Interdisciplinary Journal of Environmental and Science Education
2023, 19(2), e2309
e-ISSN: 2633-6537
https://www.ijese.com/

MODESTUM

Research Article

OPEN ACCESS

Use of aquaponics project-based environments to improve students' perception of Science, Technology, Engineering, and Mathematics (STEM) disciplines and career pathways

Kenneth R. Thompson [1]*, Carl D. Webster [2], Kirk W. Pomper [1], Rebecca M. Krall [3]

[1] College of Agriculture, Community, and the Sciences, Kentucky State University, Frankfort, KY, USA
[2] USDA-ARS Harry K. Dupree Stuttgart National Aquaculture Research Center, Stuttgart, AR, USA
[3] College of Education, University of Kentucky, Lexington, KY, USA
***Corresponding Author:** ken.thompson@kysu.edu

Citation: Thompson, K. R., Webster, C. D., Pomper, K. W., & Krall, R. M. (2023). Use of aquaponics project-based environments to improve students' perception of science, technology, engineering, and mathematics (STEM) disciplines and career pathways. *Interdisciplinary Journal of Environmental and Science Education, 19*(2), e2309. https://doi.org/10.29333/ijese/13102

ARTICLE INFO

Received: 10 Mar. 2023

Accepted: 12 Mar. 2023

ABSTRACT

There is a need for secondary schools to provide more authentic, hands-on experiences in science, technology, engineering, and mathematics (STEM), and specifically, more project-based investigation (PBI) environments in the classroom that manifest the next generation science standards following practices they prescribe. This study investigated how, and to what extent, a contextualized aquaponics project-based investigation (APBI) 10-week model unit affected 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 literature on how APBI may engage students in initiating affective attitudes and interest in STEM and aquaculture/aquaponics fields as a career choice. Using a quantitative method, quasi-experimental research design, three different student groups participated in the hands-on APBI intervention and were given a pre- and post-attitude/interest survey (n=55). The 12 survey items were rated by a 5-point Likert-type scale that measured changes in student interest and attitudes toward STEM as discipline and area of interest. In addition, the survey included a profile of the respondents with the demographic items. The results revealed that the intervention contributed to students' positive attitudes toward STEM in general, and aquaculture and aquaponics, and to students' developing an interest in STEM disciplines and/or STEM career pursuits. Results suggest that APBI models may be effective in attracting students to STEM-related disciplines and careers.

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

INTRODUCTION

As the global population increases in the coming decades, agricultural sciences will be vital to ensure a safe and abundant food supply. However, interest in agricultural sciences is not keeping pace with the number of professions that will be required in these disciplines, especially among under-represented students (Clark et al., 2021) and women (Bloodhart et al., 2020). A major industry within agriculture is aquaculture. For the past 40 years, aquaculture has been the fastest-growing sector of global agriculture (FAO, 2016) and will be critical to providing protein to the growing world populace. As aquaculture science consists of multidimensional disciplines required to culture aquatic organisms and plants, a talented pool of students is required for future growth of the discipline and industry. Further, challenges exist in recruiting and retaining students, especially under-represented students, into science, technology, engineering, and mathematics (STEM) disciplines. While approximately 52% of students are retained to complete a four-year, STEM degree, only 29% of Black students and 23% of Hispanic students are retained (NCES, 2012).

Aquaponics, the combination of aquaculture and hydroponics, can serve as a bridge to get students involved and interested in STEM disciplines (Genello et al., 2015); however, currently, there is a lack of documented research on helping us better understand how integrating aquaculture-based project-

This project was also in partial fulfillment of Kenneth R. Thompson's doctoral dissertation submitted in the College of Education at the University of Kentucky. Director and Dissertation Chair was Dr. Rebecca M. Krall. The other committee members included Dr. Jennifer Wilhelm, Dr. Kiluba Nkulu, and Dr. Kenneth Jones.

Table 1. Number of participants who completed the pre- and post-questionnaire

Instrument	Group 1 students (treatment/teacher A)	Group 2 students (treatment/teacher B)	Group 3 students (treatment/teacher C)
n=55	15	14	26

based investigation (PBI) projects during a short term curricular unit in the science classroom can foster students' attitudes toward STEM and aquaculture in particular, and interest in pursuing STEM coursework (via STEM disciplines) and/or careers/hobbies (via STEM career pathways).

While much literature has touted the benefits of contextualized science instruction to improve learning, few studies have explored in the context of using aquaponics project-based investigation (APBI) in the science classroom. Further, few researchers have explored aquaponics-based teaching in an educational setting and even less research has explored student cognitive and affective outcomes from these experiences.

The overarching goal of the present study was designed to positively influence (i.e., increase) and inspire students' attitudes toward and interest in STEM educational disciplines and/or STEM career pathway pursuits. Likewise, 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 pursuit after high school and in college.

Purpose and Objectives

The purpose of this study was to examine the effects of participation in a short-term, 10-week long APBI unit on the attitudes of high school students toward STEM in general, and aquaculture and aquaponics specifically, and whether they report a change in their interest in taking part in future STEM-related disciplines and/or consider STEM career pathways. The hope was that their 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 quantitative methodology was used to examine the possible effects the project might have, which could lead to a measurable change in attitudes toward STEM and aquaculture, and to see a possible impact on future career choices of the students participating in the project. In this study, 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 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 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 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

Data were collected by means of pre- and post-survey questionnaires containing 12 response items to test the research questions associated with this study quantitatively and thereby measure the outcomes (i.e., dependent variables). A multiple case study approach was employed because it fit the research goal to compare the independent variable, which was the different participating student groups across different school environments. It is important to note that the unit of analysis was at the level of *the student* and not the teacher or school, even though teachers are factors that can affect student outcomes. Likewise, the school environment is another important factor to consider concerning the school demographics, administration (supportive or not supportive), class schedules, and class frameworks, which can also affect how the unit is implemented. Overall, different groups of students across separate school classrooms were analyzed (i.e., independent variables in the experiment), creating a multiple case study as described by Stake (2005). Each school was a case when assessing the effects of APBI on students' attitudes and interests toward STEM and aquaculture.

It is important to note that the selection process for student participants were nonrandom (e.g., conveniently selected). Since the students in this study were not randomly assigned, the procedure is commonly called a *quasi-experiment*. The researchers used naturally-formed student groups who met in three different learning spaces (i.e., classroom) and were in separate schools. Thus, there were multiple cases in this study containing three independent variable student groups that were engaged in the APBI intervention. The outcomes were first examined by themselves (per class/group in each school) and then in a cross-case comparison amongst the groups, in that order. The population for the study consisted of ninth and tenth graders from three different public high schools in the mid-South United States and were not from the same school district. These students participated in the ten-week APBI unit in their science classrooms. It is important to note that there was not a control group used in this study to focus on the changes in the participants. There were 55 students who completed the pre- and post-questionnaires from all treatment groups (less than the total number of students due to students changing classes, leaving school, or other factors). A summary of the student population studied who completed assessments and returned consent forms is provided in **Table 1**.

Student Demographics

Regarding overall ethnicity and gender, the *student population studied* who completed the pre-and-post interest/attitude survey questionnaire (n=55) included: a

Table 2. Demographic data from participating students in the project who completed the pre- and post-interest/attitude survey instrument (i.e., the population studied)

Student groups	Ethnicity & number of students	Gender & number of students	Economically disadvantaged
Group 1	8 White & 7 Underrepresented (n=15)	8 Male, 7 Female (n=15)	64.4%
Group 2	14 White & 0 Underrepresented (n=14)	6 Male & 8 Female (n=14)	63.0%
Group 3	19 White & 7 Underrepresented (n=26)	5 Male & 21 Female (n=26)	73.0%

Note. 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; teacher C (group 3) taught a general biology 9th grade class; School setting: Rural school; & School level: High school

Table 3. Overview of the data collection and analysis process for the unit for survey

Pre- & post-survey instrument procedure	Product
Descriptive statistics (univariate analysis) across 3 treatment groups & gender using two score factors	Descriptive
Frequency distributions	Frequencies
Demographic items across all three treatment groups	Descriptive
Kruskal-Wallis test of pre- & post-test mean rank score comparison between three treatment groups; a Mann-Whitney test if there were significant differences	*KW* rank test statistic; comparison test if different using *MW*-test statistic
Exploratory factor analysis & survey instrument assessed for reliability	α-statistic

combination of White (74.5%), mixed ethnicity (9.1%), African American (7.3%), American Indian (1.8%), and other (7.3%). In addition, all students attended a rural school in the mid-south region of the United States and mostly come from low 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. Summary of the student study demographic population who *completed* the pre- and post-interest/attitude survey instrument is provided in **Table 2**.

Instrumentation: Pre- and Post-Survey (e.g., Student Attitudes and Interests)

Respondents were offered a choice of several responses from statements that connected to research questions 1 and 2. They responded to statements utilizing 5-point summated scale scores with a 1 representing strongly disagree, 2 for disagree, 3 for neutral, 4 for agree, and 5 for strongly agree.

The assessment 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. The researchers acknowledges that a limitation exists in that the sample may not represent a larger population of students who might be exposed to the same intervention. Thus, caution is warranted in generalizing the results beyond the sample.

Overview of Data Collection

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. No students decided to end their participation in the research. An overview of the data collection and the analysis process before and after the short-term APBI unit are provided in **Table 3**.

Quantitative Data Analysis

A descriptive univariate (one variable at a time) analysis of the variables was performed in this study, which also included a profile of the respondents with the demographic items. The objective was to look at every item in the survey to get a sense of the variability of responses. The study employed several ways of presenting the univariate information about the variables in the study, which included frequency distributions, statistical measures (i.e., means and standard deviations), and visual representations using graphs. Thus, the data analysis in this study used descriptive statistics, which included frequencies, percentages, means, and standard deviations for each of the twelve items within the survey. Nardi (2014) reported that calculating the mean for some ordinal scales, such as Likert, is acceptable (p. 143). Hence, this was implemented in the study. The literature identified no survey instrument that suitably matched the objectives of the study. Thus, to ensure that every participant would accurately interpret and willingly respond, wording for each statement was adjusted specifically for participants by testing the questionnaire with a pool of pilot testers who were representative of the participants in the present study and who were of similar age. The researchers decided to use participants from the same three schools that were taught by the same biology teacher who participated in the present study and another student group (a total of four student groups) from another school during the 2018-2019 academic school year. Pilot testing is considered a good approach to help validate a survey (Nardi, 2014).

Exploratory factor analysis of a pilot 2018 survey data was used to see how many factors emerged from the dataset and to evaluate the nature of the factors. Construct validity was verified, and the assessment was designed to measure two constructs (e.g., interest in STEM and future in STEM). The goal was to confirm to what extent items seem to be targeted at the same underlying construct. Two factors emerged that explained 63% of the variance, and results revealed items that associated with their construct in the pilot questionnaire did indeed load upon the intended construct having a factor loading criterion of above 0.3 coefficient. Thus, this process was carried out to validate that the instrument was functioning as intended.

The researchers then employed a reliability function, which reveals the questionnaire's reliability values in terms of Cronbach's alpha (α). The survey data analyzed from the pilot test represented a total of 95 participants who took the interest/attitude assessment during the 2018-2019 academic school year. For the pilot-survey responses, α=.832. The pre- and post-survey used in this study was also assessed for reliability using α. For the pre-survey responses, α=.863. For the post-survey responses, α=.894.

The researchers employed pre- and post-intervention descriptive statistics, as well as the Kruskal-Wallis mean rank test, to compare between the three groups for each item to reveal any significant differences between them. Results indicated that there were significant differences within some of the respective items, so the 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 three total. Hence, the statistical significance level for the Bonferroni correction was α=.05/3=0.017. The final sample size was n=55.

It is important to mention that the assumptions for the one-way ANOVA:

(a) normally distributed mean scores and

(b) equal variances of scores between groups (Aron et al., 2005) were not met when comparing between all student groups.

The assumption of normality was tested using the Shapiro-Wilk test and the assumption of equal variances was tested using Levene's test for homogeneity of variances. Hence, this was the reason why the researcher decided to use non-parametric models in this study.

QUANTITATIVE RESULTS

For the pre-intervention survey instrument, results demonstrate 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) when comparing between student groups in eleven out of the twelve items within the survey instrument. The only exception was for item 11 (at this time, aquaculture increases my curiosity in technology) as group 3 had numerically a slightly higher mean Likert scale response (3.15) compared to all other student groups (2.87 group 1: 3.14 group 2). It should be noted that group 1 students had numerically the lowest mean scale response for nine out of the twelve items (items 2-6, 8, and 10-12) compared to all other student groups.

For the post-intervention survey instrument, results demonstrate that group 2 students had numerically the highest mean ordinal Likert scale response in eight out of the twelve items when comparing between student groups within the survey instrument. The only exceptions were for questionnaire items 1 (aquaculture would be a highly interesting profession), 10 (I would encourage my friends not attending project to consider courses in aquaculture), and 11 (aquaculture activities increased my curiosity in technology), as group 3 had numerically a higher mean Likert scale response compared to all other student groups. Likewise, group 1 student had numerically a higher mean Likert scale response for item 4 (aquaculture activities increased my interest in mathematics) when compared to all other student groups.

Quantitative Descriptive Gain and Loss in STEM Attitudes and Interest of the Descriptive Data

Table 4 reveals the percent change across the pre- and post-intervention responses with respect to each of the three different student groups. When examining a positive or negative change from the pre- to post-intervention survey, the results revealed the following: Group 3 students had six statements (items 1, 6, 7, 8, 9, and 10) with "increasing" scale responses with a 5% or greater increase. Group 1 students had three statements (items 3, 4, and 12) with "increasing" scale responses with a 5% or greater increase. Group 2 students had one statement (item 6) with a 5% or greater increase and two statements (items 1 and 12) with "decreasing" scale response less than 5%.

There was a 12.4% increase in group 3 students' interest in future opportunities to study aquaculture subjects for high school and advanced credit (item 9), a 12.4% increase to encourage their friends (not attending project) to consider courses in aquaculture (item 10), and these also correspond with the statement on group 3 students' desire (5.4% increase) to take courses in aquaculture specifically (item 7). Hence, these descriptive statistics data suggest that when group 3 students responded to statements on a five-point Likert scale that relates to aquaculture subjects and courses, they tended to have a positive perception to pursue this opportunity in the future when examining the posttest responses. Furthermore, there was a 7.8% increase (gain) in group 3 students' attitudes toward aquaculture as being a highly interesting profession (item 1). In terms of the desire to take courses in a STEM-related area (item 6), there was a 6.8% increase in group 3 students on the pre- and post-intervention survey. Lastly, there was a 6.2% increase in group 3 students' aspirations to work with people who make discoveries in science after high school (item 8). Overall, data reveals that group 3 students demonstrated growth in their interest in learning hands-on STEM and working with people who are immersed in science discovery in the future. This pre- and post-intervention survey data may suggest that these group of students particularly enjoyed learning about the biological and ecological concepts when studying a "living" ecosystem and engaging in real-world research tasks in the classroom.

There was a 12% increase in group 1 students' interest in specifically engineering (item 3) and a 20% increase in their interest in specifically mathematics (item 4) with the same group of students. Likewise, there was a 6.8% increase on the pre- (2.53) and post-intervention (2.87) survey with the statement on pursuing higher education in a STEM-related field for item 12 among group 1 students, which is encouraging. The descriptive data suggests that students from this group favored more of the hands-on engineering and mathematics aspects of the project and perhaps less the ecological aspects. Further, these same students also had a 4% increase in their curiosity of technology. It could be that students in this group were more interested in the hands-on learning experiences of producing fish and plants, and subsequently, the real-life mathematics calculating growth performance of Koi carp, figuring out water quality averages-

Table 4. Descriptive statistics for percentage change comparison across the pre- and post-survey responses with respect to the treatment groups (n=55)

Dependent variable (item number)	Student groups	Pre-survey M	Post-ssurvey M	% Change M
1. Aquaculture would be a highly interesting profession.	1	3.07	3.07	0.0%
	2	3.57	3.21	-7.2%
	3	2.84	3.23	+7.8%
	Total	3.10	3.18	41.6%
2. Currently, aquaculture increases my interest in science.	1	3.07	3.13	+1.2%
	2	3.57	3.50	-1.4%
	3	3.34	3.42	+.1.6%
	Total	3.28	3.36	+1.6%
3. Currently, aquaculture increases my interest in engineering.	1	2.33	2.93	+12.0%
	2	3.36	3.21	-3.0%
	3	3.08	3.00	-1.6%
	Total	2.95	3.04	+1.8%
4. Currently, aquaculture increases my interest in mathematics.	1	2.27	3.27	+20.0%
	2	2.93	2.86	-1.4%
	3	2.61	2.54	-1.4%
	Total	2.60	2.81	+4.2%
5. My participation in the aquaculture project will increase my interest in a STEM career field.	1	2.80	2.93	+2.6%
	2	3.43	3.43	0.0%
	3	3.11	3.19	+1.6%
	Total	3.11	3.18	+1.4%
6. My participation in the aquaculture project will increase my desire to take more courses in a STEM-related area.	1	2.6,7	2.93	+5.2%
	2	3.43	3.64	+4.2%
	3	3.08	3.42	+6.8%
	Total	3.05	3.35	+6.0%
7. My participation in the project will increase my desire to take courses in aquaculture specifically.	1	2.60	2.53	-1.4%
	2	2.93	3.00	+1.4%
	3	2.54	2.81	+5.4%
	Total	2.65	2.78	+2.6%
8. When I graduate from high school, I would like to work with people who make discoveries in science.	1	2.20	2.80	+4.0%
	2	3.57	3.57	0.0%
	3	2.61	2.92	+6.2%
	Total	2.75	3.05	+6.0%
9. I am interested in future opportunities to study aquaculture and aquatic science subjects for high school and advanced credit.	1	2.60	2.73	+2.6%
	2	3.57	3.36	-4.2%
	3	2.46	3.08	+12.4%
	Total	2.78	3.05	+5.4%
10. I would encourage my friends (not attending project) to consider courses in aquaculture.	1	2.80	2.73	-1.4%
	2	3.50	3.43	-1.4%
	3	2.96	3.58	+12.4%
	Total	3.05	3.31	+5.2%
11. Currently, aquaculture increases my curiosity in technology.	1	2.87	3.07	+4.0%
	2	3.14	3.14	0.0%
	3	3.15	3.38	+4.6%
	Total	3.07	3.24	+3.4%
12. I expect to pursue higher education in a STEM-related field.	1	2.53	2.87	+6.8%
	2	3.79	3.43	-7.2%
	3	3.04	3.12	+1.6%
	Total	3.09	3.13	+0.8%

patterns-trends, and determining feed conversion ratios; had a keen interest in engineering and designing their recirculating aquaculture systems while working in small groups; and were more curious to use various technological equipment (i.e., hand-held probe devices) throughout the project. As a result, this may have sparked their motivation to pursue a STEM-related field in college related to engineering or mathematics that possibly links to agriculture science studies in the future.

There was a 5.2% moderate gain in group 2 students' desire to take more courses in a STEM-related area (item 6). However, there was a negative (loss of interest) growth (7.2%) in group 2 students' attitudes towards aquaculture as a profession (item 1) and 7.2% decrease in interest with the statement on expecting to pursue higher education in a STEM-related field (item 12). The descriptive data suggest that group 2 students had a relatively high perception of aquaculture at the beginning of the project but decreased after completing the intervention. Likewise, data suggest that group 2 students appear to have a desire to take STEM-related courses but may not consider a STEM field after high school.

Additionally, the researchers employed a Kruskal-Wallis mean rank test to compare the pretest and posttest mean rank score between the three treatment groups. The independent-samples Kruskal-Wallis test of significance of the *pre-intervention survey instrument* comparison revealed a significant difference ($p<0.05$) between the three student group populations for the following six statements: 1 (aquaculture would be a highly interesting profession), 3 (at this time, aquaculture increases my interest in engineering), 8 (when I graduate from high school, I would like to work with people who make discoveries in science), 9 (I am interested in future opportunities to study aquaculture and aquatic science subject for high school and advanced credit), 10 (I would encourage my friends (not attending project) to consider courses in aquaculture), and 12 (I expect to pursue higher education in a STEM-related field), respectively.

Since there were significant differences ($p<0.05$) in the pre-intervention survey instrument between groups, 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. Similarly, the researchers divided alpha by the number of comparisons, which was three in total. Hence, the statistical significance level for the *Bonferroni* correction was $\alpha=.05/3=0.017$. The final sample size was n=55 (group 2=15; group 3=14; and group 4=26).

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

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

Group 2 students had a significantly ($p<0.017$) higher pre-survey mean rank (19.50) compared to group 1 (mean rank of 10.80) for item 3 (at this time, aquaculture increases my interest in engineering). However, there were no significant differences found when comparing groups 3 and 1 (i.e., *Bonferroni* correction) or groups 1 and 3 for the same item 3, respectively.

Group 3 students had a significantly ($p<0.017$) higher pre-survey mean rank (19.93) compared to group 2 (mean rank of 10.40) for item 8 (when I graduate from high school, I would like to work with people who make discoveries in science). However, there were no significant differences found when comparing groups 2 and 3 (i.e., *Bonferroni* correction) or groups 1 versus 3 for the same item 8, respectively.

Group 2 students had a significantly ($p<0.017$) higher pre-survey mean rank (25.21) compared to group 3 (mean rank of 16.88) for item 9. However, there were no significant differences found when comparing groups 1 and 2 (i.e., *Bonferroni* correction) or groups 1 and 3 for the same item 9, respectively.

Group 2 students had a significantly ($p<0.017$) higher pre-survey mean rank (19.18) compared to group 1 (mean rank of 11.10) for item 10 (I would encourage my friends, not attending project, to consider courses in aquaculture). However, there were no significant differences found when comparing groups 1 and 3 or groups 2 and 3 for the same item 10, respectively.

Group 2 students had a significantly ($p<0.017$) higher pre-survey mean rank (19.50) compared to group 1 (mean rank of 10.80) for item 12 (I expect to pursue higher education in a STEM-related field). However, there were no significant differences found when comparing groups 1 and 3 or groups 2 and 3 for the same item 12, respectively.

The Kruskal-Wallis test of significance of the *post-intervention survey instrument* comparison also revealed a significant difference ($p<0.05$) among the three student group populations for statements 6 (my participation in the aquaculture project increased my desire to take more course in a STEM-related area) and 10 (I would encourage my friends, not attending project, to consider courses in aquaculture), while there were not significant differences ($p>0.05$) for the remaining ten survey items.

Similarly, since there were significant differences ($p<0.05$) found in the post-intervention survey instrument among groups for items 6 and 10, 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. Additionally, the researchers divided alpha by the number of comparisons, which was three in total. Hence, the statistical significance level for the *Bonferroni* correction was $\alpha=.05/3=0.017$. The final sample size was n=55 (group 2=15; group 3=14; and group 4=26).

Results from the Mann-Whitney mean rank test revealed that there were no significant differences ($p>0.017$) found when comparing groups 1 and 2, groups 1 and 3, and groups 2 and 3 for item 6, respectively. Relating to item 10, group 3 students had a significantly ($p<0.017$) higher post-survey mean rank (24.75) compared to group 1 (mean rank of 14.50) for item 10 (I would encourage my friends (not attending project) to consider courses in aquaculture). However, there were no significant differences found when comparing groups 1 and 2 or groups 2 and 3, respectively, for the same item 10 (**Table 4**).

Table 5 shows descriptive statistics for two mean score factors (STEM related and AQU specific related) items and comparison among the pre-survey responses with respect to gender (n=55), while **Table 6** shows descriptive statistics for two mean score factors (STEM related and AQU specific related) items and comparison among the post-survey responses with respect to gender (n=55).

DISCUSSION

The researchers posited that students' exposure to this intervention will promote positive attitudes toward STEM in general, and aquaculture, as well as 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

Table 5. Descriptive statistics for two mean score factors (STEM related and AQU specific related) items and comparison among the pre-survey responses with respect to gender (n=55)

Dependent variable	Gender	n	Pre-survey mean	Standard deviation
STEM factor items	Male	19	3.31	.721
	Female	36	3.13	.818
AQU factor items	Male	19	2.95	.827
	Female	36	3.15	.791

Note. *t-test analysis showed no significant differences among the two score factor (STEM related and AQU specific related) items with respect to gender in the pre-survey responses

Table 6. Descriptive statistics for two mean score factors (STEM related and AQU specific related) items and comparison among the post-survey responses with respect to gender (n=55)

Dependent variable	Gender	n	Pre-survey mean	Standard deviation
STEM factor items	Male	19	3.17	.708
	Female	36	2.99	.680
AQU factor items	Male	19	3.04	.713
	Female	36	2.82	.838

Note. *t-test analysis showed no significant differences among the two score factor (STEM related and AQU specific related) items with respect to gender in the post-survey responses

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, the researchers utilized this framework as a lens when discussing the outcomes.

All 55 students from the treatment groups who took the interest/attitude survey indicated that they had never taken any aquatic science/aquaculture courses in high school before the project. Hence, they had no exposure to aquaculture in a formal classroom setting prior to the implementation of this study. The results revealed that the intervention contributed to the treatment group students' positive attitudes toward STEM in general, and aquaculture and aquaponics. The present study exemplifies how an authentic, hands-on aquaponics project-based intervention can increase high school level student attitudes toward STEM and developing an interest in STEM disciplines and/or STEM career pursuits. The evidence from this study also suggest that some students developed an interest in aquaculture fields after participating in the project. The next 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

Group 1 revealed positive changes in attitudes and interest from the pre- to post-intervention. Overall, there were positive changes when examining participants' responses from the pre- to post-survey descriptive statistics, and especially in their attitudes toward engineering (12%) and mathematics (20%). Furthermore, results indicate that group 1 students improved their attitudes toward pursuing higher education in a STEM-related field (6.8%) and taking courses in a STEM-related area (5.2%). Likewise, a moderate increase was found (4%) when group 1 were asked about the project influencing their curiosity in technology specifically. This is a positive outcome, particularly since the teacher indicated that a school decision prior to this study resulted in the high-achieving students being pulled to become part of another class section. Thus, students in group 1 were comprised of mixed abilities, comprising average to lower-level students in the population. Subsequently, group 1 possibly had less motivation, lower level of confidence, and moderate-to-low interest in STEM disciplines and/or STEM career pursuits at the beginning of the project in comparison to the other two treatment groups. As mentioned previously, students from each school had different school experiences, daily life experiences, prior knowledge, abilities, teachers, and peer interaction that should be considered when deciphering the results.

Results clearly demonstrate that group 1 had an interest toward engaging with engineering design processes, performing real-world mathematics, and using various authentic tools through their authentic, hands-on project-based aquaculture STEM learning activities in the classroom. Hence, it could be that these tasks may have been more meaningful and interesting to them as opposed to learning about ecological concepts and relationships. It is important to note that this corroborates with the researchers' field visits, as it was noticed that group 1 students appeared to enjoy the responsibility of calculating growth performance of living organisms within their closed recirculating system (i.e., applied mathematics). Students from this population displayed their weekly calculations on a whiteboard in the classroom. In addition, group 1 were extremely focused on maintaining the aquaponics system throughout the project to ensure that it was running properly (i.e., engineering design). It is important to note that the teacher placed much emphasis on this task.

Group 2 Students

When interpreting the results, data reveals that group 2 students showed an interest in STEM disciplines, and aquaculture, with expectations to pursue higher education in a STEM-related field *before* they participated in the intervention. This is based on the descriptive statistics in the pre-intervention survey and analysis of the survey results and from the comparison across groups. Results indicated that group 2 students had numerically higher mean scores in eleven out of the twelve items within the survey instrument in comparison to the other two treatment groups.

Cetin (2003) stated that in a constructivist perspective, students enter the classroom with their own ideas and experiences; they shape their formal knowledge based on their existing ideas and experiences at school. Unfortunately, it is not known whether group 2 students had any agricultural experiences outside of school prior to this study, nor specifically in aquaculture and aquaponics. However, agriculture is well represented in the district where the school in located. Thus, it is likely students had agriculture experiences prior to participating in the project. Therefore, incorporating questions comprised either in the survey instrument assessment and/or detailed interview(s) at the beginning of the project about their agricultural experiences outside of school prior to the study could have helped explain the outcomes in the present study. Hence, this may be explored for future research when implementing a similar APBI intervention as the present study.

It is important to note that group 2 students were described as highly motivated students by their teacher and aspired to gain college credit at the end of the course prior to commencement of the project. Thus, these students may have been more confident and motivated in STEM and aquaculture at the beginning of the project and this explains why group 2 students from a rural school setting had higher intensity Likert scale responses and higher pretest content score compared to all other groups. One possible explanation for these findings may be that group 2 students had already chosen to enroll in an AP environmental science class for their 9th grade science credit. An assumption would be that students selecting environmental education for AP science would have prior knowledge of the topic, interest in pursuing higher education and a belief in one's ability to attain this goal (i.e., self-efficacy), and they may have had a higher level of confidence in their abilities to perform the aqua-STEM-related tasks/activities *prior* to participating in the project.

Interestingly, when examining the descriptive statistics between the pre-and post-survey intervention responses, group 2 students did show a negative change or "loss" in their interest in aquaculture as a profession (item 1) and aspirations to pursue higher education in a STEM-related field (item 12). However, when comparing the other two treatment groups' posttest survey mean scores, they had comparable interest with group 2 students in those two areas. However, when making comparisons across the three groups' mean *post-test survey responses*, results revealed no significant differences in student attitudes toward STEM, aquaculture, and interest in STEM disciplines and/or STEM career pursuits.

Results demonstrate that group 2's attitudes toward, and interest in, STEM and aquaculture numerically decreased after exposure to the intervention. However, while group 2 did demonstrate a lower interest in aquaculture and aspirations to pursue higher education in STEM-related fields after experiencing the APBI intervention, it is worth noting that the interest was not statistically significantly different from the other two treatment groups, and particularly group 3, who also demonstrated a high interest. It could be that students in group 2 were excited and more confident about an ecological project, but with limited to no experience with aquaculture and aquaponics, specifically, they may have developed a more realistic view of aquaculture because of the project. Thus, it could be that group 2 became less interested in aquaculture/aquaponics over time.

Group 3 Students

Results of the present study demonstrate that group 3 seemed to value the field of aquaculture and STEM-related disciplines. Overall, there were positive changes when examining participants' responses from the pre- to post-survey descriptive statistics in their aspirations to pursue future opportunities to study aquaculture subjects and advanced credit (12.4%), encouraging their friends to consider courses in aquaculture (12.4%), considering aquaculture as a highly interesting profession (7.8%), and willing to take courses in aquaculture specifically (5.4%) in the short-term. Furthermore, results indicate that group 3 students improved their attitudes toward taking more courses in a STEM-related area (6.8%) and developed an increase in desire to work with people who make discoveries in science (6.2%). Clearly, an increase enrollment in STEM courses while in high school is an important outcome to help develop students' mathematics and science skills. The researchers do assert that the agriculture industries in the school district could have accounted for some of the interest in students.

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 student attitudes toward STEM and developing an interest in STEM disciplines and/or STEM career pursuits. The evidence from this study also suggest that some students developed an interest in aquaculture fields after participating in the project.

Author contributions: All authors have sufficiently contributed to the study and agreed with the results and conclusions.

Funding: This study was supported by the USDA National Institute of Food and Agriculture 1890 Capacity Building Program, award #2017-38821-26442.

Acknowledgements: The authors would like to thank Bailey Vandiver for editing the manuscript. The authors also thank Dr. Tierra M. Freeman Taylor for providing guidance with the statistical analysis of Tables 5 and 6 specifically.

Ethical statement: The researchers sought permission from the University (i.e., Kentucky State University and University of Kentucky Alliance Agreement) Institutional Review Board (IRB), consent was obtained from students' parents or legal guardian, and assent was obtained from the students themselves.

Declaration of interest: No conflict of interest is declared by authors.

Data sharing statement: Data supporting the findings and conclusions are available upon request from the corresponding author.

REFERENCES

Aron, A., Aron, E. N., & Coups, E. J. (2005). *Statistics for the behavioral and social sciences: A brief course*. Prentice Hall.

Bloodhart, B., Balgopal, M. M., Casper, A. M. A., Sample McMeeking, L. B., & Fischer, E. V. (2020). Outperforming yet undervalued: Undergraduate women in STEM. PLOS One. https://doi.org/10.1371/journal.pone.0234685

Cetin, G. (2003). *The effect of conceptual change instruction on understanding of ecology concepts* [PhD thesis, Middle East Technical University].

Clark, Q. M., Knobloch, N. A., Esters, L. T., & Brown, B. R. (2021). Broadening participation in agricultural sciences through STEM intervention program. *Journal of Agricultural Education, 62*(2), 27-38. https://doi.org/10.5032/jae.2021.02027

FAO. (2016). *The state of world fisheries and aquaculture 2016*. Food and Agriculture Organization of the United Nations.

Genello, L. Fry, J. P., Frederick, J. A., Li, X., & Love, D. C. (2015). Fish in the classroom: A survey of the use of aquaponics in education. *European Journal of Health and Biology Education, 4*(2), 9-20. https://doi.org/10.20897/lectito.201502

Nardi, P. M., (2014). *Doing survey research*. *A guide to quantitative methods*. Paradigm Publishers. https://doi.org/10.4324/9781315172231

NCES. (2012). STEM in post-secondary education: Entrance, attrition, and course taking among 2003-2004 beginning postsecondary students. *National Center for Educational Statistics*. https://nces.ed.gov/pubs2013/2013152.pdf

Stake, R. E., (2005). Qualitative case studies. In N. K. Denzin, & Y. S. Lincoln (Eds.), *Handbook of qualitative research* (pp. 443-466). SAGE.