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Using a classroom aquaponics project to improve urban (city) students' perception of STEM disciplines and career pathways

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ABSTRACT

There is a need for secondary schools to provide more hands-on experiences in science, technology, engineering, and mathematics (STEM), and specifically, more contextualized project-based investigation environments in the classroom that manifest the next generation science standards. This study investigated how, and to what extent, a 10-week contextualized aquaponics project-based investigation (APBI) affected urban (city) high school students' attitudes toward STEM, aquaculture and aquaponics, and interest in future STEM-related disciplines and/or STEM career pathways. Currently, there is little research published in technical literature on how APBI may engage students in increasing attitudes and interest in aquaculture/aquaponics fields as a career choice and, more generally, STEM disciplines. Using a quantitative quasi-experimental research design, two different student groups participated in a hands-on APBI project and were given pre- and post-attitude/interest surveys (n = 22). 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 as an area of interest. In addition, the survey included a profile of the respondents with the demographic items. The results revealed that the intervention contributed to the treatment group students' positive attitudes toward STEM in general, and aquaculture and aquaponics specifically, and to students' developing an interest in the disciplines of STEM and/or as career pursuits. Results suggest that APBI models may be effective in attracting urban (city) students to STEM-related disciplines and careers.

Keywords: STEM, project-based, secondary schools, urban, attitudes, interests, aquaponics

INTRODUCTION

Aquaponics, the combination of aquaculture and hydroponics, can serve as a bridge to get students involved and interested in science, technology, engineering, and mathematics (STEM) disciplines (Genello et al., 2015). However, there is a lack of documented research to help guide us toward better understanding how integrating aquaponics-based project-based investigations (PBI) during a short term curricular unit in the science classroom can foster students' attitudes toward STEM and aquaponics in particular and cultivate interest in pursuing STEM coursework (via STEM disciplines) and/or careers or hobbies (via STEM career pathways) (Hart et al., 2013; Schneller et al., 2015; Thompson et al., 2023a, 2023b).

The present project was designed using a PBI model that is well documented in the literature (Krajcik & Blumenfeld, 2006; Polman, 2000; Singer et al., 2000; Wilhelm & Confrey, 2005; Wilhelm et al., 2008). In this model, students are exposed to the real-world phenomenon of building and maintaining aquaponics systems using scaled down models commonly used in the field. Ensuing research experiences offer vivid, real-world learning opportunities for students that include constructing and monitoring their own recirculating aquaculture system (RAS) or an aquaponics system (Thompson et al., 2022, 2023a, 2023b). Thompson et al. (2024) reported that aquaculture experiential learning offers opportunities to incorporate technology to support high school student-driven investigations using real-time data in their research. Teachers can incorporate these tools in their classrooms and create an engaging, student-centered, learning environment. Students can also be exposed to real-life mathematics problem-solving through aquaculture, such as in monitoring fish growth, survival, and feed efficiency, within an aquaponics system (Thompson et al., 2023a, 2023b).

The purpose of the intervention utilized in the present study was to engage urban (city) high school students in authentic, hands-on classroom PBI environments to solve complex problems in the context of real-world situations.

Activities were designed to replicate real-life work of agriculture scientists through enriching experiences to develop a depth of learning of standard-based ecological concepts and greater awareness of agricultural-based STEM fields. In the USA, urban schools often face challenges such as limited access to instructional and scientific resources, high teacher turnover, and low student performance. Students need to be actively engaged in real-world experiential learning opportunities over an extended period and hands-on project-based science 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). When carefully planned, experiential learning experiences can naturally articulate science and engineering practices in learning along with many of the next generation science standards (NGSS). Thompson et al. (2023a, 2023b, 2024) reported that extended aquaculture projects they studied have resulted in some students becoming more aware of (as it relates to aquaculture/aquaponics)

(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 food safely and reliably (i.e., sustainable food production), and/or
(4) the usefulness of STEM disciplines in everyday situations.

While much literature has touted the benefits of contextualized science instruction to improve learning (Borko & Putman, 2000; Bouillion & Gomez, 2001; Brickhouse, 1994), few studies have explored in the context of using aquaponics project-based investigation (APBI) in the science classroom (Hart et al., 2013; Schneller et al., 2015; Thompson et al., 2023a, 2023b). In their review of the literature, Thompson et al. (2023a) found that few researchers have explored aquaponics-based teaching in a formal K-12 educational setting and even fewer studies has explored student cognitive and affective outcomes from these experiences.

The overarching goals of the present study were to positively influence (i.e., increase) and inspire urban (city) students' attitudes toward and interest in STEM educational disciplines and/or interest in STEM career pathway pursuits. In addition, a similar goal was to participation 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 field.

Incorporating real-world aquaculture and aquaponics 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 and aquaponics 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.

Description of the Classroom Intervention and Connections to 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 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.

A reform in science education is under way. *A framework for K-12 science education* (National Research Council [NRC], 2012) and the 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). This vision is called three-dimensional science learning, as it emphasizes the integration of disciplinary core ideas (DCI), 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 NRC framework and the NGSS identify *Interdependent relationships in ecosystems* as part of a DCI 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 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. 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 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 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 in 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.

Strategy of Project-Based Instruction

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). 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. 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 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 basic 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).

Contextualized Project-Based Instruction

Rivet and Krajcik (2008) found strong evidence for the role of contextualizing PBI in science classrooms to support student learning. The study focused on two 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 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.

Contextualized 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 RAS 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 urban (city) 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 PBI 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 science ideas and concepts to their everyday lives and the phenomenon 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 agrees with published reports (Bouillion & Gomez, 2001; Kozma, 1991; Lee & Songer, 2003; Rivet & Krajcik, 2008). 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.

Anchoring Events

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 for maintaining their recirculating system in the classroom over the duration of the project. Where problems arise they need 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 logbook, 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 logbooks. 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 PBI model as there was a culminating experience students took part in 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.

PBI 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).

Purpose and Objectives

The purpose of this study was to examine the effects of participation in a 10-week long APBI unit on the attitudes of urban (city) high school students toward STEM in general, and aquaponics specifically. Further, the study sought to explore whether students report a change in their interest in taking part in future STEM-related disciplines and/or consider STEM career pathways after participating in the project. The hope was that students' experiences in the classroom might encourage them to consider taking more STEM classes in high school and consider a future STEM-related career, such as aquaculture.

A pre-posttest quantitative methodology was used to examine the possible effects the project might have on student outcomes. In particular, data collection focused on measurable changes in students' attitudes toward STEM and aquaculture, and to identify possible impacts on students' consideration of future career choices. In this study, pre- and post-questionnaires were used to test whether the participation in the hands-on APBI unit led to a shift in attitudes and interest in a STEM-related discipline and/or career pathway of the urban (city) high school students engaged in the intervention.

The objectives of this study were to address the following research questions:

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

METHODS

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 quasi-experimental research design utilizing quantitative methods was employed in the data collection and analysis.

A multiple case study approach was employed to investigate the present study because it fit the research goal to compare the independent variable (the different participating student groups across different school environments) and the dependent variables (students' interest and attitudes toward STEM and aquaculture and as potential future career plans). The unit of analysis was at the level of the student rather than the teacher or school, even though teachers are factors that can affect student outcomes. The school environment is another important factor to consider in the analysis. School demographics, administration views toward science and/or STEM (e.g., supportive or not supportive), class schedules, and class frameworks, also can affect how the unit is implemented. Therefore, the teacher and school factors were taken into consideration when considering differences in outcomes across the student groups and within each group.

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 to test groups, the procedure is commonly called a quasi-experimental study. The researchers used naturally-formed student groups who met in two different classroom learning spaces (i.e., classroom) that were located in two separate schools. Thus, there were two cases in this study that were identified as the independent variable: two student groups from two different schools that completed the APBI unit.

Description of the Two Participating Schools

The two schools represented in the present study were located in the mid-southern region of the United States and were classified as public urban (city) high schools. The two schools were located in two different school districts in the same state. They were selected because of their urban status, the high percentage of students that were eligible for free or reduced lunch, and the fact that two of the teachers that had been integral to developing and testing the APBI unit and taught biology classes at these two schools.

The teachers' participation in the study was paramount for selecting educators familiar with the unit and who had expertise in leading students in APBIs within the context of the unit. The two teachers also were selected because they had been members of the first cohort to teach from the aquaculture unit and both taught in urban high schools. They also had been participants in the testing of the unit with the first cohort of students. The two teachers also collaborated with the researchers to finalize the APBI unit that was implemented in the present study. Both teachers had implemented the unit at least twice with their own students and had expertise in teaching secondary life science and ecology specifically. Thus, students engaged in the APBI intervention were taught by two experienced biology teachers with expertise in teaching the hands-on APBI unit curriculum. The teachers had volunteered to participate in the study and their school administration supported their participation.

Population and Sample

The students participating in this study were enrolled in one of the two selected science classes mentioned previously and were in ninth, tenth, or eleventh grade. The selection process for students was nonrandom (i.e., conveniently selected) since the students were already assigned to the teachers' classrooms before the start of the academic year. The researchers also used naturally intact classroom groups that had been predetermined by the school and teacher prior to the study. Treatment group 1 and group 2 were composed of consenting students that were enrolled in one of the two selected classrooms, who participated in the ten-week APBI unit, and completed the pre- and the post-surveys. It is important to note that the APBI intervention was part of the curricula the teachers implemented in these two classrooms. All students enrolled in these two classes, regardless of their willingness to participate in the research study, completed the APBI unit. However, data were only collected from consenting students.

Participating Student Demographics

Students in the sample all had completed the pre and post assessments and submitted completed parental consent forms and their student assent forms. All of the participating students attended an urban (city) school in the mid-south region of the USA and mostly came from low socioeconomic backgrounds. Of the 22 participating students, 68.2% identified as White, 13.6% identified as Asian (13.6%), 9.1% identified as African American/Black (9.1%), and 4.5% identified as American Indian (4.5%). A few students selected "other" (4.5%) to describe the ethnicity with which they identified. There was a relatively high number of students identifying as female (68.2%) compared to students identifying as male (31.8%). The student groups were comparable with some variation in the number of students identifying as White. Of the 9 participating students in group 1, five identified as White and four identified as an underrepresented population. There were 13 students in group 2, 10 of which identified as White and three identified as an underrepresented population.

Student Attitudes and Interests Pre-/Post-Survey

The survey instrument utilized in this study was constructed, pilot tested and used by researchers in a previous and similar study. This 12-item Likert-type survey (instrument) was designed to measure two main constructs, which included students' attitudes toward STEM and aquaculture and students' interest in future STEM career pathways that were equally divided. Respondents were offered a choice of several response options for each question that utilized a 5-point summated Likert-type scale where 1 represented strongly disagree, 2 represented disagree, 3 represented neutral response, 4 represented agree, and 5 represented strongly agree. This 12-item survey instrument also was used in the present study because it aligned with the target student outcomes (i.e., dependent variables).

In the 2018-2019 academic year the survey had been pilot tested with 95 secondary students from a similar region in the United States to the present study (Thompson et al., 2023a). Calculation of the Cronbach's alpha co-efficient was utilized to assess the internal consistency of the questions based on the responses. The coefficient for the pilot survey responses was .832, indicating an acceptable level of variability and high internal consistency. A Cronbach's alpha also determined the pre- and post-survey responses from the present study to be highly internally consistent (pre-survey, .864; post-survey, $\alpha = .841$).

Data Collection

The instrument was administered as a pre-survey at the beginning of the APBI unit and as a post-survey at the end of the APBI unit. The survey was administered by the teacher from each school. The survey was administered as a paper and pencil survey. It should be noted participating students were reminded that although their parents or legal guardians had consented to their participation in the study and the students also had assented to their participation, they still had the right to discontinue their participation at any time. All students chose to participate through the entirety of the study.

Quantitative Data Analysis

A descriptive univariate analysis of the variables was performed in this study using IBM SPSS statistics version 22. Data included a profile of the respondents' demographics along with their answer selection of the 12 tasks. The objective was to look at every item in the survey to get a sense of the variability of responses and then review responses as a whole

Table 1. Descriptive statistics for pre-intervention survey instrument comparison with respect to the treatment groups (n = 22)

Dependent variable (item number)	Groups	Mean	Standard deviation	n
1. Aquaculture would be a highly interesting profession	1	3.67	.866	9
	2	3.77	1.01	13
	Total	3.73	.935	22
2. At this time, aquaculture increases my interest in science	1	4.00	.500	9
	2	3.62	.768	13
	Total	3.77	.685	22
3. At this time, aquaculture increases my interest in technology	1	3.33	.707	9
	2	3.39	1.190	13
	Total	3.36	1.000	22
4. At this time, aquaculture increases my interest in engineering	1	3.00	.866	9
	2	3.46	1.130	13
	Total	3.27	1.030	22
5. At this time, aquaculture increases my interest in mathematics	1	2.22	.971	9
	2	2.38	.768	13
	Total	2.31	.839	22
6. My participation in the aquaculture project will increase my interest in a STEM career field	1	2.89	.928	9
	2	3.39	1.040	13
	Total	3.18	1.010	22
7. My participation in the aquaculture project will increase my desire to take more courses in a STEM-related area	1	3.22	1.09	9
	2	3.46	.967	13
	Total	3.36	1.000	22
8. My participation in the project will increase my desire to take courses in aquaculture specifically	1	3.22	1.200	9
	2	3.62	1.120	13
	Total	3.45	1.140	22
9. When I graduate from high school, I would like to work with people who make discoveries in science	1	3.56	1.420	9
	2	3.31	1.030	13
	Total	3.41	1.180	22
10. I am interested in future opportunities to study aquaculture and aquatic science subjects for high school and advanced credit	1	3.67	1.32	9
	2	3.54	.776	13
	Total	3.59	1.010	22
11. I would encourage my friends (not attending project) to consider courses in aquaculture	1	3.56	1.010	9
	2	3.85	1.070	13
	Total	3.73	1.030	22
12. I expect to pursue higher education in a STEM-related field	1	3.44	1.33	9
	2	2.77	1.170	13
	Total	3.09	1.250	22

to gain insight into students' attitudes and views. In addition, descriptive statistics, which included frequencies, percentages, means, and standard deviations for each of the twelve items within the survey were utilized in the analysis. Nardi (2014) reported that calculating the mean for some ordinal scales, such as Likert, is acceptable in the analysis process. Hence, this was implemented in the present study. The outcomes were first examined by themselves (per class/group in each school) and then in a cross-case comparison between the two groups. To identify patterns in students' responses, researchers employed several ways of presenting the univariate information about the variables in the study, including frequency distributions, statistical measures (i.e., means and standard deviations), and visual representations using graphs.

The researchers employed pre- and post-intervention descriptive statistics, as well as the Kruskal-Wallis mean rank test, to draw comparisons between the two groups for each item and to reveal any significant differences between them. If significant differences were found, the researchers 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. The researchers divided *alpha* by the number of comparisons, which was two, representing the two treatment groups. Hence, the statistical significance level for the Bonferroni correction was $\alpha = .05/2$ or 0.025 with the sample size of n = 22.

RESULTS

Pre-Intervention Survey Outcomes

Results from the pre-intervention survey demonstrated that group 2 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) compared to group 1 students in eight out of the twelve items (**Table 1**). The only exception was for item 2 (at this time, aquaculture increases interest in science); item 9 (when I graduate from high school; I would like to work with people who make discoveries in science); item 10 (I am interested in future opportunities to study aquaculture and aquatic science subjects for high school and advanced credit); and item 12 (I expect to pursue higher education in a STEM-related field).

Table 2. Descriptive statistics for pre-intervention survey instrument comparison with respect to the treatment groups

Dependent variable	Groups	Standard error	95% confidence interval	
			LL	UL
1. Aquaculture would be a highly interesting profession	1	.319	3.00	4.33
	2	.265	3.22	4.32
2. At this time, aquaculture increases my interest in science	1	.225	3.53	4.47
	2	.187	3.23	4.01
3. At this time, aquaculture increases my interest in technology	1	.342	2.62	4.05
	2	.285	2.79	3.98
4. At this time, aquaculture increases my interest in engineering	1	.343	2.28	3.72
	2	.286	2.87	4.06
5. At this time, aquaculture increases my interest in mathematics	1	.285	1.63	2.82
	2	.237	1.89	2.88
6. My participation in the aquaculture project will increase my interest in a STEM career field	1	.333	2.19	3.58
	2	.277	2.81	3.96
7. My participation in the aquaculture project will increase my desire to take more courses in a STEM-related area	1	.340	2.51	3.93
	2	.283	2.87	4.01
8. My participation in the project will increase my desire to take courses in aquaculture specifically	1	.385	2.42	4.03
	2	.320	2.95	4.28
9. When I graduate from high school, I would like to work with people who make discoveries in science	1	.401	2.72	4.39
	2	.334	2.61	4.00
10. I am interested in future opportunities to study aquaculture and aquatic science subjects for high school and advanced credit	1	.343	2.95	4.38
	2	.286	2.94	4.14
11. I would encourage my friends (not attending project) to consider courses in aquaculture	1	.349	2.83	4.28
	2	.290	3.24	4.45
12. I expect to pursue higher education in a STEM-related field	1	.412	2.59	4.30
	2	.343	2.05	3.48

Table 2 illustrates a similar trend as group 2 students had numerically the highest lower bound (LL) mean ordinal Likert scale response for all items with the exception of items 2, 9, 10, and 12. Likewise, group 2 students had numerically the highest upper bound (UL) mean ordinal Likert scale response for all twelve items with the exception of items 1, 2, 9, 10, and 12 (**Table 2**).

Descriptive Statistics Findings of Post-Survey Responses

Both groups demonstrated positive changes in their attitudes and interests toward STEM and aquaculture in the post-survey results. The post-survey results demonstrated that group 2 students tended to have a numerically higher mean score across the responses compared to group 1 students in 7 of the 12 items (**Table 3**).

The only exceptions were for questionnaire item 1 (aquaculture would be a highly interesting profession); item 7 (my participation in the aquaculture project increased my desire to take more courses in a STEM-related area; item 9 (when I graduate from high school, I would like to work with people who make discoveries in science); item 10 (I would like future opportunities to study aquaculture and aquatic science

Table 3. Descriptive statistics for post-intervention survey instrument comparison with respect to the treatment groups (n = 22)

Dependent variable (item number)	Groups	Mean	Standard deviation	n
1. Aquaculture would be a highly interesting profession	1	4.22	.833	9
	2	3.69	.751	13
	Total	3.91	.811	22
2. At this time, aquaculture increases my interest in science	1	4.00	.866	9
	2	4.08	.760	13
	Total	4.05	.785	22
3. At this time, aquaculture increases my interest in technology	1	3.22	.833	9
	2	3.61	.961	13
	Total	3.45	.912	22
4. At this time, aquaculture increases my interest in engineering	1	2.89	1.170	9
	2	3.31	.947	13
	Total	3.14	1.040	22
5. At this time, aquaculture increases my interest in mathematics	1	2.44	1.420	9
	2	2.54	1.050	13
	Total	2.50	1.190	22
6. My participation in the aquaculture project will increase my interest in a STEM career field	1	3.44	1.420	9
	2	3.46	.877	13
	Total	3.45	1.100	22
7. My participation in the aquaculture project will increase my desire to take more courses in a STEM-related area	1	3.89	1.170	9
	2	3.69	.855	13
	Total	3.77	.973	22

Table 3 (Continued). Descriptive statistics for post-intervention survey instrument comparison with respect to the treatment groups (n = 22)

Dependent variable (item number)	Groups	Mean	Standard deviation	n
8. My participation in the project will increase my desire to take courses in aquaculture specifically	1	3.56	1.130	9
	2	3.92	.954	13
	Total	3.45	1.020	22
9. When I graduate from high school, I would like to work with people who make discoveries in science	1	3.89	1.170	9
	2	3.61	.870	13
	Total	3.73	1.160	22
10. I am interested in future opportunities to study aquaculture and aquatic science subjects for high school and advanced credit	1	3.67	1.320	9
	2	3.54	.776	13
	Total	3.59	1.010	22
11. I would encourage my friends (not attending project) to consider courses in aquaculture	1	3.67	.866	9
	2	4.46	660	13
	Total	3.73	.834	22
12. I expect to pursue higher education in a STEM-related field	1	3.44	1.420	9
	2	3.31	1.030	13
	Total	3.36	1.180	22

Table 4. Descriptive statistics for post-intervention survey instrument comparison with respect to the treatment groups (cont.)

Dependent variable	Groups	Standard error	95% confidence interval	
			LL	UL
1. Aquaculture would be a highly interesting profession	1	.262	3.68	4.77
	2	.218	3.24	4.15
2. At this time, aquaculture increases my interest in science	1	.268	3.44	4.60
	2	.223	3.61	4.54
3. At this time, aquaculture increases my interest in technology	1	.304	2.59	3.86
	2	.253	3.09	4.14
4. At this time, aquaculture increases my interest in engineering	1	.347	2.17	3.61
	2	.289	2.71	3.91
5. At this time, aquaculture increases my interest in mathematics	1	.405	1.60	3.29
	2	.337	1.84	3.24
6. My participation in the aquaculture project will increase my interest in a STEM career field	1	.376	2.66	4.23
	2	.313	2.81	4.11
7. My participation in the aquaculture project will increase my desire to take more courses in a STEM-related area	1	.330	3.20	4.58
	2	.275	3.12	4.27
8. My participation in the project will increase my desire to take courses in aquaculture specifically	1	.343	2.84	4.27
	2	.285	3.33	4.52
9. When I graduate from high school, I would like to work with people who make discoveries in science	1	.397	2.95	4.61
	2	.330	3.00	4.38
10. I am interested in future opportunities to study aquaculture and aquatic science subjects for high school and advanced credit	1	.333	3.19	4.58
	2	.277	3.04	4.19
11. I would encourage my friends (not attending project) to consider courses in aquaculture	1	.250	3.15	4.19
	2	.208	4.03	4.90
12. I expect to pursue higher education in a STEM-related field	1	.401	2.61	4.28
	2	.334	2.61	4.00

subjects for high school and advanced credit); and item 12 (I expect to pursue higher education in a STEM-related field).

Table 4 illustrates a similar trend relating to the LL and UL mean ordinal Likert scale student responses between the two different student groups.

Changes in Students' STEM Attitudes and Interest

Table 5 reveals the percentage change across the pre- and post-responses with respect to each of the two different student groups. When examining a positive or negative change from the pre- to-post-intervention survey, the results revealed the following: group 1 students had five statements (items 1, 6, 7, 8, and 9) with increasing scale responses with a 5% or greater increase (pre-to-post survey means for item 1, 3.67 to 4.22; item 6, 2.89 to 3.44; item 7, 3.22 to 3.89; item 8, 3.22 to 3.56; and item 9, 3.56 to 3.89). More specifically, group 1 demonstrated positive changes in their interest toward the following areas: interest in aquaculture as a profession (item 1, +11%); interest in a STEM career field (item 6, +11%); students desire to take more courses in a STEM-related area (item 7, +13.4%); interest to take courses in aquaculture (item 8, +6.8%); and a desire to work with people who make discoveries in science (item 9, +6.6%).

Hence, the post-test results suggest that when group 1 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. There was a 6.8% (pre = 3.22; post = 3.56) increase in group 1 students' attitudes toward taking courses in aquaculture specifically (item 8) and an 11% increase in group

Table 5. Descriptive statistics for percentage change comparison across the pre and post responses with respect to the treatment groups (n = 55)

Dependent variable (item number)	Groups	Pre-survey mean	Post-survey mean	Percentage change mean
1. Aquaculture would be a highly interesting profession	1	3.67	4.22	+11.0
	2	3.77	3.69	-1.6
	Total	3.73	3.91	+1.8
2. At this time, aquaculture increases my interest in science	1	4.00	4.00	0.0
	2	3.62	4.08	+9.2
	Total	3.77	4.05	+5.6
3. At this time, aquaculture increases my interest in technology	1	3.33	3.22	-2.2
	2	3.39	3.61	+4.4
	Total	3.36	3.45	+1.8
4. At this time, aquaculture increases my interest in engineering	1	3.00	2.89	-2.2
	2	3.46	3.31	-3.0
	Total	3.27	3.14	-2.6
5. At this time, aquaculture increases my interest in mathematics	1	2.22	2.44	+4.4
	2	2.38	2.54	+3.2
	Total	2.31	2.50	+3.8
6. My participation in the aquaculture project will increase my interest in a STEM career field	1	2.89	3.44	+11.0
	2	3.39	3.46	+1.4
	Total	3.18	3.45	+5.4
7. My participation in the aquaculture project will increase my desire to take more courses in a STEM-related area	1	3.22	3.89	+13.4
	2	3.46	3.69	+4.6
	Total	3.36	3.77	+5.4
8. My participation in the project will increase my desire to take courses in aquaculture specifically	1	3.22	3.56	+6.8
	2	3.62	3.92	+6.0
	Total	3.45	3.45	0.0
9. When I graduate from high school, I would like to work with people who make discoveries in science	1	3.56	3.89	+6.6
	2	3.31	3.61	+6.0
	Total	3.41	3.73	+6.4
10. I am interested in future opportunities to study aquaculture and aquatic science subjects for high school and advanced credit	1	3.67	3.67	0.0
	2	3.54	3.54	0.0
	Total	3.59	3.59	0.0
11. I would encourage my friends (not attending project) to consider courses in aquaculture	1	3.56	3.67	+2.2
	2	3.85	4.46	+12.2
	Total	3.73	3.73	0.0
12. I expect to pursue higher education in a STEM-related field	1	3.44	3.44	0.0
	2	2.77	3.31	+10.8
	Total	3.09	3.36	+5.4

1 students' attitudes toward aquaculture as a profession. These results also suggest that when group 1 students responded to the questionnaire, they tended to have a positive perception to pursue this opportunity in the future when examining the responses. There was an 11% increase on the pre (2.89) and post (3.44) intervention survey with the statement on interest in a STEM career field for item 6 among group 1 students. Likewise, there was a 13.4% increase on the pre (3.22) and post (3.89) intervention survey with the statement on desire to take more courses in a STEM-related area for item 7 among group 1 students.

Overall, the data revealed that group 1 students were interested in learning STEM in using active strategies. Post-survey results demonstrated growth in their interest towards learning through hands-on science, using technology, and learning engineering and math (STEM), and working with people who are immersed in science discovery in the future. The positive changes in student attitudes suggests that group 1 students particularly enjoyed learning about the biological and ecological concepts as they constructed, maintained, and researched a "living" ecosystem. The experiences also served to create a rich, authentic context for learning about ecosystems in situ.

Group 2 students also demonstrated growth in their interest in learning STEM, and science in particular, and in aquaculture. Group 2 students had five statements (items 2, 8, 9, 11, and 12) with "increasing" scale responses with a 5.0% or greater increase in pre-to-post survey means for item 2, 3.62 to 4.08; item 8, 3.62 to 3.92; item 9, 3.31 to 3.61, item 11, 3.85 to 4.46; and item 12, 2.77 to 3.31). Hence, these data suggest that when group 2 students responded to statements that relates to interest in science (item 2, 9.2% gain); increased desire to take courses in aquaculture (item 8, 6.0% gain); work with people who make discoveries in science (item 9, 6.0% gain); encourage friends to consider courses in aquaculture (item 11, 12.2% gain); and expectations to pursue higher education in a STEM-related field (item 12, 10.8% gain), they tended to have a positive perception when examining these responses.

Hence, data suggest that group 2 students responded to statements that relates to science, aquaculture courses, and expect to pursue higher education in a STEM-related field, they tended to have a positive perception when examining the responses.

In terms of the desire to take courses in a STEM-related area (item 7), there was a 4.6% moderate increase in group 2

Table 6. Kruskal-Wallis mean rank pre-intervention survey instrument comparison with respect to the treatment groups

Dependent variable[a]	Groups	n	Mean rank	Significance[a] (test-statistics[b])
1. Aquaculture would be a highly interesting profession	1	9	10.78	.625
	2	13	12.00	
	Total	22		
2. At this time, aquaculture increases my interest in science	1	9	13.33	.198
	2	13	10.23	
	Total	22		
3. At this time, aquaculture increases my interest in technology	1	9	9.67	.249
	2	13	12.77	
	Total	22		
4. At this time, aquaculture increases my interest in engineering	1	9	10.72	.613
	2	13	12.04	
	Total	22		
5. At this time, aquaculture increases my interest in mathematics	1	9	9.61	.233
	2	13	12.81	
	Total	22		
6. My participation in the aquaculture project will increase my interest in a STEM career field	1	9	10.50	.526
	2	13	12.19	
	Total	22		
7. My participation in the aquaculture project will increase my desire to take more courses in a STEM-related area	1	9	10.28	.442
	2	13	12.35	
	Total	22		
8. My participation in the project will increase my desire to take courses in aquaculture specifically	1	9	12.50	.533
	2	13	10.81	
	Total	22		
9. When I graduate from high school, I would like to work with people who make discoveries in science	1	9	12.33	.600
	2	13	10.92	
	Total	22		
10. I am interested in future opportunities to study aquaculture and aquatic science subjects for high school and advanced credit	1	9	10.33	.442
	2	13	12.31	
	Total	22		
11. I would encourage my friends (not attending project) to consider courses in aquaculture	1	9	11.00	.751
	2	13	11.85	
	Total	22		
12. I expect to pursue higher education in a STEM-related field	1	9	13.61	.192
	2	13	10.04	
	Total	22		

Note. [a]$p < 0.05$ (significant difference) & [b]$df = 2$

students on the pre- and post-intervention survey and their interest in a STEM career field (item 6) slightly increased to 1.4%, respectively. However, there was a negative (loss) growth (1.6%) in group 2 students' attitudes towards aquaculture as a profession (item 1) and 3.0% loss with the statement on interest in engineering (item 4).

Findings Comparing the Two Student Groups

Additionally, the researcher employed a Kruskal-Wallis mean rank test. The independent-samples Kruskal-Wallis test of significance of the pre-intervention survey instrument comparison revealed no significant differences ($p > 0.05$) between the two student groups (**Table 6**).

Since there were no significant differences ($p > 0.05$) in the pre-intervention survey instrument between groups, the researcher did not employ a series of Mann-Whitney tests and compare two populations (student groups) at a time. However, the Kruskal-Wallis test of significance of the post-intervention survey instrument comparison did reveal a significant difference ($p < 0.05$) between the two student group populations for statement 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 eleven survey items. An overview of this post-survey data is provided in **Table 7**.

Since there were significant differences ($p < 0.05$) found in the post-intervention survey instrument between groups for item 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 two in total. Hence, the statistical significance level for the *Bonferroni* correction was $\alpha = .05/2 = 0.025$. The final sample size was n = 22 (group 1 = 9; group 2 = 13). The results of the Mann-Whitney U test for the post-intervention survey are shown in **Table 8**.

Results from the Mann-Whitney mean rank test revealed that there were no significant differences ($p > 0.025$) found when comparing group 1 and group 2. Relating to item 10, group 1 students did not have a statistically significantly ($p > 0.025$) higher post-survey mean rank (8.17) compared to group 2 (mean rank of 13.81).

Table 7. Kruskal-Wallis mean rank post-intervention survey instrument comparison with respect to the treatment groups

Dependent variable[a]	Groups	n	Mean rank	Significance[a] (test-statistics[b])
1. Aquaculture would be a highly interesting profession	1	9	13.78	.138
	2	13	9.92	
	Total	22		
2. At this time, aquaculture increases my interest in science	1	9	11.44	.971
	2	13	11.54	
	Total	22		
3. At this time, aquaculture increases my interest in technology	1	9	9.89	.310
	2	13	12.62	
	Total	22		
4. At this time, aquaculture increases my interest in engineering	1	9	10.94	.728
	2	13	11.88	
	Total	22		
5. At this time, aquaculture increases my interest in mathematics	1	9	11.61	.944
	2	13	11.42	
	Total	22		
6. My participation in the aquaculture project will increase my interest in a STEM career field	1	9	12.28	.625
	2	13	10.96	
	Total	22		
7. My participation in the aquaculture project will increase my desire to take more courses in a STEM-related area	1	9	10.28	.444
	2	13	12.35	
	Total	22		
8. My participation in the project will increase my desire to take courses in aquaculture specifically	1	9	12.28	.624
	2	13	10.96	
	Total	22		
9. When I graduate from high school, I would like to work with people who make discoveries in science	1	9	12.89	.381
	2	13	10.54	
	Total	22		
10. I am interested in future opportunities to study aquaculture and aquatic science subjects for high school and advanced credit	1	9	8.17	.033[a]
	2	13	13.81	
	Total	22		
11. I would encourage my friends (not attending project) to consider courses in aquaculture	1	9	10.22	.417
	2	13	12.38	
	Total	22		
12. I expect to pursue higher education in a STEM-related field	1	9	12.06	.718
	2	13	11.12	
	Total	22		

Note. [a]$p < 0.05$ (significant difference) & [b]$df = 2$

Table 8. Mann-Whitney comparison mean rank test for post-intervention survey instrument with respect to the treatment groups (n = 22)

Variable	Student group	n	Mean rank	Significance[a]	Test-statistics[b]
10. I would encourage my friends (not attending project) to consider courses in aquaculture	Group 1 students	9	8.17	.033	28.5
	Group 2 students	13	13.81		

Note. [a]Significance is not below 0.025 & [b]Mann-Whitney U test statistic

DISCUSSION

The researchers posited the APBI unit intervention would promote in high school students positive attitudes toward STEM and aquaculture, as well as cultivate positive changes in their short-term interests in STEM disciplines and/or STEM career pathways. A situated-learning theoretical framework that encompasses a constructivist theoretical framework, but specifically integrates the environmental factors present in the space where the study occurred guided the study (e.g., teacher's instructional styles, class environments, and student demographics). Thus, we utilized this framework as lens when discussing the outcomes (Thompson et al., 2023a).

The majority of the 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 participating in the project. Hence, they had no exposure to aquaponics in a formal classroom setting prior to the implementation of this study. The results revealed that the intervention contributed to students' positive attitudes toward STEM in general, aquaponics, specifically. 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 suggests that some students developed an interest in aquaculture fields after participating in the project. The next sections will focus on each student group who participated in the authentic, hands-on APBI intervention, uncover, and reveal student-learning outcomes.

Group 1 Students

Post-test responses from group 1 collected after the APBI intervention revealed positive changes in students' attitudes and interest in comparison to their pre-survey responses. Areas in which students group 1 demonstrated the greatest changes: overall, there were positive changes when examining participants' responses from the pre- to post-survey descriptive statistics, and especially in their attitudes toward the desire to take more courses in a STEM-related area (13.4%), interest in a STEM career field (11%), and aquaculture being a highly interesting profession (11%). Furthermore, results indicate that group 1 students improved their attitudes toward the desire to take courses in aquaculture specifically (6.8%) and would like to work with people who make discoveries in science (6.6%). Likewise, a moderate increase was found (4.4%) when group 1 students were asked about the aquaculture project influencing their interest in mathematics specifically.

Group 2 Students

When interpreting the results, data reveals that group 2 students showed an interest in science (9.2% positive change), would encourage their friends (not attending project) to consider courses in aquaculture (12.2% positive change), and expect to pursue higher education in a STEM-related field (10.8% positive change). Furthermore, their desire to take courses in aquaculture specifically (6.0% positive change) and their desire to work with people who make discoveries in science increased (6.0% positive change). Likewise, a moderate increase was found (4.4% positive change) when group 2 students were asked about the aquaculture project as it increased their interest in technology and their desire to take more courses in a STEM-related area (4.6% positive change).

In conclusion, the intervention contributed to the treatment group students' positive attitudes toward STEM in general, and aquaculture and aquaponics. This study exemplifies how an authentic, hands-on aquaponics project-based intervention can increase high school level students from urban areas and their attitudes toward STEM and developing an interest in STEM disciplines and/or STEM career pursuits. The evidence from this study also suggests that some students developed an interest in aquaculture fields after participating in the project and students' responses seem to indicate greater interest in STEM and aquaponics following the APBI unit. This agrees with Thompson et al. (2023a). Results suggest in this study that APBI models may be effective in attracting urban (city) students to STEM-related disciplines and careers. The limitation of this study includes small sample size, urban schools with high percentage of White students, quantitative data with limited ability to identify what students liked about the unit, and no content assessment to tease out what they might have learned.

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