

QUALITATIVE STUDY

Integrating Aquaculture to Support STEM Education: A Qualitative Assessment to Identify High School Students' Attitudes, Interests, and Experiences

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ABSTRACT

This study explored the impact of an active project-based, aquaculture constructivist-learning program, as perceived by high school students. The purpose of this case study was to discover if participation in the program influenced students' interest, engagement, and future educational and career aspirations in science, technology, engineering, and mathematics (STEM) when integrating aquaculture in and outside the classroom. Likewise, the study also wanted to explore students' knowledge about aquaculture and skill development after their participation in the program. The study employed a qualitative methods approach to explore students' attitudes and experiences. Qualitative data were collected from post-student focus groups at three different public, rural high schools in Kentucky. Other qualitative data included teacher journal reflections (e.g., personal documents) and public newspaper articles (e.g., public documents). Four emergent themes were found: (1) Students show excitement and enthusiasm in the hands-on, aquaculture program; (2) students show attention to detail in the hands-on, aquaculture tasks, it sticks, and are more responsible; (3) students are collaboratively engaged with their peers; and (4) greater interest and confidence in STEM through practical application. Results demonstrated that the program engaged learners in real-world problem-solving and decision-making situations while working collaboratively in small works. It also appears that students gained an important life skill, responsibility, as well as self-confidence in STEM, after participating in the program.

KEY WORDS: Aquaculture; aspirations; engagement; interests; project-based; qualitative methods; science, technology, engineering, and mathematics

INTRODUCTION

Aquaculture is the culture of aquatic organisms (fish, shellfish, crustaceans, algae, etc.) in a controlled environment and is considered the aquatic complement to agriculture (Lovell, 1979; Wingenbach et al., 1999). 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 added to a curriculum. Research suggests that aquaculture is an effective teaching tool because it easily integrates many disciplines including biology, physiology, chemistry, economics, math, physics, and engineering; and can provide hands-on experiences that complement classroom teaching (El-Ghamrini, 1996; Conroy and Peasley, 1997; Wingenbach, 2000). Students engaged in aquaculture projects are exposed to real-world phenomena that they may not have encountered before. As it is important to have students experience real-world content (Conroy and Walker, 2000; Frykholm and Meyer, 2002), aquaculture can create an authentic science, technology, engineering, and mathematics (STEM) project-based investigation (PBI) experience.

Students exposed to real-world phenomena provide vivid experiences and learning opportunities, which may include constructing their own recirculating aquaculture system (RAS) or an aquaponics project (Thompson et al., 2022, 2023a, 2023b). Aquaculture experiential learning also offers opportunities to incorporate technology to support student investigations of research data through real-time data. Teachers can incorporate these tools in their classrooms and create an engaging, student-centered, learning environment (SCLE). Students can also be exposed to real-life mathematics problem-solving through aquaculture such as monitoring fish growth, survival, and feed efficiency when grown in an aquaponic system (Thompson et al., 2023a, 2023b). Wingenbach et al. (1999) stated that successful aquaculture production is rooted in scientific and mathematical knowledge, as well as technological skills, needed to produce repeated harvests of marketable aquatic products. As a result, the authors emphasized the value and benefits of incorporating and/or developing aquaculture curricula at the secondary school level. This would be considered a transdisciplinary approach where knowledge and skills from two or more disciplines are applied to real-world problems and projects with the aim of shaping the total learning experience (English, 2016). Notably,

the author reported that student interest and engagement might increase if they are encouraged to make new and productive connections across two or more of the STEM disciplines.

Rosati and Henry (1991) found that when incorporated into an 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 (Mengel, 1999; Conroy 1999; Conroy and Walker, 2000). 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. Likewise, Conroy and Walker (2000) stated that teachers, students, and administrators viewed aquaculture as having the potential to address workplace skills and promote youth development.

The present study explored the notion that integrating a real-world aquaculture program into a secondary science and/or agriculture classroom could influence student interest, engagement, and choice to pursue a STEM-related field and career. Students were actively engaged in real-world problem-solving situations in the classroom and hands-on activities were designed to parallel the work of “real-life” aquaculture scientists. Likewise, participants were introduced to hands-on demonstration tours outside the classroom to see how STEM disciplines are conducted in the real world and how aquaculture is relevant to their lives. Notably, this was an important targeted student-learning outcome of the program. This strategy agrees with Anderson and Smith (1987) who stated that effective teaching provides students with opportunities to relate the scientific concepts they are studying to a range of appropriate phenomena through hands-on activities, demonstrations, audiovisual aids, and discussions of familiar phenomena.

Theoretical Framework

The foundation of active SCLEs is rooted in situated learning theory as students are asked to carry out certain tasks and do their best to solve problems that reflect the nature of such tasks in the real world (Brown et al., 1989). The same authors reported that situated learning theory explains that knowledge, thinking, and the contexts for learning are inextricably tied and situated in practice. Savery (2006) stated that situated authentic practices are tied to hands-on project-based instruction and design, in which students find solutions to problems and participate in project-oriented activities that can make connections to everyday life. Project-based activities are well suited to helping students become “active” learners by frequently engaging students in the exploration and analysis of data and situates learning in real-world problems and situations (Hmelo-Silver, 2004).

Project-based approaches (PBA) offer students an experimental, interactive, investigative, and cooperative form of learning

(Schwab, 1964; Willis and Mehlinger, 1996). PBA also provide student’s opportunities to construct meaning based on peer interaction as it has been shown that collaborative learning is an essential component of these active learning environments (Bhattacharyya and Bhattacharya, 2009). The instructor’s role in PBA is mainly of the facilitator who fosters a student-centered environment (Marx et al. 1997). Land et al. (2012) reported that students in active SCLEs are engaged in self-directed inquiry in which they may collect and analyze real-world data, take responsibility for their own learning, make connections to everyday experiences, compare results among their peers or experts on completion of the project, and take time to reflect on their learning experiences. Grounded in situated learning theory and PBA, this study explores students’ interest, engagement, and career aspirations in STEM disciplines when exposed to an active program that is student-centered and constructive. The present project was based on a PBI model (Singer et al., 2000; Polman, 2000; Wilhelm and Confrey, 2005; Krajcik and Blumenfeld, 2006; Wilhelm et al., 2008).

Rationale

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 (Roegge and Russell, 1990; Enderlin and Osborne, 1992; Mabie and Baker, 1996; Balshweid et al., 2000; Conroy and Walker, 2000; Balschweid and Thompson, 2002). Mabie and Baker (1996) stated, “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 the transformation of pedagogies toward creating student-centered multidisciplinary, authentic learning experiences. Similarly, Myers and Washburn (2008) found in their quantitative survey research study that many 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 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 a curriculum integrating agriculture and science with authentic, hands-on activities may promote depth of understanding and problem-solving in a variety of contexts.

A rationale for this research project was to establish a strong outreach model aquaculture program while engaging students in project-based learning (PBL) environments inside, and outside, the classroom, mirroring real-life scientists. This program strived to enact change in the high school classroom by introducing an “active” learning pedagogy through hands-on aquaculture activities and demonstrations outside the classroom. The study examined student interest and engagement in STEM and agricultural fields within these dynamic student-centered aquaculture-learning environments (SCLEs) and documented their future aspirations in a STEM-related field. Currently, there is a lack of documented research that describes the benefits of integrating aquaculture education as perceived by secondary students regarding engagement, interest, and future choices in a STEM-related area.

Significance of the Problem

Honey et al. (2014) reported that research needs to address how integrated STEM programs might encourage more student engagement, motivation, and perseverance and that research that targets STEM integration is in its embryonic stages. English (2016) agreed stating that more research is required to help students make STEM connections more transparent and meaningful across disciplines. Currently, there appears to be inadequate STEM integration research that yields evidence of desired student learning outcomes (Honey et al., 2014; English, 2016). Therefore, the present study was conducted to identify student outcomes within a PBL aquaculture-integrated program; address student engagement (i.e., degree of attention, curiosity, and interest); and discover their academic/career goals in STEM-related professions. At present, this research is lacking in the literature and will thus, fill a much-needed void for educators wishing to integrate aquaculture into a secondary school system.

The enrollment of high school student populations in the STEM circuit needs to increase to strengthen the Nation’s scientific and professional workforce. Therefore, a STEM-outreach-education-model program was established through the collaboration of an 1890 Land Grant University (one of several Historically Black Colleges and Universities, established under the Second Morrill Act of 1890) with selected secondary rural school systems (districts) in Kentucky. Higher education can play a key role in outreach initiatives to high school and pre-college programs. Pre-college programs often involve engaging students in educational hands-on activities and investigations, common in a college setting, and provide them exposure to what a career in a science-related field will entail (National Research Council, 2012). It is believed by the program organizers that this partnership strategy would provide students with firsthand knowledge of the broader educational and career opportunities in the agricultural STEM areas such as aquaculture. Further, this collaboration would ultimately help cultivate and develop the next generation of scientists in the workforce. The United States Department of Agriculture reported that during the next 5 years, U.S. college graduates would find good employment opportunities

if they have expertise in food, agriculture, renewable natural resources, or the environment, which are considered, STEM areas. The Bureau of Labor Statistics expects that employment opportunities will grow more than 5% between 2015 and 2020 for college graduates with bachelor’s or higher degrees in those areas that address the U.S. priorities of food security, sustainable energy, and environmental quality. Currently, there is a deficiency in the number of high school students pursuing degrees in agricultural science and the ag-STEM circuit.

Program Description

A 10-week aquaculture STEM program was organized by the College of Agriculture, Community, and the Sciences. The target population in this study was high school-age students as the primary unit of analysis who were from three different public and rural high schools. Participating students from each participating high school were engaged in real-world aquaculture discovery learning activities in and outside the classroom.

Students in the classroom designed and engineered a 270-gallon indoor RAS containing an in-tank biofilter. After 1 month of allowing the beneficial bacteria to become established, students in the program worked in small groups, stocked approximately 75 juvenile Koi and/or tilapia, and recorded initial weights, lengths, and total numbers into their respective logbooks. Students in the program engaged in the following tasks: Fed fish 2 to 3 times daily on a regular schedule; monitored fish behavior daily; analyzed specific water quality parameters twice weekly; siphoned tank when needed; monitored and maintained the RAS daily; and calculated overall fish growth performance and feed efficiency at the conclusion of the program. These activities were integrated into an active project-based unit developed by the researcher containing several benchmark lessons and facilitated by the teachers from each participating high school.

For the study, the following framework was established: the role of the educator will be to facilitate, monitor, and mentor students, which includes conducting lectures, outside field demonstrations, and hands-on inside (or outside) laboratory classroom activities. Students were to be “active contributors” to the learning process. Inside or outside classroom and laboratory settings will be a dynamic learning environment in which roles (i.e., educator and student) should constantly exchange ideas and learning will be relevant to student lives and communities to enhance student engagement, interest, and learning. Hence, students received direct, hands-on PBL opportunities. Students learned how to use scientific instruments, collect, and analyze real-world growth performance data in the classroom. The project-based unit provided interactive “hands-on” learning activities that enabled students to develop integrated, meaningful understandings. The unit situated learning in real-world problems that students could understand, see, and relate to within their everyday lives.

A major goal of the project-based unit was to ensure that students knew the practical importance of aquaculture and to

give them experiences that are vivid and hold significance to their lives. Overall, students were infused with new learning opportunities while engaged in real-world science inquiry practices, which encouraged them to use their critical thinking, problem-solving, decision-making, and communication skills. Likewise, the unit provided opportunities for students to work collaboratively with their peers. Participants also visited a state-of-the-art Aquaculture Research Center (Kentucky State University, Frankfort, KY, USA) for a behind-the-scenes hands-on demonstration tour with the aim to increase their interest, curiosity, knowledge, and awareness of the field of aquaculture and why it is important to their lives. The aquaculture demonstration tour also sought to increase awareness of the career opportunities for students in the ag-STEM circuit. A signature goal of the program was to provide hands-on experiential learning opportunities in the classroom while exposing students to STEM research instruments and data collection techniques.

Purpose and Objectives

The present study focused on three (3) aspects of the aquaculture experience: affect feelings/emotions/opinions (e.g., attitudes), students' attitudes and future decisions (e.g., actions, choices), and cognitive knowledge and skill development in aquaculture (e.g., purpose statement; Table 1).

Three (3) broad central research questions guided this qualitative study to explore students' views of their experiences in the aquaculture program. The objectives of this study were to address the following research questions:

1. How do student participants describe their attitudes toward aquaculture and STEM due to their experiences in the program (e.g., self-reported engagement, curiosity, and interest)?
2. How do student participants describe their future career plans in a STEM-related field, or taking more courses

in one or more STEM areas such as aquaculture due to the program (e.g., educational and career aspirations, decisions, actions, choices)?

3. How do student participants describe their knowledge of aquaculture and STEM skills due to their experiences in the program (e.g., knowledge, skills)?

METHODOLOGY

The research methodology of this study was exploratory based as well as open-ended systematic inquiry to provide a rich understanding of students' attitudes and experiences. This case study employed a qualitative methods approach. Creswell (2014) indicated that case study design is popular across the social and health sciences today and involves a detailed description of the setting or individuals, followed by analysis of the data for themes or issues. Qualitative research methods were selected since it has been reported by Patton (2002) that this type of research provides an in-depth understanding of people's experiences in a specific environment and this method of inquiry allows stories to be told in context and compiles evidence drawn from several methods of data collection (i.e., triangulation). The use of different qualitative approaches to learn how an educational program may have influenced students' perceptions and insight may allow researchers and educators to gain an understanding that cannot be obtained with predefined and structured survey instruments (interpretivism). Indeed, Crotty (1998) reported that interpretivism focuses on ways in which participants make meaning of their experiences, actions, and performances by interpreting their interactions with people and the world around them. Bhattacharyya and Bhattacharyya (2009) reported that interpretivism seeks to understand how people make meaning with others and relies on inductive approaches to data collection and analysis. The authors reported that inductive analysis works up from the data

Table 1: Organizational structure of focus group open-ended questions

Affect (attitudes)

- a. What things did you accomplish in the program that was exciting for you?
- b. What kept you engaged about the program?
- c. What work have you been most proud of or were the most interested in doing in the program?
- d. What have you done in this program that you didn't think you would ever be able to do?

Subject, major, or career aspirations

- a. How has your view toward STEM changed due to the program?
- b. How has your interest toward a STEM-related path in college changed due to the program?
- c. What do you think about taking a dual-credit aquaculture class while in high school?
- d. As you conclude the experience, tell me about your interest and curiosity in aquaculture?
- e. As you conclude the experience, tell me about your interest and curiosity in other STEM-related fields?
- f. How did the program change you? (e.g., how you think about aquaculture, your engagement, your interest, your curiosity, your decisions, your knowledge)
- g. What did you learn about yourself or can take with you from this experience?

Cognitive-knowledge and skills

- a. What knowledge about aquaculture have you learned through this experience?
- b. Will this knowledge change the way you think about anything? How so?
- c. What skill (s) have you learned that you feel will be most helpful to you now?
- d. In the future?
- e. How will these skills be helpful to you?

to reveal basic patterns and trends that emerge and identifies themes from all data sources collected. This is in agreement with Creswell (2014) who stated that qualitative researchers build their patterns, categories, and themes from the bottom up by organizing the data into increasingly more abstract units of information.

Instruments

Qualitative data were collected from post-audio-recorded student focus groups at three different public, rural high schools in Kentucky. It should be noted that permission of the participants was obtained before audio-recording. Focus group interviews are an ideal methodological approach since it contains open-ended, unstructured questions to promote good discussion and avoid using questions that can be answered “Yes” or “No.” Interviewers wanted the respondents to use their own words, thought patterns, and values when answering the questions (Patton, 1980). Thus, the objective of the interview(s) was to have the respondents to talk, be comfortable, and elaborate in a group setting. Further, questions were purposefully short so that participants could easily understand and remember them and matched the research questions for easy and accurate data analysis. It should be noted that qualitative data collected from the post-focus group interviews are considered the primary data sources in this study. Individual teachers from each school randomly selected eight to twelve students to participate in the post-focus group. Data did not utilize focus group questions with other high schools students.

Additional qualitative data included teacher journal reflections (e.g., personal documents) and teacher interviews with a local newspaper reporter (e.g., public document) about their insights learned from the program. Regarding the teacher journal reflection notes, teachers were given questions to help guide their field notes throughout the program and they documented weekly reflexive logs from what they were seeing and hearing in and outside the classroom.

Data Analysis

Post-focus-group interviews, teacher reflection notes, and other documents were read, organized, and assigned codes or labels (e.g., indexing) to reveal basic patterns and trends that emerged and grouped participants’ views (opinions) and attitudes into specific categories. Once all data sources were coded, codes were grouped together or within a cluster and created cluster titles (e.g., management) in which typically these broader labels are called categories in qualitative research. A summary statement was then developed for each category, and these became the key themes to report (Table 2).

Notably, the focus group interviews were the foundational data sources that served as the beginning points of analysis. Data analysis involved an iterative process of data coding, management, interpretation, and verification of data and it continued until dominant themes had been refined and isolated that represented the participants’ narrative attitudes and experiences toward the program. It has been reported

that interpretive data analysis in qualitative methods is always iterative and involves working up from small, manageable sections of data to create codes and categories that lead to identifying generalizable themes across all data sources (LeCompte and Preissle, 1993; Miles and Huberman, 1994). Hence, thematic analysis was employed to analyze the qualitative data in the present study. Categories were examined across all data sources in an effort to answer the research questions by discovering relationships and patterns between the triangulated data. The researcher searches for reoccurring themes from the multiple data sources. It should also be noted that the overall themes identified were not verified with other researchers and solely came by the senior author of this paper.

The study included only those groups of students in the population who participated in the focus group interviews and completed the parent consent and student assent forms; they represent the total number in the study. There were 57 students who participated in the post-focus group interviews from all three treatment groups. A summary of the student population studied who participated and returned consent forms is provided in Table 3.

Student Demographics

Regarding overall ethnicity and gender, the *student population studied* who completed the interviews ($n = 57$) 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 came from low socio-economic 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. A summary of the student study demographic population is provided in Table 4.

The researchers sought permission from the University (i.e., Kentucky State University and University of Kentucky Alliance Agreement) Institutional Review Board, consent was obtained from students’ parents or legal guardians, 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 the research project. 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, they still had the right to discontinue at any time.

RESULTS AND DISCUSSION

Qualitative Data

Themes that emerged and were identified after conducting qualitative data analysis in the present study demonstrate how experiences in hands-on aquaculture activities helped students become more emotionally engaged (e.g., feelings of excitement and enthusiasm), behaviorally engaged (e.g., involvement in tasks, effort, asking questions, paying

Table 2: Thematic analysis of qualitative data collected in the study

Group into categories (cluster titles)

1. Show enjoyment working with the aquaculture recirculating system and fish in particular
2. Excited about getting fish in the classroom
3. Celebrating the decline of ammonia levels

Group 1 codes (theme): *Students show excitement and enthusiasm in the hands-on, aquaculture program* (e.g., emotionally engaged)

1. Focused in researching how to remove algae in the tanks which is a problem
2. Constantly asking the teacher to write notes to get them out of class to work on fish project
3. Diligent to keep a close eye on both qualitative and quantitative data taken
4. Make appropriate adjustments to ensure fish survival
5. Students take responsibility in the program
6. Have the responsibility to keep the ecosystem going
7. Self-rotating and prompting others to join in on the various tasks
8. Showing others how each test works and what the results mean for fish health
9. Paying close attention to the fishes' actions
10. Show confidence in their ability to solve problems

Group 2 codes (theme): *Students show attention to detail in the hands-on, aquaculture tasks, it sticks, and are more responsible* (e.g., behaviorally engaged)

1. Totally engaged and recruit and teach others the way of the fish
2. One student actively communicates with the teacher daily through text and pictures
3. Work collaboratively to eliminate the algae and find solutions to the problem
4. Learning how to do water quality and explaining to others what the tests are telling them
5. Self-rotating and prompting others to join in on the various tasks
6. Showing others how each test works and what the results mean for fish health
7. Program-reinforced teamwork skills
8. Program more engaging compared to learning from the textbook
9. One student fully engaged with the aquaculture system versus struggles in a normal classroom setting
10. Students learn that fish, plants, and bacteria must work together to keep the ecosystem going
11. Students make connections about living things within the ecosystem

Group 3 codes (theme): *Students are collaboratively engaged with their peers* (e.g., cognitively engaged)

1. Looking at aquaculture in a different way and more appreciation for fish farming
2. Interest in pursuing a career in aquaculture and other STEM career pathways
3. Program helped students have confidence in STEM
4. More interested in mathematics due to practical application

Group 4 codes (theme): *Greater interest and confidence in STEM through practical application* (e.g., interest and future choices)

Table 3: Number of participants who participated in the focus group interviews

Focus group	Group 1 Students (Treatment; Teacher A)	Group 2 Students (Treatment; Teacher B)	Group 3 Students (Treatment; Teacher C)
(n=57)	21	13	23

attention), and cognitively engaged (e.g., genuine investment in learning, working hard, and exceeding expectations). Results from this qualitative study indicate that the aquaculture program may have influenced students' engagement, interest, and curiosity about aquaculture and STEM and some even expressed a desire to pursue it as a career after high school. Results demonstrate that the program engaged learners in real-world problem-solving and decision-making situations while working collaboratively in small works. It also appears that students gained important life skills, and responsibility, after participating in the program. Results agree with several studies that have shown that aquaculture education is an avenue to address workplace skills (i.e., teamwork, communication,

leadership, and responsibility) and promote youth development (Wingenbach et al., 1999; Conroy and Walker, 2000; Thompson et al., 2023). The next section will elaborate on four emergent themes with excerpts from post-focus group interviews with students at the three participating high schools, teacher journal reflections from two out of the three participating high schools, and one newspaper article (e.g., public document) in which a teacher (Teacher A) was interviewed by a local reporter at their school.

Students show excitement and enthusiasm in the hands-on, aquaculture program

An emergent theme that resulted from the qualitative data collected and analyzed demonstrates that students were *excited* and *enthusiastic* about the hands-on, aquaculture program. Students showed *enjoyment* working with the aquaculture recirculating system and were particularly *excited* about getting fish in the classroom and all celebrated the decline in ammonia during a specific time in the program. Ryan and Deci (2000) stated that intrinsically motivated students have a greater likelihood of having quality educational experiences in the classroom due to their interest and enjoyment in learning for

Table 4: Demographic data from participating students in the project who completed the focus group interviews (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	Rural schools	High School	11 White 10 Underrepresented n=21	10 Male 11 Female n=21	64.4%
Group 2	Rural schools	High School	13 White 0 Underrepresented n=13	6 Male 7 Female n=13	63%
Group 3	Rural schools	High School	16 White 7 Underrepresented n=23	5 Male 18 Female n=23	73%

In the present study, Teacher A (Group 1) taught a General Biology 10th-grade class; Teacher B (Group 2) taught an AP Environmental Science 9th-grade class; and Teacher C (Group 3) taught a General Biology 9th-grade class

the sake of learning. One teacher wrote in her reflection, “*The students constantly ask when they will arrive.*” Another teacher wrote in their reflection, “*Students have been enjoying looking at the fish and working with them.*” The teacher interviewed by the newspaper reporter stated, “*I believe the students were excited before everything was delivered, but the real excitement came when the last item was delivered, the Koi.*” The article reported that students nagged their science teacher for details on the status of the project and there was an uptick in interest in aquaculture when the school was chosen to participate in the program.” One teacher talked about how students had already made plans for the aquaponics coming next semester and they were excited about engaging in the design and choosing which plants they wanted to grow.

A student in a focus group interview stated, “*It was really engaging (i.e., the program). It was way more engaging than a textbook would have been, but it was also challenging to keep up with all of those records and data.*” Another student in a focus group interview stated, “*It was really fun because I have never had got to work with animals like fish and stuff before. I really like learning about the water, and I want to go into marine biology. So, I really liked working and seeing the interactions.*” Another student in a focus group interview stated, “*I enjoyed the crayfish more than the koi fish. You had your own station with the group. It was more personalized.*”

These findings in this category suggest that students showed genuine enjoyment working with the aquaponics recirculating system and were excited about the various fish and science activities in the classroom (e.g., emotionally engaged).

Students show attention to detail in the hands-on, aquaculture tasks; it sticks, and are more responsible

A second emerging theme that resulted from the qualitative data in this study was that students in the program were fully immersed and showed much effort and determination in the various hands-on, aquaculture tasks. One teacher wrote in her reflection, “*Students are diligent to monitor water quality and fish behavior and keep a close watch on both quantitative and qualitative data taken.*” The teacher indicated that the students

in her classroom were noticeably paying close attention to the fishes’ actions and making appropriate adjustments to ensure the fish’s survival. The same teacher wrote, “*Students are constantly asking for me to write notes to get them out of another class so that they can help with the fish project.*” She also wrote, “*I have one young man who tends to struggle in a normal classroom setting but is fully engaged with our aquaculture system.*” Another teacher wrote in their reflection, “*Students are engaged in research to determine how to get algae out of the tanks and found new ways to eliminate the problem.*” Another school was engaged in regulating water flow from the pump into the biological reactor and creating a design so that it does not overflow into the tank below.

A student in a focus group interview stated, “*The program helped me keep track of stuff and my work ethic which will help when I become a surgeon.*” Another student in a focus group interview stated, “*I want to go into nursing, so we’ve been keeping track of data on the fish and plants which is needed if you ever want to become a nurse. So, documentation helps out.*”

Further, students in a focus group interview stated, “*The program helps me remember a lot more.*” Interestingly, many students who participated in the program spoke about this during the group interviews in terms of its stick-ability (i.e., it sticks). A student in a focus group interview stated, “*It is teaching us like routine. Like before this project, I never really had to remember to do something every day. Now I will remember, oh we have not checked the tank this week. We forgot to feed our crayfish. It is simple to forget. Sometimes people are lazy, but other times you just forget.*”

Another teacher commented that a group of girls that has taken on full responsibility has amazed her and one student actively communicates with her daily through text and pictures. Notably, many students commented during the focus group interview that the program taught them responsibility. A student in a focus group interview stated, “*This project for me taught me responsibility because before I wasn’t really as responsible as I am now. Now it’s like having to keep up with these fish and stuff really helped that.*” Another student in a

focus group interview stated, *“The most challenging part of the project was the responsibility, to be honest. Because you had to be responsible, and you had to know what to feed the crayfish or the fish and when to feed them. If you don’t, you could easily kill them.”*

These findings in this category suggest that some students in the program were highly active in the aquaculture tasks, showed much effort and determination, the experiences helped them remember better (i.e., it sticks), and the program taught them responsibility (e.g., behaviorally engaged).

Students Collaboratively Engaged with Their Peers

A third emerging theme that resulted from the qualitative data was that students were actively engaged while working collaboratively on the various tasks with their peers. One teacher wrote in her reflection, *“Many students are showing others how each test works and what the results tell us about the overall health of the fish.”* The students learned how to do water quality and were eager to explain to others what the tests were telling them. Interestingly, the teacher stated, *“Students are self-rotating as to which job they will perform and prompting others to join in.”* The same teacher wrote in her reflection, *“Students are totally engaged and recruit and teach others the way of the fish.”* Another teacher wrote in his reflection, *“Students work collaboratively to eliminate algae,” as they find solutions to the problem.*

A student in a focus group interview stated, *“I just thought that like usually we can’t work together very well, but when it came to the fish, people were like alternating and taking turns and actually working together to get like the data and putting fish back and forth.”* Another student in a focus group interview stated, *“I gained communication skills from this program. If you didn’t know how to do something, or like if you had a certain job, you could go to that person (another student) who had that job before and have them talk to you and explain it to you.”*

These findings in this category suggest that some students in the program exceeded teacher expectations and had a genuine investment in learning and working hard and reinforced teamwork skills (e.g., cognitively engaged).

Greater interest and confidence in STEM through practical application

A fourth emerging theme from the qualitative data revealed that students looked at aquaculture in a different way and gained more appreciation for fish farming based on what the teachers were hearing and seeing in the classroom. Likewise, the program appeared to increase students’ interest and confidence in STEM, and, helped them mathematically. In fact, many students during the focus group interviews mentioned that the project helped their confidence in STEM. For example, during one focus group interview when asked who in this class is considering majoring in a STEM field in college. Approximately half of the class raised their hands that they wanted to pursue a STEM-related degree in college.

These results are in agreement with Thompson et al. (2023) findings who used survey methodology approaches to data collection. The project in the present study helped solidify students’ desire to go into a STEM field. A student in a focus group interview stated, *“I already know how to like multiply and stuff and use the calculator, but I didn’t know that you had to add all of those numbers together and divide them and multiply again. This put a practical application to my regular mathematics.”* Another student in a focus group interview stated, *“Getting to apply mathematical knowledge is great.”* One student in a focus group interview stated, *“The math was complicating, but you get a more interesting result from it. It was not like a random answer, but it tells you something about it. It is relevant. It is more meaningful.”* Another student in a focused interview stated, *“This also helped me see different parts of science because I didn’t know science was like numbers, adding, and taking care of stuff. I thought it was just like hard stuff, chemicals mixing, testing, etc. However, this project made me realize it is like there is a lot of other stuff. There is a lot of aspects or subjects involved.”*

These findings in this category suggest that some students expressed a desire to pursue a career in a STEM field and had more confidence in science and mathematics after participating in the program (e.g., interest and future choices).

CONCLUSION AND IMPLICATIONS

Results indicate that students showed an enthusiastic attitude and appeared to be having fun doing the hands-on benchmark lessons. Likewise, students showed a genuine concern of fish health, survival, water quality, and maintaining their aquaculture systems to the best of their ability. Students demonstrated sustained interest early in the program, appeared motivated, and fully engaged in the aquaculture tasks when facilitated by their teachers. Data analysis also demonstrated that students not only enjoyed their hands-on aquaculture experiences but also have gained problem-solving and decision-making skills when applied to real-world projects in the classroom. However, more data needs to be collected and analyzed to see if the experiences of conducting hands-on aquaculture activities and projects may have enhanced students’ conceptual understanding of aquaculture and making connections to real-life situations. Notably, one teacher stated that her students had very little prior knowledge of aquaculture and this was the case with other participating schools. Further, more data needs to be collected and analyzed to see if the aquaculture program influenced students’ aspirations to pursue STEM areas of study and careers after high school. Findings suggest that this program may help other teachers develop and cultivate similar experiences for secondary students and offer invaluable insights when integrating real-world aquaculture activities in the classroom. Grubb et al. (1991) stated that academic educators suffer criticism for developing a

curriculum that lacks opportunities for students to connect learning to “real world” events. However, it was interesting to learn that one science teacher in the program faced constraints when integrating aquaculture into the classroom. The teacher stated, “*There is so many standards that must be taught throughout the year that it is difficult to find time to layer in the aquaculture.*”

The program investigated in the present study appeared to have broadened the student experience using aquaculture as an interactive teaching tool for STEM education. Findings from this study may be useful to help transform K-12 classrooms by the integration of real-world aquaculture projects into science and/or agriculture curricula. A long-term outcome of this program is that teachers would become more aware of ways to encourage students to appreciate and like STEM disciplines if they introduce aquaculture in their classroom/laboratory settings. Consequently, students who are exposed to hands-on, project-oriented aquaculture activities in and outside the classroom may enhance their interest, engagement, and curiosity for STEM and perhaps pursue STEM-related fields of study and careers such as aquaculture in the future. Another long-term student outcome explored was to see if the program might have influenced participants’ desire and aspirations to take aquaculture dual credit courses if the project-based curriculum is available while in high school. Further, information on the results to be disseminated to the public may also ignite widespread aquaculture integration into other secondary classrooms. An important aspect of the program was to educate students on the importance of food and the demand for more food in our growing world population. The need for animal protein is crucial, so introducing students to the field of aquaculture may foster new knowledge, awareness, and ideas. Findings may suggest that aquaculture when implemented into a traditional secondary science or agriculture classroom may foster creativity through an active hands-on activity learning culture and students’ experiences are meaningful to their lives.

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