008$) were found when comparing between Group 2 students (mean rank of 18.40) and Group 3 students (mean rank of 17.47) (.805 statistical significance), respectively.

Overall, to summarize, these findings reveal that Group 4 students had a significantly higher ($P < 0.008$) mean difference (improvement) score when compared to all other groups. Hence, data suggests that students from this population (Group 4) had the highest knowledge increase between the pre-and post-content assessment. Likewise, student populations from (Groups 2 and 3 were similar statistically) with respect to mean difference (improvement) scores. However, it is important to note that students' knowledge improved in all three treatment groups and was significantly ($P < 0.008$) higher compared to the control group (Group 1). Clearly, this is a positive outcome in the present study as it was expected that the three treatment groups would have a greater improvement in scores compared to the control group (Group 1), since they participated in the authentic, hands-on intervention in the classroom.

The results also revealed that the intervention contributed to the treatment group students' positive attitudes toward STEM in general, and aquaculture and aquaponics in particular. The present study exemplifies how an authentic, hands-on aquaponics project-based intervention can increase high school level student attitudes toward STEM and developing an interest in STEM disciplines and/or STEM career pursuits. The evidence from this study also suggest that some students developed an interest in aquaculture fields after participating in the project. The next section will focus on each student group who participated in the authentic, hands-on APBI intervention and uncover and reveal student learning outcomes.

Group 3 Students. When interpreting the results, data reveals that Group 3 students showed an interest in STEM disciplines, and aquaculture in particular, with expectations to pursue higher education in a STEM-related field *before* they participated in the intervention. This is based on the descriptive statistics in the pre-intervention survey and analysis of the survey results and from the comparison across groups. Results indicated that Group 3 students had numerically higher mean scores in eleven out of the twelve items within the survey instrument in comparison to the other two treatment groups which included: mean pre-intervention scores for survey (item 1, 3.57), aquaculture would be a highly interesting profession; (item 2, 3.57), at this time, aquaculture increases my interest in science; (item 3, 3.36), at this time, aquaculture increases my interest in engineering; (item 4, 2.93), at this time, aquaculture increases my interest in mathematics; (item 5, 3.43), my participation in the aquaculture project will increase my interest in a STEM career field; (item 6, 3.43), my participation in the aquaculture project will increase my desire to take more courses in a STEM-related area;

(item 7, 2.93), my participation in the project will increase my desire to take courses in aquaculture specifically; (item 8, 3.57), when I graduate from high school, I would like to work with people who make discoveries in science; (item 9, 3.57), I am interested in future opportunities to study aquaculture and aquatic science subjects for high school and advanced credit; (item 10, 3.50), I would encourage my friends not attending project to consider courses in aquaculture; and (item 12, 3.79), I expect to pursue higher education in a STEM-related field. Likewise, Group 3 students demonstrated significantly higher pre-survey mean rank scores in several of the survey items. Specifically, the Mann-Whitney comparison test revealed that Group 3 students valued aquaculture as a highly interesting profession, showed an interest in opportunities to study aquaculture for high school and dual credit, and would encourage friends to consider courses in aquaculture prior to participating in the project. It is important to note that all fifty-five students from the treatment groups who took the interest/attitude survey indicated that they had never taken any aquatic science/aquaculture courses in high school before the project. Hence, they had no exposure to aquaculture in a formal classroom setting prior to the implementation of this study. Likewise, it is important to note that Group 3 students had an interest in engineering, working with people who make discoveries in science, and had expectations to pursue higher education in a STEM-related field *prior* to participating in the APBI intervention.

Therefore, while Group 3 students had no school experiences in aquaculture prior to participating in the project, the researcher asserts this group may have had prior knowledge or informal ideas about STEM and aquaculture *before* coming to the science classroom based on the pre-survey instrument utilized in the present study. Cetin (2003) pointed that in a constructivist perspective, students enter the classroom with their own ideas and experiences and they shape their formal knowledge based on their existing ideas and experiences at school. Unfortunately, it is not known whether or not Group 3 students had any agricultural experiences outside of school prior to this study and specifically aquaculture and aquaponics. Therefore, incorporating questions comprised either in the survey instrument assessment and/or detail interview(s) at the beginning of the project about their agricultural experiences outside of school prior to the study could have helped explain the outcomes in the present study. Hence, this may be explored for future research when implementing a similar APBI intervention as the present study.

Additionally, it is important to note that Group 3 students had a numerically higher mean pretest content score (12.13; 20.2% total score) and significantly higher pretest mean rank content scores when utilizing the Mann-Whitney comparison test across the three treatment groups. One possible explanation for these findings may be that Group 3 students had already chosen to enroll in an AP Environmental Science class for their 9^{th} grade science credit. An assumption would be that students selecting environmental education for AP science would have prior knowledge of the topic, interest in pursuing higher education and a belief in one's ability to attain this goal (i.e., self-efficacy), and they may have had a higher level of confidence in their abilities to perform the aqua-STEM-related tasks/activities *prior* to participating in the project. Moreover, Group 3 students likely had a keen interest in ecology and environmental science, which both are closely integrated in the aquaponics system. It is important to note that Group 3 students were described as highly motivated students by their teacher and had aspirations to gain college credit at the end of the course prior to commencement of the project. Thus, these particular students may have been more confident and motivated in STEM and aquaculture at the beginning of the project and this explains why Group 3 students from a rural school setting had higher intensity Likert scale responses and higher pretest content score compared to all other groups.

Interestingly, when examining the descriptive statistics between the pre-and post-survey intervention responses, Group 3 students did show a negative change or "loss" in their interest in aquaculture as a profession (item 1) and aspirations to pursue higher education in a STEM-related field (item 12). In survey item 1, Group 3 students' pre and post-intervention mean scores changed from 3.57 to 3.21, while survey item 12 changed from 3.79 to 3.43. However, when comparing the other two treatment groups' posttest survey mean scores, they had comparable interest with Group 3 students in those two areas. However, when making comparisons across the three groups' *posttest survey responses*, results revealed no significant differences in student attitudes toward STEM, aquaculture in particular, and interest in STEM disciplines and/or STEM career pursuits. The only significance found was in item 10 (I would encourage my friends (not attending project) to consider courses in aquaculture) for which Group 4 students had a significantly higher mean rank score compared to Group 2.

Results clearly demonstrate that Group 3 students' attitudes toward and interest in STEM, and aquaculture in particular, numerically decreased after exposure to the intervention. However, while Group 3 students living in rural school setting with a majority receiving free or reduced lunch did demonstrate a lower interest in aquaculture and aspirations to pursue higher education in STEM-related field after experiencing the APBI intervention, it is important to note that the interest was not statistically significantly different from the other two treatment groups, and particularly Group 4, who also demonstrated a high interest. It could be that students in Group 3 were excited and more confident about an ecological project, but with limited to no experience with aquaculture and aquaponics, specifically, they may have developed a more realistic view of aquaculture as a result of the project. Thus, it could be that Group 3 students became less interested in aquaculture/aquaponics overtime. A survey instrument assessment measuring students' confidence in learning the standard-based ecological concepts as well as performing the authentic, hands-on tasks may have been helpful to uncover and explain Group 3 students' outcomes in the present study. Hence, this may be explored in a future research project when utilizing a similar APBI intervention.

Overall, to summarize, there were positive changes when examining participants' responses from the pre to post-survey descriptive statistics in their attitudes toward desire to take more courses in a STEM-related area (5.2%). However, Group 3 students had a negative improvement in their attitudes towards aquaculture as a profession (7.2% loss) and expecting to pursue higher education in a STEM-related field (7.2% loss). The descriptive data reveals that Group 3 students had a relatively high perception of aquaculture at the beginning of the project, but decreased after completing the intervention. Likewise, data analyzed in the present study suggest that Group 3 students appears to have a desire to take STEM-related courses, but may not consider pursuing higher education in a STEM field after high school.

Additionally, results demonstrated that Group 3 mean difference (improvement) content scores and posttest content mean rank scores were numerically and significantly lower when compared to Group 4 students. However, it is important to note that Group 3 students had significantly higher mean difference (improvement) content scores compared to Group 1 students (control) and similar statistically to Group 2 students.

Group 2 students. Group 2 students revealed positive changes in attitudes and interest from the pre to post-intervention. Overall, there were positive changes when examining participants' responses from the pre to post-survey descriptive statistics, and especially, in their attitudes toward engineering (12%) and mathematics (20%). Furthermore, results indicate that Group 2 students improved their attitudes toward pursuing higher education in a STEM-related field (6.8%) and taking courses in a STEM-related area (5.2%). Likewise, a moderate increase was found (4%) when Group 2 students were asked about the project having an effect on their curiosity in technology specifically. This is a positive outcome, particularly since the teacher indicated that a school decision prior to this study resulted in the high-achieving students had been pulled to become part of another class section. Thus, students in Group 2 were comprised of mixed abilities comprising average to lower level students in the population. Subsequently, Group 2 students possibly had less motivation, lower level of confidence, and moderately to low interest in STEM disciplines and/or STEM career pursuits at the beginning of the project in comparison to the other two treatment groups. As mentioned previously, students from each school had different school experiences, daily life experiences, prior knowledge, abilities, teacher, and peer interaction that should be considered when deciphering the results.

Results clearly demonstrate that Group 2 students had an interest toward engaging with engineering design processes, performing real-world mathematics, and using various authentic tools through their authentic, hands-on project-based aquaculture STEM learning activities in the classroom. Hence, it could be that these tasks may have been more meaningful and interesting to them as opposed to learning about ecological concepts and relationships. It is important to note that this corroborates with the researchers field visits as it was noticed that Group 2 students appeared to enjoy the responsibility of calculating growth performance of living organisms within their closed recirculating system (i.e., applied mathematics). Students from this population showcased their weekly calculations on a whiteboard in the classroom. In addition, Group 2 students were extremely focused on maintaining the aquaponics system throughout the project to ensure that it was running properly (i.e., engineering design). It is important to note that the teacher placed much emphasis on this task possibly due to previous experiences during the 2018-2019 academic year (i.e., water overflow in the classroom). Further, it could be that Group 2 students had existing ideas, experiences, and prior knowledge in these areas. Group 2 students also may have found that the *carry capacity* concept is abstract, difficult, confusing, and complicated and had common misconceptions about ecological concepts compared to Group 3 and Group 4 students prior to participating in the project. Cetin (2003) asserted that when new information or experiences are presented to the students in the classroom, they will either reject or reformulate their existing cognitive structures whether their knowledge and experiences are connected to their background information. Unfortunately, it is not known whether or not Group 2 students had prior knowledge and experience in ecological concepts before engaging in the project. Hence, this may have been advantageous to include in the survey instrument assessment, and thus, something to consider for future research.

Additionally, Group 2 students had numerically the lowest pretest mean content score (4.35; 7.3% total score) compared to the other three groups and numerically the second lowest posttest mean content score (16.30) when tested on specifically ecological concepts and relationships that was taught in the classroom by their teacher. Likewise, Group 2 students mean difference (improvement) sum content score (11.95; 20.0% total score) were significantly lower compared to Group 4 students (31.95; 53.3% total score). However, Group 2 students mean difference (improvement) sum scores were statistically similar to Group 3 (10.07; 16.8% total score) and significantly higher than Group 1 students (3.13; 5.2% total score).

Overall, to summarize, results demonstrate that these particular high school students living in rural school setting with a majority receiving free or reduced lunch may have preferred and had more confidence in their ability to engage in authentic hands-on, engineering and mathematical tasks and using various authentic technological tools pertaining to aquaculture. The fact that high achieving students at this particular school were separated into another science class prior to the project may have been an important factor to explain the outcomes. However, Group 2 students content scores after completing the project were similar statistically to Group 3 students who chose to take AP Environmental Science and significantly higher than the students from the control group intervention. Possible next steps for future research may include the need to address and concentrate on lower level students and compare their learning outcomes with more advanced students who experience the same authentic instructional intervention.

Group 4 students. Results of the present study demonstrate that Group 4 students seemed to value the field of aquaculture and STEM-related disciplines. Overall, there were positive changes when examining participants' responses from the pre to post-survey descriptive statistics in their aspirations to pursue future opportunities to study aquaculture subjects and advanced credit (12.4%), encouraging their friends to consider courses in aquaculture (12.4%), considering aquaculture as a highly interesting profession (7.8%), and willing to take courses in aquaculture specifically (5.4%) in the short-term. Furthermore, results indicate that Group 4 students improved their attitudes toward taking more courses in a STEM-related area (6.8%) and developed an increase in desire to work with people who make discoveries in science (6.2%). Clearly, an increase enrollment in STEM courses while in high school is an important outcome in order to help develop students' mathematics and science skills. Overall, results demonstrate that these particular high school students living in rural school setting with a majority receiving free or reduced lunch had a positive change in attitudes toward STEM and interests in the field of aquaculture.

Additionally, results from the pre-and post-attitude/interest survey corresponds to their mean difference (improvement) sum content scores with respect to the content assessment. As mentioned previously, Group 4 students had a statistically significantly higher mean difference (improvement) sum score (31.95; 53.3% total score) and significantly higher posttest mean rank content scores compared to all other treatment groups. Group 4 students were described as being motivated learners by their teacher.

When explaining these findings, it is important to note that the majority of Group 4 students were *female*. Specifically, there were 21 females and 5 males who took the pre- and post-intervention survey and 20 females and 2 males who took the pre- and post-content assessment. In contrast, Group 2 students had 8 males and 7 females who took the pre- and post-intervention survey and 11 males and 9 females who took the pre- and post-content assessment. Likewise, Group 3 students had 8 females and 6 males who took the pre- and post-intervention survey and 9 females and 6 males who took the pre- and post-content assessment. Further, the control group (Group 1 students) had approximately the same number of males (15) and females (16) who took the pre- and post-content assessment. Thus, Group 4 student population had a much higher female: male ratio when compared to all other groups in this study. The teacher expressed from her observations that the females were more diligent than the males and this may be one possible factor to consider when explaining the results. Future research should explore gender differences in content understanding of ecological concepts and identify potential knowledge gaps that may result from similar APBI units such as the one used in this study.

Furthermore, it may be important to mention that the teacher in Group 4 indicated that the other classes she taught of a similar age group, and from the same school, did not demonstrate the same level of academic success as compared to her 5th period students who participated in the present study. It could be that Group 4 were higher level students academically and thereby more motivated to learn the concepts when compared to all other groups. It is important to note that the teacher indicated that Group 4 students who participated in the project *loved the real world science opportunities* given through the aquaponics unit. Therefore, it could be that Group 4 students were more interested and confident in learning about science, and subsequently, the ecological concepts and relationships when studying a “living” aquaponics ecosystem when compared to all other groups.

It is also important to note that the researcher observed during his classroom visits that Group 4 students were noticeably different compared to the other treatment groups. They asked thoughtful questions, interacted well with their peers, and seemed to be very attentive and interested in the ecological project. In addition, the researcher noticed that Teacher D (Group 4) supported her students to ask questions and come to their own conclusions and appeared to have an innate skill to keep students engaged throughout the class period. As a reminder, Group 4 had a larger number of participants who completed the intervention in the classroom (26 total) with less class time each day (45 minutes) compared to the number of participants in Group 2 (20 total) having a 61 minute daily class time and to the number of participants in Group 3 (15) having a 54 minute daily class time. Thus, the researcher asserts that it could be that Teacher D had to be more efficient teaching the content and facilitating the APBI intervention due to these challenges. Furthermore, the researcher observed in the classroom that Teacher D (Group 4) implemented more of a constructivist teaching approach when compared to the other two teachers. She allowed wait time when asking questions in class, encouraged students when working in groups to interact with each other and her, asked thoughtful and open-ended questions, encouraged students to reflect on their experiences, and asked students to articulate their ideas about ecological concepts before she presented her understanding of the concepts. This was evident each time the researcher visited Group 4 students’ classroom.

The composition of the student groups sampled in each of the groups is another factor to consider. Group 1, the control, included a larger percentage of underrepresented students (54.8%) than the three treatment groups, respectively. For example, of the 20 students sampled in Group 2, 45% were from underrepresented populations. Similarly, of the 15 students sampled in Group 3, 6.7% were from underrepresented populations. Likewise, of the 22 students sampled in Group 4, 22.7% were from underrepresented populations. It is important to note that these were students who took the pre- and post-content-aligned assessment.

5.2 Implications of the Findings

The findings in the present study have numerous implications for future aquatic ecosystem instruction in the high school level classroom. There is a need for more authentic exploratory experiences such as the intervention implemented in the present study to provide science/STEM that articulates NGSS and *A Framework for K-12 Science Education*. Developing authentic exploratory interventions that explicitly integrates scientific practices, disciplinary core ideas, and crosscutting concepts may also provide motivation to students who receive these authentic exploratory experiences.

In terms of research, it is essential to provide teachers educational/professional development opportunities prior to implementing APBI interventions in the classroom, and especially if the population is comprised of lower level students who may need more support when compared to higher level students. The biology teachers in the present study were provided opportunities to help develop the unit materials, learn the content, and had direct experience implementing the aquaponics PBI intervention over a period of several semesters while working with different student groups containing mixed abilities. The three biology teachers selected student groups who were considered high level academically and they also gained experience working with lower level students before volunteering to participate in the present study. Likewise, they participated in a teacher professional development workshop, organized by the researcher, during the summer of 2019. While teachers outside this study may not ever receive such an extensive experience and training as the three biology teachers in the present study, it is crucial that they are prepared prior to facilitating an aquaculture/aquaponics PBI unit.

The study examined the effects of an authentic PBI unit in a specific context model system (i.e., aquaculture and aquaponics) on students' understanding of ecosystems and the interdependent relationships that exist. A Framework for K-12 Science Education and the NGSS identify *Interdependent relationships in ecosystems* as part of a disciplinary core idea in life sciences and system models as a crosscutting concept that makes connections across disciplinary boundaries (NGSS Lead States, 2013; NRC, 2012). As a review, *carrying capacity* is the central concept of the NGSS life science core idea Ecosystems: Interactions, Energy, and Dynamics (NGSS for Lead States, 2013), heretofore referred to as the core idea of Ecosystems. The unit addressed ecosystem performance expectations HS-LS2-1 through HS-LS2-4 and HS-LS2-6 that draws upon practices of mathematical and computational representations to support explanations of factors that affect *carrying capacity* of ecosystems at different scales. Emphasis is on quantitative analysis and comparison of the relationships among interdependent factors including boundaries, resources, climate, and competition. Mathematical comparisons may include graphs, charts, histograms, and population changes gathered from various data sets. Thus, the unit in this study was designed to purposefully integrate mathematics and science in meaningful ways situated by the context of an aquaponics ecosystem. It provided an exemplar for authentic, student-centered STEM investigations articulating NGSS. Furthermore, the project addressed disciplinary core ideas (DCI), such as ecosystems have *carrying capacities*, which are limits to the numbers of organisms and populations they can support. These limits result from such factors as the availability of living and nonliving resources and from such challenges such as predation, competition, and disease. Students learn that organisms would have the capacity to produce populations of great size were it not for the fact that environments and resources are finite. This fundamental tension affects the abundance (number of individuals) of species in any given ecosystem (NGSS for Lead States, 2013). Therefore, the project provided participants with student-centered, problem solving experiences with real-world applications and implications.

Providing contextualized PBI instruction in the secondary school classroom that is *relevant* and *meaningful* to their lives and community may also help learners integrate ideas, connect the information, and thus, make it *stick* as compared to traditional instructional practices (Rivet & Krajcik, 2008). Likewise, collaborations between universities and secondary schools may play a critical role going forward in order to implement these types of interventions in K-12 classrooms. Subsequently, this contributes to the *scholarship of engagement* concept described in Chapter 2. Clearly, schools may not always have the class time, the teacher training time, or the resources available to implement aquaculture-based interventions in classrooms. This was discussed extensively in Chapter 2. Research demonstrates that teachers believe time mostly impacts success of the integration of other disciplines (Myers & Washburn, 2008; Conroy & Walker, 2000). Myers and Washburn (2008) also indicated that a majority of teachers felt insufficient funding, concerns about large class size, support to plan for implementation, and personal lack of experience in science integration were barriers to integrating science concepts into an agricultural education curriculum. Thus, partnerships between universities and secondary school systems may be essential for sustained success going forward.

Overall, the intervention utilized in this study promoted a more successful STEM learning experience and students gained a foundational understanding of the target concepts during the inquiry process. Rivet and Krajcik (2008) asserted that not only does PBI motivate students, but also promotes students' thoughtful consideration of the science ideas and relationships. The present study supports the notion that contextualizing PBI can play a powerful role in facilitating student learning through both motivational and cognitive means.

5.3 Limitations of this Study

Attention should be given to the limitations of this study. First, the findings are applicable to only the participants in the present study. Moreover, the results about the comparisons among the different student groups are based on small sample sizes, and therefore the results cannot be generalized. Thus, participation of student groups with a larger sample size could have resulted in more comprehensive results. Second, the short-term nature of the intervention implemented in the present study may be a limitation. While short-term interventions can provide evidence that reveals the development of positive student attitudes toward STEM, interests in STEM-course taking, and their knowledge relative to STEM, future studies could examine more long-term or downstream effects which might include the following: 1) STEM career pursuits (i.e., STEM career interest, the number of college STEM courses, and students' attitudes toward STEM) several years later after participation in the project-based investigation intervention; 2) effects on high-school STEM classroom actions relating to promoting STEM course-taking while in high school; 3) and the effects of improving mathematics and science standardized test scores on a college preparatory examination (ACT) for adolescents when exposed to an authentic, hands-on project-based aquaculture intervention.

5.4 Future Research Considerations

Future studies could rely more on student self-reports (i.e., individual and/or group interviews) utilizing qualitative methods approaches with the intent to explore deeper into students' STEM career pursuits after high school and in college, how might this intervention develop students' mathematics and science skills, and whether or not the intervention encourages students to take more STEM courses while in high school. Future research considerations could examine particular STEM skills when exposed to the intervention such as engineering design activities as it relates to their recirculating aquaculture systems assembled in the classroom. Another consideration may be to assess student understanding of the targeted concepts utilizing model drawing tasks. For example, model drawings may allow researchers to see depictions of the nitrogen cycle process thereby illustrating their understanding how the mechanisms operate in the context of aquatic ecosystems. It is important to note that the researcher plans to analyze the test results in this study by item to learn more about the effect of the intervention on student understanding of specific concepts assessed on carrying capacity and nitrogen cycle in ecosystems. Further, collecting information from teachers as the unit of analysis through teacher journal reflections and/or individual interviews may provide unique insights into the benefits, challenges, and implementation limitations of this project. It would also be interesting to investigate the implementation of a similar project-based learning model aligned with the NGSS (NGSS Lead States, 2013) when infused in "out-of-school" STEM education environments. It may be advantageous to investigate informal authentic learning environments that correspond directly to the needs of a particular community as students engage with STEM activities outside of school.

Another future consideration for research may be to examine specifically urban school settings which is an important demographic category. Jin et al. (2019) asserted that in the U.S., suburban schools tend to have highly qualified teachers, rigorous curricula, and high student performance, while urban schools often face challenges such as low resources, high teacher turnover, and low student performance. Further, the authors emphasized that rural schools tend to be small and many are situated in remote and poor areas. It is important to note that this is a good depiction of the schools in the present study as they are dealing with similar challenges facing urban schools, such as poverty. For instance, many students in the present study were eligible for free or reduced school lunches. Jin et al. (2019) stated that school lunch status is often used as an indicator of Socioeconomic Status (SES). Therefore, future research considerations should also include examining how aquaponics PBI might promote urban school students' understanding of ecosystem concepts and provide students authentic, hands-on STEM education opportunities with goals to foster students' attitudes toward and interest in STEM disciplines and/or STEM career pathways. A future consideration for research may be to compare performance gaps for diverse student populations after taking the pre- and post-content assessment utilized in the present study. This is yet another subgroup that could be examined more extensively.

Another future consideration for research may be to target middle school level students from various school settings and expose them to authentic, hands-on interventions that align with the NGSS in similar ways as demonstrated in the present study.

5.5 Concluding Remarks

In conclusion, Conroy and Walker (2000) stated that many educators view aquaculture education as an ideal vehicle to facilitate the integration of academic and vocational subject matter when it is infused into secondary or other agriculture curriculum. Research suggests that aquaculture is an effective "teaching tool" because it easily integrates many disciplines including biology, chemistry, economics, math, physics, and can provide hands-on experiences that complement academic theory (Conroy & Peaslely, 1997; El-Ghamrini, 1996; Wingenbach, 2000). Conroy and Walker (2000) reported that aquaculture provides experiential science and mathematics education to help meet demands for cross-curricular integration. Mabie and Baker (1996) stated that agriculture is by nature a hands-on discipline and would seem to be a perfect match for integration into the science curriculum. Therefore, this provides a basis for using aquaculture to create an authentic STEM-related PBI experience in the present study. Actively engaging students in practical, hands-on authentic tasks that focus on real-world problems they investigate in the classroom provides learners unique experiential learning opportunities. Students investigated, analyzed, and communicated their carrying capacity findings in an aquaculture context. In doing so, students were able to get in touch with basic STEM concepts and skills as they connected with aquaculture and aquaponics which is a unique and sustainable method of growing plants and fish together in a closed recirculating loop system. These super-efficient systems provided students opportunities to develop their critical thinking and problem solving skills as they created and managed a living ecosystem while studying the interactions of fish, plants, and bacteria. Likewise, students were given opportunities to work in small groups and were assigned a job similar to what a STEM worker might do in the field. Weekly job rotations also allowed students to experience and master tasks assigned to each job. These experiences allowed students to practice teamwork and develop their communication skills and gain responsibility. Overall, students took ownership of their learning while investigating, exploring, analyzing, interpreting, and reflecting amongst their peers the tasks at hand which fostered positive learning outcomes.

Overall, the implications of this study suggest APBI models may create authentic science learning environments that promote student learning of scientific concepts while piquing their interest in STEM related disciplines and/or career pathways. To date, few studies have explored, and little research exists, in this context in the science classroom. Hence, this study begins to fill a void and to help educators in the future. Prior to this study, there has been a need to document the actual use of aquaculture and aquaponics as a teaching and learning tool for the expansion of this context in secondary education and the development of appropriate aquaculture-based curricula aligned with NGSS.

5.6 Summary

The results in this study reveals that environments rich in hands-on approaches to learning (via group project work), and providing students "real-life" situations in an aquaculture context, fosters students content learning and helps participants gain a deeper understanding of ecological relationships and concepts pertaining to the phenomena carrying capacity. Students were given opportunities to become active learners and experience an aquaculture "real-life" context in ways they had never encountered that connected to their daily lives. The 10-week APBI aided to improve students' understanding of scientific and mathematical practices through problem solving, discovering new principles, and opportunities to apply their understanding while pursuing answers to research questions. Hence, the project-based environment experiences designed in the classroom assisted students to think scientifically and mathematically during the inquiry learning process when studying aquatic ecosystems.

Overall, the gain in understanding and appreciation for and interest in STEM and aquaculture can be attributed to the project-enhanced unit. The evidence from this study suggest that authentic instructional experiences can facilitate students' understanding of standard-based ecological concepts and knowledge of ecosystems. The intervention design and findings in the present study may provide educators new insights and ideas on how to incorporate and use contextualized, aquaponics project-based instruction as a teaching and learning tool and thereby, develop appropriate curricula for secondary K-12 classrooms while adhering to the Next Generation Science Standards (NGSS).

APPENDICES

APPENDIX A – ATTITUDE SURVEY – PRE-INTERVENTION

ID # _______

Students Attitudes toward Aquaculture (Aquaponics) Project (Before)
Read each question below, then, circle the ONE response that best expresses your opinion.

Aquaculture would be a highly interesting profession.

1	2	3	4	5
Strongly disagree	Disagree	Neither agree nor disagree	Agree	Strongly agree

At this time, aquaculture increases my interest in science.

1	2	3	4	5
Strongly disagree	Disagree	Neither agree nor disagree	Agree	Strongly agree

At this time, aquaculture increases my interest in engineering.

1	2	3	4	5
Strongly disagree	Disagree	Neither agree nor disagree	Agree	Strongly agree

At this time, aquaculture increases my interest in mathematics.

1	2	3	4	5
Strongly disagree	Disagree	Neither agree nor disagree	Agree	Strongly agree

My participation in the aquaculture project will increase my interest in a STEM career field.

1	2	3	4	5
Strongly disagree	Disagree	Neither agree nor disagree	Agree	Strongly agree

My participation in the aquaculture project will increase my desire to take more courses in a STEM-related area.

1	2	3	4	5
Strongly disagree	Disagree	Neither agree nor disagree	Agree	Strongly agree

My participation in the project will increase my desire to take courses in aquaculture specifically.

1	2	3	4	5
Strongly disagree	Disagree	Neither agree nor disagree	Agree	Strongly agree

When I graduate from high school, I would like to work with people who make discoveries in science.

1	2	3	4	5
Strongly disagree	Disagree	Neither agree nor disagree	Agree	Strongly Agree

I am interested in future opportunities to study aquaculture and aquatic science subjects for high school and advanced credit.

1	2	3	4	5
Strongly disagree	Disagree	Neither agree nor disagree	Agree	Strongly agree

I would encourage my friends (not attending project) to consider courses in aquaculture.

1	2	3	4	5
Strongly disagree	Disagree	Neither agree nor disagree	Agree	Strongly agree

At this time, aquaculture increases my curiosity in technology.

1	2	3	4	5
Strongly disagree	Disagree	Neither agree nor disagree	Agree	Strongly agree

College Questions:

I expect to pursue higher education in a STEM-related field.	1	2	3	4	5
Have you taken any aquatic science/aquaculture courses in high school before the project?	Yes			No	

Male Female

Which of the following do you identify yourself? ☐

☐

What is your race? (Please circle)

American Indian, Asian, Black or African American, Native Hawaiian or other Pacific Island, Mixed, White, Other

*Pretest Interest/Attitude Survey Instrument

APPENDIX B – ATTITUDE SURVEY – POST-INTERVENTION

ID # _______

Students Attitudes toward Aquaculture (Aquaponics) Project (After)

Read each question below, then, circle the ONE response that best expresses your opinion.

Aquaculture would be a highly interesting profession.

1	2	3	4	5
Strongly disagree	Disagree	Neither agree nor disagree	Agree	Strongly agree

Aquaculture activities increased my interest in science.

1	2	3	4	5
Strongly disagree	Disagree	Neither agree nor disagree	Agree	Strongly agree

Aquaculture activities increased my interest in engineering.

1	2	3	4	5
Strongly disagree	Disagree	Neither agree nor disagree	Agree	Strongly agree

Aquaculture activities increased my interest in mathematics.

1	2	3	4	5
Strongly disagree	Disagree	Neither agree nor disagree	Agree	Strongly agree

My participation in the aquaculture project increased my interest in a STEM career field.

1	2	3	4	5
Strongly disagree	Disagree	Neither agree nor disagree	Agree	Strongly agree

My participation in the aquaculture project increased my desire to take more courses in a STEM-related area.

1	2	3	4	5
Strongly disagree	Disagree	Neither agree nor disagree	Agree	Strongly agree

My participation in the project increased my desire to take courses in aquaculture specifically.

1	2	3	4	5
Strongly disagree	Disagree	Neither agree nor disagree	Agree	Strongly agree

When I graduate from high school, I would like to work with people who make discoveries in science.

1	2	3	4	5
Strongly disagree	Disagree	Neither agree nor disagree	Agree	Strongly agree

I would like future opportunities to study aquaculture and aquatic science subjects for high school and advanced credit.

1	2	3	4	5
Strongly disagree	Disagree	Neither agree nor disagree	Agree	Strongly agree

I would encourage my friends (not attending project) to consider courses in aquaculture.

1	2	3	4	5
Strongly disagree	Disagree	Neither agree nor disagree	Agree	Strongly agree

Aquaculture activities increased my curiosity in technology.

1	2	3	4	5
Strongly disagree	Disagree	Neither agree nor disagree	Agree	Strongly agree

College Questions:

I expect to pursue higher education in a STEM-related field.	1	2	3	4	5
Have you taken any aquatic science/aquaculture courses in high school before the project?	Yes			No	

Which of the following do you identify yourself? Male ☐ Female ☐

What is your race? (Please circle)

American Indian, Asian, Black or African American, Native Hawaiian or other Pacific Island, Mixed, White, Other

*Posttest Interest/Attitude Survey Instrument

APPENDIX C – CONTENT-ALIGNED TEST WITH RUBRICS

AQUAPONICS UNIT ASSESSMENT

This assessment will test your knowledge of ecosystems. You may not know all the answers and that is okay, however it is important that you do your best. Please follow the guidelines below as you answer each question.

Answer every question to the best of your ability.

Write “I guessed” on questions that you are unsure about.

Write “I do not know” for questions that you cannot answer.

School (select)

Group 1 Students

Group 2 Students

Group 3 Students

Group 4 Students

Male or Female?

Male

Female

Personal Identity (You may check as many boxes as you would like).

American Indian or Alaska Native

Asian

Black or African American

Hispanic or Latino

Native Hawaiian or Other Pacific Islander

White

Add option or add other

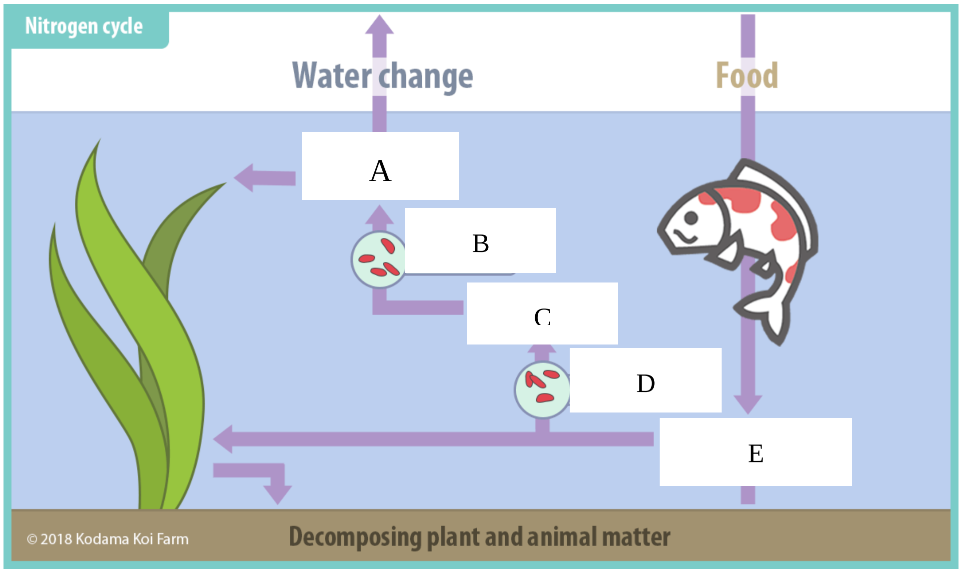
Last Name

First Name

ECOSYSTEMS (PART A)

HS-LS2-4

The nitrogen cycle is also an important process in the life of aquatic ecosystems. Show your understanding of the nitrogen cycle in a pond ecosystem by matching the correct description with the correct location in the image below. Please, no guessing. Select "I do not know" instead of guessing. Thank you!



	1	This Nitrosomonas bacteria consumes ammonia and oxygen to produce nitrite.
	2	The form of nitrogen usable by plants.
	3	Fish excrete ammonia directly in the water
	4	One of the most toxic substances on Earth for a fish.
	5	This nitrifying bacteria consumes nitrite and oxygen to produce nitrate.

CARRYING CAPACITY

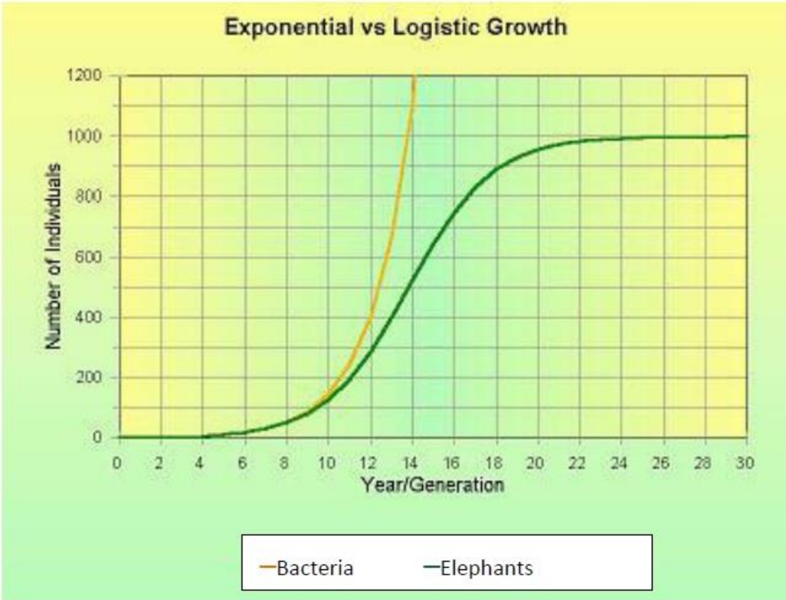
HS-LS2-1, HS-LS2-2 and HS-LS2-6

Analyze the graph to the right to answer questions 2-8.

What is the carrying capacity of the ecosystem for the logistic growth curve from this graph? HS-LS2-1

What is exponential growth?

HS-LS2-1



What is logistic growth?

HS-LS2-1

What is overshoot?

HS-LS2-1

What might a scientist conclude about the bacterial population from this graph?

HS-LS2-2 and

HS-LS2-6

What might a scientist conclude about the elephant population from this graph?

HS-LS2-2 and HS-LS2-6

What three factors can affect the number of organisms that live in a certain ecosystem?

HS-LS2-1

SCIENTIFIC ARGUMENT (PART B)

HS-LS2-1 and HS-LS2-2

Use the information below and Table 1 to answer questions 9-10.

Juvenile Australian red claw crayfish (8 g mean weight) were stocked at three rates of 12,000/ha, 18,000/ha, and 24,000/ha into three 0.02-ha earthen ponds (Kentucky). The red claw were fed the same amount of pelleted marine shrimp diet twice daily for 70 days.

(ha = hectare = $10^4 m^2$)

Table 1. Mean value for water quality parameters measured in ponds with red claw crayfish stocked at three densities.

Stocking density (number of crayfish/ha)

	12,000	18,000	24,000
pH	9.0	9.0	8.9
Total Ammonia Nitrogen (mg/L)	0.5	0.5	0.7
Nitrite	0.1	0.1	0.1
Temperature (°C)	28.06	27.40	28.06
Dissolved oxygen (mg/L)	10.09	9.54	10.11
Survival (%)	32.7	47.8	47.5

Analyze the different stocking rates (number of organisms) in a particular area (0.02-ha pond). Then explain what the scientists might have concluded about the effect the number of organisms might have had on water quality and survival.

HS-LS2-2

According the data in Table 1, was carrying capacity met? How do you know? Does the data support your claim?

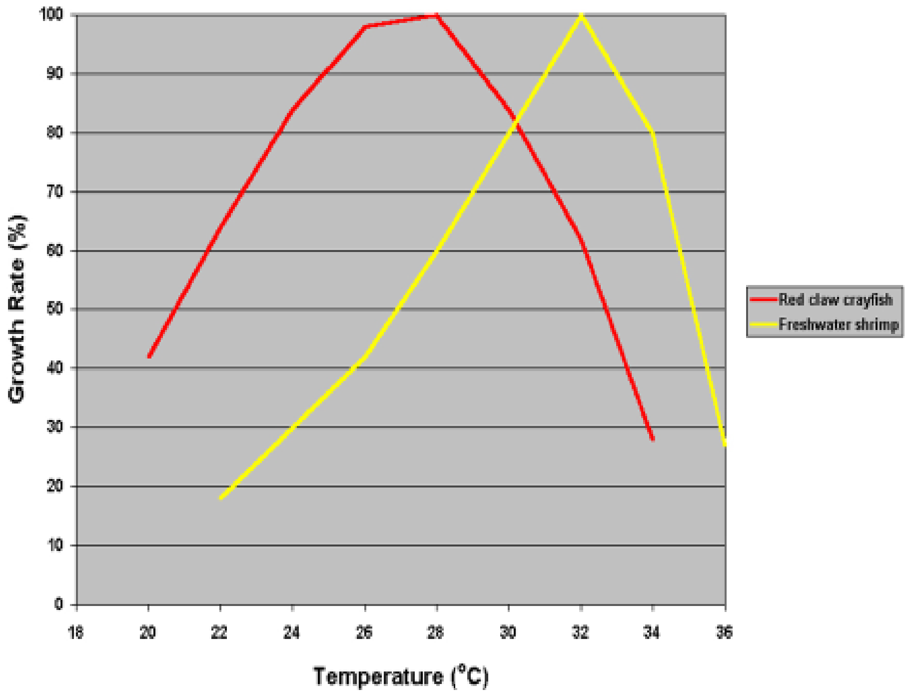
HS-LS2-1

HS-LS2-1, HS-LS2-2 and HS-LS2-6

Use the graph below to answer question eleven.

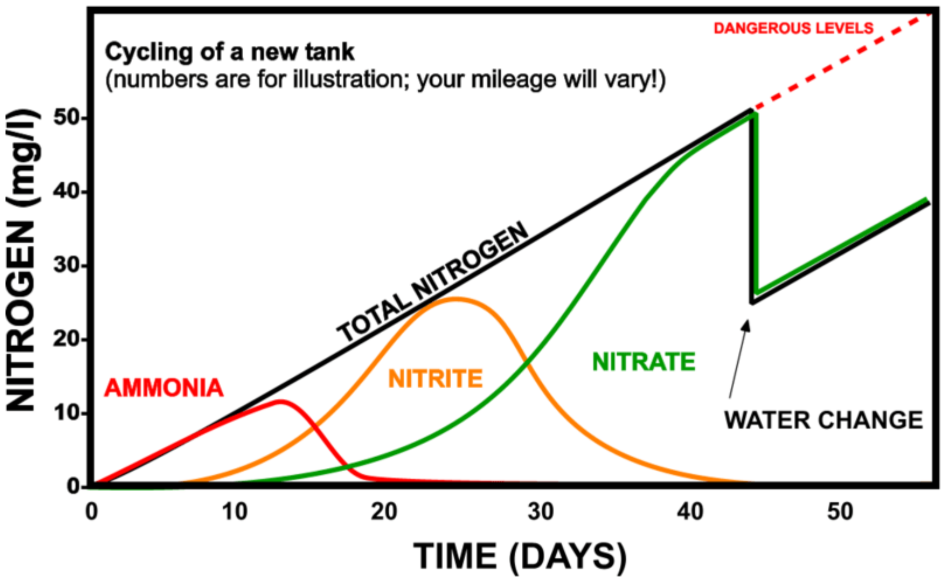
HS-LS2-1, HS-LS2-2 and HS-LS2-6

If you were going to raise red claw crayfish and fresh water shrimp together what is the optimal temperature at which you can raise them? Explain your answer.



HS-LS2-3, HS-LS2-1

Use the graph below to answer question twelve concerning the cycling of a new aquaponics system.



What might a scientist conclude about the decreasing ammonia levels and increasing nitrite levels on day 15?

Evaluation Rubric for Student Short Answers in Part A and B

Level of Knowledge	Numeric Score and Level of Understanding	Scoring Criteria
	0-No understanding	No response (provides no answer), unclear response, or no explanation give for answer choice. Hard to analyze understanding. Response does not make sense, no written response.
Low Level Knowledge	1-Incorrect/Scientific Misconceptions	Very basic/vague content knowledge and still incorrect. Inaccurate, no scientific reasoning to justify response, non-scientific justification, incorrect explanation.
	2-Partial Scientific with misconceptions/nonscientific fragment/facts	Basic/vague content knowledge with some misconceptions, but correct (scientific fragments/facts). Some portion of the answer is incorrect, includes some inaccuracies or misconceptions in rationale.
Developing Knowledge	3-Partially scientific notion	Vague but correct response showing incomplete knowledge with no connections. No justification, includes some overgeneralizations in rationale, or poor justification.
	4-Scientific minor justification	Correct response but provides minor explanation/justification with no misconceptions.
In-Depth Knowledge	5-Scientific with justification	Response contain all parts of a scientific answer.

*Scoring criteria are intended to help guide scoring decisions.

Carrying Capacity (Part A): Question 2:

What is the carrying capacity of the ecosystem for the logistic growth curve from this graph?

5 – Scientific & in depth response

Student describes the characteristics of the logistic growth curve (this is addressed in the questions that follow – the question does not ask for this) and particularly the green line (elephant population) having a carrying capacity of 1000 individuals.

The student accurately identifies carrying capacity from the graph.

4 – Scientific, but not in-depth

Student accurately identifies carrying capacity from the graph, but provides minor in-depth justification/explanation with no misconceptions.

3 – Partially scientific (scientific fragments) with no non-scientific conceptions

Correct response identifying the carrying capacity, but without justification.

Includes overgeneralizations in rationale, or poor justification.

No non-scientific conceptions.

2 – Partially scientific (non-scientific fragments) with non-scientific conceptions

Some portion of the answer is incorrect.

Includes some inaccuracies or misconceptions in rationale.

Confusion with lack of connections.

1 – Non-scientific rationale

Incorrect explanation

0 – Illegible/Non-codable/no response

Response does not make sense

No written response

Carrying Capacity (Part A): Question 3:

What is exponential growth?

5 – Scientific & in depth response

Student describes exponential growth characteristics which is a rapid population increase due to an abundance of resources (food, shelter/space, and mates) and lack of predation or competition within an ecosystem.

4 – Scientific, but not in-depth

Correct response, but student provides minor in-depth explanation with no misconceptions.

3 – Partially scientific (scientific fragments) with no non-scientific conceptions

Correct response identifying a rapid increase, but without explanation.

Includes overgeneralizations in rationale, or poor justification.

No non-scientific conceptions.

2 – Partially scientific (non-scientific fragments) with non-scientific conceptions

Some portion of the answer is incorrect.

Includes some inaccuracies or misconceptions in rationale.

Confusion with lack of connections.

1 – Non-scientific rationale

Incorrect explanation

0 – Illegible/Non-codable/no response

Response does not make sense

No written response

Carrying Capacity (Part A): Question 4:

What is logistic growth?

5 – Scientific & in depth response

Student describes logistic growth characteristics as this type of growth is due to a population facing limited resources (food, shelter/space, mates) and facing predation and competition, characterized by a period of slow growth, a period of exponential growth, and then the population levels off as it reaches the carrying capacity.

4 – Scientific, but not in-depth

Correct response, but student provides minor in-depth explanation with no misconceptions.

3 – Partially scientific (scientific fragments) with no non-scientific conceptions

Correct response identifying characteristics, but poor explanation.

Includes overgeneralizations in rationale.

No non-scientific conceptions.

2 – Partially scientific (non-scientific fragments) with non-scientific conceptions

Some portion of the answer is incorrect.

Includes some inaccuracies or misconceptions in rationale.

Confusion with lack of connections.

1 – Non-scientific rationale

Incorrect explanation

0 – Illegible/Non-codable/no response

Response does not make sense

No written response

Carrying Capacity (Part A): Question 5:

What is overshoot?

5 – Scientific & in depth response

Student describes overshoot which is the population surpassing its carrying capacity.

In the graph, overshoot is not shown. There is not a spike in the elephant population over the carrying capacity.

4 – Scientific, but not in-depth

Correct response, but student provides minor in-depth explanation with no misconceptions.

3 – Partially scientific (scientific fragments) with no non-scientific conceptions

Correct response identifying characteristics, but poor explanation.

Includes overgeneralizations in rationale.

No non-scientific conceptions.

2 – Partially scientific (non-scientific fragments) with non-scientific conceptions

Some portion of the answer is incorrect.

Includes some inaccuracies or misconceptions in rationale.

Confusion with lack of connections.

1 – Non-scientific rationale

Incorrect explanation

0 – Illegible/Non-codable/no response

Response does not make sense

No written response

Carrying Capacity (Part A): Question 6:

What might a scientist conclude about the bacterial population from this graph?

5 – Scientific & in depth response

Student makes a claim concerning the bacterial population and backs it with graphical evidence.

Student describes that the bacterial population is experiencing exponential growth due to the continued population increase past 1200 individuals. One can assume that the population has unlimited resources, no predation and or competition from other species. Eventually, resources will play out, space and waste will become an issue, but that is not yet shown in the graph.

4 – Scientific, but not in-depth

Correct response, but student provides minor in-depth explanation with no misconceptions.

3 – Partially scientific (scientific fragments) with no non-scientific conceptions

Correct response identifying characteristics, but poor explanation.

Includes overgeneralizations in rationale.

No non-scientific conceptions.

2 – Partially scientific (non-scientific fragments) with non-scientific conceptions

Some portion of the answer is incorrect.

Includes some inaccuracies or misconceptions in rationale.

Confusion with lack of connections.

1 – Non-scientific rationale

Incorrect explanation

0 – Illegible/Non-codable/no response

Response does not make sense

No written response

Carrying Capacity (Part A): Question 7:

What might a scientist conclude about the elephant population from this graph?

5 – Scientific & in depth response

Student makes a claim concerning the elephant population and backs it with graphical evidence.

Student describes that the elephant population began slowly, experienced exponential growth from generation 10 through about 18 and reached carrying capacity between generation 24 and 26. From then on, the elephant population plateaued – death rate = birthrate.

4 – Scientific, but not in-depth

Correct response, but student provides minor in-depth explanation with no misconceptions.

3 – Partially scientific (scientific fragments) with no non-scientific conceptions

Correct response identifying characteristics, but poor explanation.

Includes overgeneralizations in rationale.

No non-scientific conceptions.

2 – Partially scientific (non-scientific fragments) with non-scientific conceptions

Some portion of the answer is incorrect.

Includes some inaccuracies or misconceptions in rationale.

Confusion with lack of connections.

1 – Non-scientific rationale

Incorrect explanation

0 – Illegible/Non-codable/no response

Response does not make sense

No written response

Carrying Capacity (Part A): Question 8:

What three factors can affect the number of organisms that live in a certain ecosystem?

5 – Scientific & in depth response

Student list 3 factors that affect organisms in an ecosystem.

Factors that can affect the number of organisms that live in a certain ecosystem may include: abundance of food sources, sustainability of different food sources, and competition for food from other species, predation, reproduction sites, recruitment (immigration), emigration, and hunting/human impact.

4 – Scientific, but not in-depth

Correct response, but student provides minor in-depth explanation with no misconceptions.

3 – Partially scientific (scientific fragments) with no non-scientific conceptions

Correct response identifying characteristics, but poor explanation.

Includes overgeneralizations in rationale.

2 – Partially scientific (non-scientific fragments) with non-scientific conceptions

Some portion of the answer is incorrect.

Includes some inaccuracies or misconceptions in rationale.

Confusion with lack of connections.

1 – Non-scientific rationale

Incorrect explanation

0 – Illegible/Non-codable/no response

Response does not make sense

No written response

Scientific Argument (Part B): Questions 9-10:

Analyze the different stocking rates (number of organisms) in a particular area (0.02-ha pond). Then explain what the scientists might have concluded about the effect the number of organisms might have had on water quality and survival.

According the data in Table 1, was carrying capacity met? How do you know? Does the data support your claim?

5 – Scientific & in depth response

Student makes a claim about how stocking rates affect water quality.

They provide quantitative evidence from the chart to support water quality conclusions.

They use accurate scientific reasoning about how stocking rates affect survival rates.

They provide quantitative evidence from the chart to support survival rate conclusions.

Student makes a claim about carrying capacity.

Student provides evidence from the chart to support or refute carrying capacity claim.

Student provides accurate scientific reasoning to support carrying capacity claim.

Evidence (quantitative number data) from chart to support their claim <u>may include</u>: In terms of the first question (a), there appears to be no advantage to stocking red claw crayfish at rates below 24,000/ha in terms of water quality and survival percentage. Students may suggest that a scientist would recommend that crayfish be stocked at or above 24,000/ha citing water quality conditions and/or survival rates

Reasoning (explanation and analysis of how the evidence supports their claim): Water quality parameters did not increase at higher stocking densities and the highest stocking rate did not appear to exceed the *carrying capacity* of the pond ecosystem. Thus, a population of 24,000 red claw did not surpass its *carrying capacity*

In terms of the second question (b), evidence (quantitative number data) indicates that the carrying capacity was not met. The population did not crash at 24,000/ha.

4 – Scientific, but not in-depth

Correct response, but student provides minor in-depth explanation with no misconceptions.

3 – Partially scientific (scientific fragments) with no non-scientific conceptions

Correct response identifying characteristics, but poor explanation.

Includes overgeneralizations in rationale.

No non-scientific conceptions.

2 – Partially scientific (non-scientific fragments) with non-scientific conceptions

Some portion of the answer is incorrect.

Includes some inaccuracies or misconceptions in rationale.

Confusion with lack of connections.

1 – Non-scientific rationale

Incorrect explanation

0 – Illegible/Non-codable/no response

Response does not make sense

No written response

Scientific Argument (Part B): Questions 11:

Students will identify the Independent and Dependent Variable, compare the growth rates of red claw crayfish and freshwater shrimp, and determine the optimal temperature at which you can raise them together. They must explain their answer.

5 – Scientific & in depth response

Student identifies the independent variable - temperature

Student identifies the dependent variable – growth rates

Student compares the growth rates of red claw crayfish and freshwater shrimp.

Student cites quantitative data from the graph to support the comparison.

Student provides accurate scientific reasoning to support comparison.

Student cites the correct optimal of temperature to raise crayfish and shrimp together.

Student provides accurate scientific reasoning for optimal temperature to raise crayfish and shrimp together based upon quantitative data from the graph.

Evidence (quantitative number data) from graph to support their claim includes: Water temperature (degree C) is the independent variable and growth rate percentage is the dependent variable. The graph shows that red claw crayfish can tolerate a broader temperature range (20-34°C). However, the shrimp can tolerate higher temperatures based on the graph provided. Likewise, the optimal water temperature range for red claw crayfish is between 26-29°C, where shrimp is about 32°C.

Reasoning (explanation and analysis of how the evidence supports their claim regarding question 11): The optimal water temperature is 28°C for optimal growth rate for both species raised together based upon the graph.

4 – Scientific, but not in-depth

Correct response, but student provides minor in-depth explanation with no misconceptions.

3 – Partially scientific (scientific fragments) with no non-scientific conceptions

Correct response identifying characteristics, but poor explanation.

Includes overgeneralizations in rationale.

No non-scientific conceptions.

2 – Partially scientific (non-scientific fragments) with non-scientific conceptions

Some portion of the answer is incorrect.

Includes some inaccuracies or misconceptions in rationale.

Confusion with lack of connections.

1 – Non-scientific rationale

Incorrect explanation

0 – Illegible/Non-codable/no response

Response does not make sense

No written response

Scientific Argument (Part B): Question 12:

What might a scientist conclude about the decreasing ammonia levels and increasing nitrite levels on day 15?

5 – Scientific & in depth response

Student makes a claim about the ammonia and nitrite levels at day 15.

Student provides quantitative evidence from the graph to support the claim.

Student provides accurate scientific reasoning to support conclusions made.

Evidence (quantitative number data) from graph to support their claim includes: The graph shows that the Nitrosomonas bacteria is well established in the new aquaponics cycle system on day 15 as ammonia levels are on the decline (below 10 mg/L). However, the nitrobacter bacteria population in the cycle system does not appear to be adequate as nitrite levels are on the upswing (above 10 mg/L total nitrogen).

Reasoning (explanation and analysis of how the evidence supports their claim): Nitrite levels are increasing due to lack of nitrobacter, however some are present with slowly increasing nitrate levels at day 15.

4 – Scientific, but not in-depth

Correct response, but student provides minor in-depth explanation with no misconceptions.

3 – Partially scientific (scientific fragments) with no non-scientific conceptions

Correct response identifying characteristics, but poor explanation.

Includes overgeneralizations in rationale.

No non-scientific conceptions.

2 – Partially scientific (non-scientific fragments) with non-scientific conceptions

Some portion of the answer is incorrect.

Includes some inaccuracies or misconceptions in rationale.

Confusion with lack of connections.

1 – Non-scientific rationale

Incorrect explanation

0 – Illegible/Non-codable/no response

Response does not make sense

No written response

APPENDIX D – LIST OF THE INTERVENTION CONNECTONS TO CURRENT

NGSS STANARDS

Carrying Capacity and Biodiversity Standards

HS-LS2-1. Use mathematical and/or computational representations to support explanations of factors that affect carrying capacity of ecosystems at different scales. [Clarification Statement: Emphasis is on quantitative analysis and comparison of the relationships among interdependent factors including boundaries, resources, climate, and competition. Examples of mathematical comparisons could include graphs, charts, histograms, and population changes gathered from simulations or historical data sets.] [Assessment Boundary: Assessment does not include deriving mathematical equations to make comparisons.]

HS-LS2-2. Use mathematical representations to support and revise explanations based on evidence about factors affecting biodiversity and populations in ecosystems of different scales. [Clarification Statement: Examples of mathematical representations include finding the average, determining trends, and using graphical comparisons of multiple sets of data.] [Assessment Boundary: Assessment is limited to provide data.]

HS-LS2-6. Evaluate claims, evidence, and reasoning that the complex interactions in ecosystems maintain relatively consistent numbers and types of organisms in stable conditions, but changing conditions may result in a new ecosystem. [Clarification Statement: Examples of changes in ecosystem conditions could include modest biological or physical changes, such as moderate hunting or a seasonal flood; and extreme changes, such as volcanic eruption or sea level rise.]

HS-LS2-8. Evaluate evidence for the role of group behavior on individual and species' chances to survive and reproduce. [Clarification Statement: Emphasis is on: (1) distinguishing between group and individual behavior, (2) identifying evidence supporting the outcomes of group behavior, and (3) developing logical and reasonable arguments based on evidence. Examples of group behaviors could include flocking, schooling, herding, and cooperative behaviors such as hunting, migrating, and swarming.]

Matter Cycles and Energy Flow Standards

HS-LS2-3. Construct and revise an explanation based on evidence for the cycling of matter and flow of energy in aerobic and anaerobic conditions. [Clarification Statement: Emphasis is on conceptual understanding of the role of aerobic and anaerobic respiration in different environments.] [Assessment Boundary: Assessment does not include the specific chemical processes of either aerobic or anaerobic respiration.]

HS-LS2-4. Use mathematical representations to support claims for the cycling of matter and flow of energy among organisms in an ecosystem. [Clarification Statement: Emphasis is on using a mathematical model of stored energy in biomass to describe the transfer of energy from one trophic level to another and that matter and energy are conserved as matter cycles and energy flows through ecosystems. Emphasis is on atoms and molecules such as carbon, oxygen, hydrogen and nitrogen being conserved as they move through an ecosystem.] [Assessment Boundary: Assessment is limited to proportional reasoning to describe the cycling of matter and flow of energy.]

HS-LS2-5. Develop a model to illustrate the role of photosynthesis and cellular respiration in the cycling of carbon among the biosphere, atmosphere, hydrosphere, and geosphere. [Clarification Statement: Examples of models could include simulations and mathematical models.] [Assessment Boundary: Assessment does not include the specific chemical steps of photosynthesis and respiration.]

Human Impact on Ecosystems Standards

HS-LS2-7. Design, evaluate, and refine a solution for reducing the impacts of human activities on the environment and biodiversity.* [Clarification Statement: Examples of human activities can include urbanization, building dams, and dissemination of invasive species.]

HS-ETS1-1. Analyze a major global challenge to specify qualitative and quantitative criteria and constraints for solutions that account for societal needs and wants.

HS-ETS1-2. Design a solution to a complex real-world problem by breaking it down into smaller, more manageable problems that can be solved through engineering

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VITA

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Biographical Sketch

EDUCATION:

- Master of Science degree in Aquaculture/Aquatic Science, 2002
  Kentucky State University, Frankfort, KY
- B.S. degree in Biology with a minor in Aquaculture, 1997
  Kentucky State University, Frankfort, KY

EXPERIENCE:

Presently employed as Research & Extension Associate – AFE Educator, Aquaculture Research Center (ARC), Kentucky State University, Frankfort, KY 40601, 2015-present.

Co-Investigator of Aquaculture, Aquaculture Research Center (ARC), Kentucky State University, Frankfort, KY 40601, 2002-2015.

Research Assistant of Aquaculture, ARC, Kentucky State University, Frankfort, KY 40601, 1999-2002.

Fish Culturist Assistant/Research Assistant of Aquaculture, ARC, Kentucky State University, Frankfort, KY 40601, 1993-1998.

Lab Technician/Fish Culturist of Bayor Corporation, Agriculture Division, Aquatic Ecotoxicology Lab, Stilwell, KS 66085, 1998.

Aquaculture Internship (7 months) at Walt Disney World EPCOT Center of Aquaculture, Walt Disney World Company, Lake Buena Vista, FL 32830-1000, 1996.

HONORS:

*First student to receive Aquaculture Master's and Minor in Aquaculture/Aquatic Science at Kentucky State University.

*Dean's list, Kentucky State University, graduate student (every semester from 1999-2002).

*Received the Conservation Education Award "In Recognition of your contribution to bring environmental awareness to the 6th grade students of Scott County Middle School through your education and support of the York Conservation Education Tours, through Aquatics and Aquatic Habitat and educating on the importance of conservation of our natural resources" Scott County Conservation District, 33rd Harvest Day, October 16, 2014.

*Awarded a Travel Award by the U.S. Aquaculture Society at the Aquaculture America 2002 Conference, San Diego, CA for one of the five best abstracts submitted to the conference by a student (out of approximately 150 abstracts).

*Awarded the Walter M. Landry Award by the Striped Bass Growers Association, 2001. This National Award is presented to the graduate student who has demonstrated the most meritorious research concerning hybrid striped bass and/or striped bass. The Walter M. Landry Award was presented at the Aquaculture 2001 conference in Orlando, FL.

*2nd Place for Best Oral Presentation (Small Farms and Rural Development), 2000 1890 Institution Association of Research Directors Symposium, Washington, D.C.

*Served as Student Worker Coordinator for the Aquaculture 2000 Conference.