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Use of a project-based aquaponics curriculum in rural Kentucky school districts increases secondary students' understanding of ecosystems

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ABSTRACT

There is a need for secondary schools to provide more authentic, hands-on experiences in science, technology, engineering, and mathematics (STEM) and, specifically, project-based investigation environments in the classroom that manifest the next generation science standards (NGSS) 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' understanding of standard-based ecological relationships and concepts concerning interactions in ecosystems and, specifically, the phenomena carrying capacity and bacterial nitrification process. Using a quantitative method, quasi-experimental research design, three different student groups who participated in the authentic, hands-on APBI curriculum (i.e., treatment groups) and a control group were given a pre- and post-content-aligned test (n=88), which measured changes in students' ecological knowledge. The results in this study revealed that the curriculum was an effective method to provide meaningful learning and content understanding of standard-based ecological concepts and relationships. The evidence from this study suggests that authentic instructional experiences can facilitate students' understanding of standard-based ecological concepts and knowledge of ecosystems, as the three treatment group students showed statistically significantly higher mean difference (improvement) sum scores after taking the pre- and post-content-aligned assessment when compared to the control group. Overall, the gain in understanding can be attributed to the project-enhanced unit implemented in this study. The implications of this study suggest APBI models may create authentic science learning environments that promote student learning of scientific concepts. In addition, APBI can offer engaging curricula that articulates NGSS.

Keywords: STEM, project-based, secondary schools, ecosystems, understanding, aquaponics

INTRODUCTION

Research suggests that aquaculture is an effective teaching tool because it easily integrates many disciplines including biology, chemistry, economics, math, physics, and provides hands-on experiences for students (Conroy & Walker, 2000; El-Ghamrini, 1996; Wingenbach & Gartin, 2000). Similarly, aquaponics, a combination of aquaculture and hydroponics, also utilizes these same disciplines. Hart et al. (2013) stated that aquaponics education provides a practical, hands-on way to get students in touch with basic science, technology, engineering, and mathematics (STEM) concepts due to its interdisciplinary nature.

Currently, there is a lack of documented research on helping to better understand how integrating an aquaculture/aquaponics-based, project-based investigation (PBI) during a short-term curricular unit in the science classroom can foster students' knowledge and skills in STEM. While much literature has touted the benefits of contextualized science instruction to improve learning, few studies have explored using aquaponics project-based investigation (APBI) in the science classroom. Schneller et al. (2015) stated that future research should assess outcomes when the technology and curriculum relating to aquaponics is implemented in a public primary school with different social and administrative climates and those that require greater adherence to common core state standards and the next generation science standards (NGSS). Hart et al. (2013) suggested that documenting the actual use of aquaponics, as a teaching and learning tool will be critical for the expansion of aquaponics in education and the development of appropriate aquaponics-based curricula. The present study assessed student learning outcomes and the benefits of implementing aquaponics education in three different public high school classrooms. The curriculum design and findings may also provide new insights and ideas on how to incorporate and use contextualized aquaponics instruction as a teaching and learning tool and, thereby, develop appropriate curricula for secondary K-12 classrooms.

The present project was designed using a PBI model that is well documented in the literature (Krajcik & Blumenfeld 2006; Polman, 2000; Singer et al., 2000; Wilhelm & Confrey 2005; Wilhelm et al., 2008). The high school curriculum was designed to increase students' understanding of ecological relationships and concepts regarding interactions and processes in ecosystems; namely, the limiting interdependent factors that affect *carrying capacity* of ecosystems. Overall, learning goals were to provide students with real-world research engagement experiences that were practical and aligned with project-based science learning environments in the classroom while exposing them to the following: developing and using models related to their recirculating aquaculture system; defining problems and designing solutions for engineering their closed recirculating system; planning and carrying out investigations related to the phenomenon *carrying capacity* and learning about the biotic and abiotic interactions in ecosystems; monitoring the nitrogen cycle and water quality aspects; using real-life mathematics application such as investigating growth performance of fish, plants, and feed efficiency; analyzing and interpreting quantitative and qualitative data; making charts and graphs; collaborating with their peers (i.e., rotating jobs); and acquiring skills and techniques needed to operate aquaculture STEM research instruments commonly used by real-world scientists (Rickinson et al., 2004).

Carrying capacity is the central concept of NGSS life science core idea ecosystems: interactions, energy, and dynamics (NGSS Lead States, 2013), henceforth referred to as the c*ore idea of ecosystems*. The unit addresses ecosystem performance expectations HS-LS2-1 through HS-LS2-4 and HS-LS2-6. One goal of the study was to ensure that students participating in the curriculum would have a better understanding of the needs of living things, including plants, fish, and bacteria (i.e., biotic factors), and how these species depend on each other and form a close symbiotic interdependent relationship within the ecosystem. Further, students were provided opportunities to measure many "non-living" parts in the ecosystem including water temperature, dissolved oxygen, alkalinity, ammonia, nitrite, nitrate, and pH (i.e., abiotic factors). Consequently, students learned the interactions between biotic and abiotic factors, the concept of reaching carrying capacity, and an understanding of the limiting factors because of their direct experiences in the curriculum. The underlying question examined in the present study was, "what is the effectiveness of using a *real-life context of aquaculture* (aquaponics) to bridge students' understanding of ecological relationships and concepts (via carrying capacity and the nitrogen cycle)?"

Purpose and Objectives

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

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

The objective of this study was to address the following research question:

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

METHODS

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

The selection process for student participants was nonrandom (e.g., conveniently selected). Since the students in this study were not randomly assigned, the present study is a *quasi-experiment*. The present study used naturally formed student groups who met in four 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 curriculum (i.e., treatment groups) and one independent variable student group that did not engage in the APBI curriculum (i.e., control group).

Table 1. Demographic data from participating students in project who completed pre- & post-content assessment (i.e., population studied)

Student groups	School setting	School level	Ethnicity & number of students	Gender & number of students	Economically disadvantaged
Group 1: Control & teacher A	Rural	High school	14 White & 17 underrepresented & *n*=31	15 male & 16 female & *n*=31	67.3%
Group 2: Treatment teacher B	Rural	High school	11 White & 19 underrepresented & *n*=20	11 male & nine female & *n*=20	64.4%
Group 3: Treatment & teacher C	Rural	High school	14 White & one underrepresented & *n*=15	Six male & nine female & *n*=15	63.0%
Group 4: Treatment & teacher D	Rural	High school	17 White & five underrepresented & *n*=22	Two male & 20 female & *n*=22	73.0%

Table 2. Illustration of different student population groups in study

	Group 1	Group 2	Group 3	Group 4
Grade levels	Grade 10	Grade 10	Grade 9	Grade 9
Class time[a]	55-60	61	54	45
Class period	MWF 8:30-9:30; T/R 8:30-9:25	11:15-12:16	12:22-1:16	12:47-1:32
Course	General biology	General biology	AP environmental science	General biology

Note. [a]Classes met daily

The students in this study were ninth and tenth graders from four different Kentucky public high schools; they were not from the same school district. There were three different classrooms that represented the treatment groups (group 2, group 3, and group 4) and these students participated in the ten-week APBI unit in their science classrooms. The APBI curriculum was part of their science classroom instruction and all students participated. The study also employed an outside control group of students (group 1) who had no exposure to APBI curriculum. The selection process for participants in this study was nonrandom (i.e., conveniently selected) and the researchers used naturally intact classroom groups.

Actual Number of Students Participating in the Study

The researchers included only those groups of students in the population who took the pre- and post-assessments and completed the parent consent and student assent forms; they represent the total number in the study. There were 88 students who completed the pre-and post-content-aligned assessment, which included the three treatment groups and the control group.

Students' Demographics

Regarding overall ethnicity and gender, the *student population studied* who completed the pre-and-post-content-aligned assessment (*n*=88) included: a combination of White (47.7%), African American (15.9%), mixed ethnicity (15.9%), and other (20.5%). In addition, all students attend a rural school in the mid-south region of the United States and mostly come from low socioeconomic backgrounds. Further, there was a relatively high number of females (61.4%) compared to males (38.6%) within all four student groups (includes the control group). Summary of the student study demographic population who *completed* the pre- and-post-content assessment (**Table 1**) and classroom schedule (**Table 2**) are provided.

Content-Aligned Assessment

An original content-aligned pre- and post-assessment instrument was developed for this study in July 2019 by the researchers and participating biology teachers to measure changes in students' understanding of the target concepts and ensure that it connected to the standard-based concepts addressed in the unit. It is important to note that all four student groups (including the control group; *n*=88) completed the content test. The focus of the assessment is the concepts that can be learned through participating in an aquaponics project based on current NGGS standards, while some of the cognitive tasks are specific to aquatic ecosystems. The goal is that these tasks may reveal growth in learning (i.e., evidence of a change in scores by individual) between the pre- and post-assessments. However, it is important to note that the assessment was created to be applicable to *all* students, whether they completed the aquaponics project.

Likewise, three different scorers assessed student responses independently to establish interrater reliability. This study determined if interrater reliability was established at 90.0% or better between scores as described by Rivet and Krajcik (2008). Results indicate that the percentage of agreement between the three scorers in this study was 92.6%.

Overview of Data Collection

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. All the participants who completed the consent and assent forms were asked to volunteer in the study and complete the pre- and post-content assessments. It should be noted that every participant was made aware that although they and their parents or legal guardian had consented to the study, they still had the right to discontinue at any time.

Quantitative Data Analysis

The researchers sought to find whether there was a statistically significant difference between the pre- and the post-content scores. To address this objective, the researchers used a paired-samples *t*-test (within subject design) on the pre-and post-content test scores. The paired-samples *t*-test

Table 3. Paired-samples *t*-test comparison between pre- & post-test scores with respect to all four student group populations

	Paired differences			
	Mean	Standard deviation	df	p^a
Post-/pre-test score	13.52	13.41	87	.000

Note. $^a p<0.05$ (significant difference) & df: Degree of freedom

Table 4. Shapiro-Wilk test of normality for differences between pre- & post-content scores with respect to all four student groups

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

Note. [a]SW value: Shapiro-Wilk statistic; df: Degree of freedom; *$p<0.05$ (significant difference); Skewness=.561; & Kurtosis=-.662

was used to compare the pre-test to the post-test scores across *all 88 participants* (subjects) in the study by means of the statistical analysis software SPSS (version 22). There were two measurements from the same individual (subject) at different times in the curriculum, which eliminated the error of it being a different person or between subjects. A *t*-test formula is designed to assess the difference in means while considering the connection or correlation between the two measures (i.e., paired samples *t*-test). Likewise, *t*-test is a statistical technique commonly used to compare the means of two populations when the sample size is small like this study. Comparable methods were performed by Marx et al. (2004) and Rivet and Krajcik (2008) as *t*-test analyses was conducted to compare their pre- and post-test results in terms of overall improvement and gains for each of the science learning goals of the project.

Results of the paired-samples *t*-test showed that there was a statistically significant difference between the pre- and post-content test scores across *all 88 participants* among the four student group populations. It is important to note that these results do not make comparisons or show which student groups had better improvement in scores. An overview of the results is provided in **Table 3**.

The one assumption underpinning the paired-samples *t*-test was that the differences between the mean scores are normally distributed (Aron et al., 2005). Hence, prior to *t*-test analysis, the researchers sought to find whether the data was normally distributed. To test this assumption, the researchers employed the Shapiro-Wilk test, which is suited for sample sizes like the present study (n=88). The Shapiro-Wilk test is a numerical means of assessing normality. Results showed that the data was statistically significantly different from a normal distribution. Results revealed a skewness of .561 and kurtosis of negative .662 indicating that the difference (improvement) data did not have a normal distribution. An overview of the results is provided in **Table 4**.

In addition, to test the assumption of equal variances of the dependent variable, the researchers employed the Levene's test for homogeneity of variances. Levene's test is an inferential statistic used to assess the equality of variances for a variable calculated for two or more groups. The researchers did not want to automatically assume that variances of the populations were equal, so Levene's test was employed to assess this assumption. Results indicated that the assumption

Table 5. Levene's test for homogeneity of variance with respect to all four student groups

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

Note. [a](df_1, df_2)=(3, 84) & *$p<0.05$ (significant difference)

of homogeneity of variance were not met, as the error variance of the dependent variable is not equal across groups. An overview of the results is provided in **Table 5**.

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

(a) 1 vs. 2,

(b) 1 vs. 3,

(c) 1 vs. 4,

(d) 2 vs. 3,

(e) 2 vs. 4, and

(f) 3 vs. 4, respectively.

Objective of this test was to see if mean difference (improvement) between student groups was significantly different or not.

QUANTITATIVE RESULTS

The study examined the "raw" pre- and post-test content sum mean scores and 60 being the total possible points. Results revealed that group 3 students had numerically the highest average *pre-test sum score* (12.13) compared to the other three groups. Group 1 students had numerically the second highest average pre-test sum score (6.19), while group 4 (5.31) and group 2 (4.35) were numerically the lowest at the beginning of the authentic, hands-on PBI curriculum (unit). A summary of the descriptive statistics when comparing between the four student groups of the *pre-test content mean scores* are provided in **Table 6** and **Table 7**.

Group 2 students had numerically the lowest pre-test mean content score (4.35; 7.3% total score) compared to the other three groups and numerically the second lowest post-test mean content score (16.30) when tested on specifically ecological concepts and relationships that were taught in the classroom by their teacher.

Table 6. Descriptive statistics for pre-test content sum score comparison with respect to four student groups

	Dependent variable: Pre-test score		
	Mean	Standard deviation	*n*
Group 1 students (control)	6.19	7.30	31
Group 2 students	4.35	4.14	20
Group 3 students	12.13	5.79	15
Group 4 students	5.31	4.38	22
Total	6.57	6.35	88

Table 7. Descriptive statistics for pre-test content sum score comparison with respect to four student groups (control)

	Standard error	95% confidence interval	
		Lower level	Upper level
Group 1 students (control)	1.31	3.51	8.87
Group 2 students	0.93	2.41	6.29
Group 3 students	1.50	8.93	15.34
Group 4 students	0.93	.3.38	7.26

Table 8. Descriptive statistics for post-test content sum score comparison with respect to four student groups

	Dependent variable: Post-test score		
	Mean	Standard deviation	*n*
Group 1 students (control)	9.32	7.39	31
Group 2 students	16.30	11.38	20
Group 3 students	22.20	7.70	15
Group 4 students	37.27	5.82	22
Total	20.09	13.56	88

Likewise, group 2 students mean difference (improvement) sum content score (11.95; 20.0% total score) were significantly lower compared to group 4 students (31.95; 53.3% total score). However, group 2 students mean difference (improvement) sum scores were statistically like group 3 (10.07; 16.8% total score) and significantly higher than group 1 students (3.13; 5.2% total score).

Results revealed that group 4 students had numerically the highest average *post-test sum score* (37.27) compared to the other three groups. Group 3 students had numerically the second highest average post-test sum score (22.20), while group 2 students were slightly lower (16.30), and the control group students had numerically the lowest (9.32) average post-test sum score. A summary of the descriptive statistics when comparing between the four student groups of the *post-test content mean scores* are provided in **Table 8** and **Table 9**.

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

A summary of the descriptive statistics (which includes the mean, standard deviation, number of participants who took the pre- and post-assessment, standard error, and lower and upper bound for overall difference (improvement) sum score comparison with respect to the four student groups) are presented in **Table 10** and **Table 11**.

Table 9. Descriptive statistics for post-test content sum score comparison with respect to four student groups (control)

	Standard error	95% confidence interval	
		Lower level	Upper level
Group 1 students (control)	1.33	6.61	12.03
Group 2 students	2.50	11.07	21.53
Group 3 students	1.99	17.94	26.47
Group 4 students	1.24	34.69	39.86

Table 10. Descriptive statistics for overall mean difference (improvement) sum score comparison with respect to four student groups

	Dependent variable: Difference		
	Mean	Standard deviation	*n*
Group 1 students (control)	3.13	6.05	31
Group 2 students	11.95	9.57	20
Group 3 students	10.07	7.61	15
Group 4 students	31.95	6.72	22
Total	13.52	13.41	88

Table 11. Descriptive statistics for overall mean difference (improvement) sum score comparison with respect to four student groups (control)

	Standard error	95% confidence interval	
		Lower level	Upper level
Group 1 students (control)	1.33	0.49	5.77
Group 2 students	1.65	8.66	15.24
Group 3 students	1.91	6.27	13.87
Group 4 students	1.57	28.82	35.09

Likewise, a profile plot visual representation showing the estimated marginal means of difference (improvement) of each school is provided in **Figure 1**.

For comparative analysis (between subject design), the researchers sought to find if there was a difference statistically between the four student group populations. We looked at the *mean difference (improvement)* sum scores between all groups (n=88) after participants took the pre-and post-content assessment and data was analyzed by means of SPSS.

To address this objective, instead of using an independent samples t-test, a corresponding non-parametric statistic (*Mann-Whitney U test* and a series of mean rank tests) were used to test whether the mean difference (improvement) sum scores between student groups were significantly different or not. A *Mann-Whitney U test* statistic was selected since the assumptions of normal distribution and equal variances of the dependent variable across groups were not met. This procedure compared two populations (student groups) at a time, which provided mean ranks for each, with a *Bonferroni* correction to control for type 1 errors. Alpha was divided by the number of comparisons, which was six in total. The statistical significance level for the total comparison and then divided across the six comparisons (via *Bonferroni* correction) was α=0.05/6=0.008.

Results from this study revealed a statistically significant difference (p<0.008) when comparing between group 1 students (mean rank of 20.34) and group 2 students (mean rank

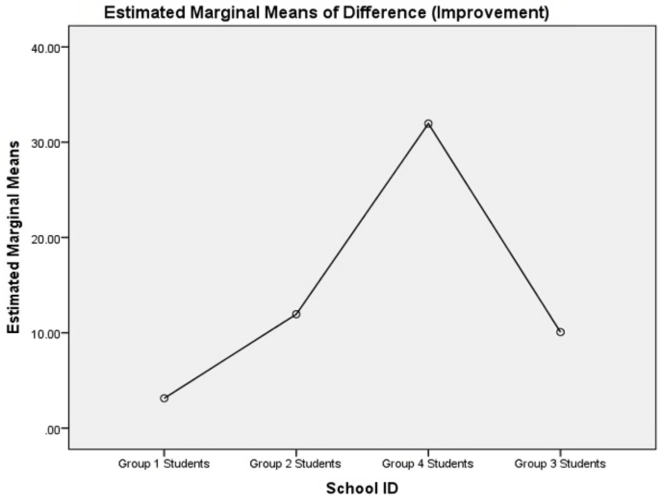

Figure 1. Means of difference (improvement) across four groups (Source: Authors' own elaboration, using IBM SPSS Statistics 22)

Table 12. Mann-Whitney rank test of mean difference (improvement) between pre- & post-content scores with respect to four student groups (*n*=88)

SID	Two population	Dependent variable: Difference		
		Mean rank	MW-test statistic[a]	Sig.[b]
Group 1	Group 1	20.34	134.50	.001
	Group 2	34.78		
Group 1	Group 1	19.39	105.00	.003
	Group 3	32.00		
Group 1	Group 1	16.00	0.00	.001
	Group 4	42.50		
Group 2	Group 2	18.40	142.00	.805
	Group 3	17.47		
Group 2	Group 2	11.23	14.50	.001
	Group 4	30.84		
Group 3	Group 3	8.13	2.00	.001
	Group 4	26.41		

Note. [a]*Mann-Whitney U test* statistic & [b]Mean difference is significant at 0.008 level

of 34.78) (p=0.001 statistical significance); group 1 students (mean rank of 19.39) and group 3 students (mean rank of 32.0) (p=0.003 statistical significance); and group 1 students (mean rank of 16.0) and group 4 students (mean rank of 42.5) (p=0.001 statistical significance), respectively. These results demonstrate that the control group students (group 1) had significantly (p<0.008) lower mean difference (improvement) scores compared to all other student group populations.

Likewise, results demonstrate that there was a statistically significant difference (p<0.008) when comparing between group 2 students (mean rank of 11.23) and group 4 students (mean rank of 30.84) (p=0.001 statistical significance); and with group 3 students (mean rank of 8.13) and group 4 students (mean rank of 26.41) (p=0.001 statistical significance), respectively. These results demonstrate that group 4 students had a significantly higher mean difference (improvement) score compared to all other student groups. However, no statistically significant differences (P>0.008) were found when comparing between group 2 students (mean rank of 18.40) and group 3 students (mean rank of 17.47) (p=0.805 statistical significance), respectively.

These data reveal that group 4 students had a significantly higher (p<0.008) mean difference (improvement) score when compared to all other groups. Hence, data suggests that students from this population (group 4) had the highest knowledge increase between the pre-and post-content assessment.

Likewise, student populations from (group 2 and group 3 were similar statistically) with respect to mean difference (improvement) scores. However, students' knowledge improved in all three treatment groups and was significantly (p .008) higher compared to the control group (group 1). Clearly, this is a positive outcome in the present study (**Table 12**).

DISCUSSION

We postulated, and were confirmed by the present data, that a classroom rich in authentic, hands-on project-based instructional experiences will help participants gain a deeper conceptual understanding of ecosystem processes and their interactions. This agrees with Cetin's (2003) assertion that to provide conceptual change and meaningful learning of science concepts, there is a need for using effective techniques for overcoming those misconceptions in science. The present study was guided by a situated learning theoretical framework, which encompasses a constructivist theoretical framework, but specifically integrates the environmental factors present in the space, where the study occurred (e.g., teacher's instructional styles, class environments, and student demographics). Thus, the researchers utilized this framework as a lens when discussing the outcomes.

Group 2 Students

Overall, the fact that high-achieving students at this school were separated into another science class prior to the project may have been an important factor to explain the outcomes. However, group 2 students' content scores after completing the project were similar statistically to group 3 students who chose to take AP environmental science and significantly higher than the students from the control group curriculum. Possible next steps for future research may include the need to address and concentrate on lower-level students and compare their learning outcomes with more advanced students who experience the same authentic instructional curriculum.

Group 2 students mean pre-test content score (4.35) and mean post-test content score (16.30) demonstrates a positive growth pattern and compared favorably with group 3 even with the marked differences in the two groups as group 2 were more representative of average to slightly below average achievers in science.

Group 3 Students

Group 3 students had a numerically higher mean pre-test content score (12.13; 20.2% total score) and significantly higher pre-test mean rank content scores when utilizing the Mann-Whitney comparison test across the three treatment groups. As this class was AP environmental science, it may be that these students had previous knowledge in the subject matter. The classroom teacher described these students as highly motivated 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.

Additionally, results demonstrated that group 3 mean difference (improvement) content scores and post-test content mean rank scores were numerically and significantly lower when compared to group 4 students, but similar to group 2 students, which may indicate that the groups pre-test score accurately estimated student's desire to learn the subject matter.

Group 4 Students

Group 4 students had a statistically significantly higher mean difference (improvement) sum score (31.95; 53.3% total score) and significantly, higher post-test mean rank content scores compared to all other treatment groups. Group 4 students were described as motivated learners by their teacher.

When explaining these findings, it may be worth noting that most of group 4's students were female. Specifically, there were 20 females and two males who took the pre- and post-content assessment. In contrast, group 2 students had 11 males and nine females who took the pre- and post-content assessment. Likewise, group 3 students had nine females and six males who took the pre- and post-content assessment. Further, the control group (group 1 students) had approximately the same number of males (15) and females (16) who took the pre- and post-content assessment. Thus, group 4 student population had a much higher female: male ratio when compared to all other groups in this study. The teacher expressed from her observations that the females were more diligent than the males, and this may be one possible factor to consider when explaining the results. As the data were not analyzed by gender, possible differences based upon gender should be investigated in the future.

The teacher indicated that group 4 students who participated in the project *loved the real-world science opportunities* given through the aquaponics unit. Therefore, it could be that group 4 students were more interested and confident in learning about science, and subsequently, the ecological concepts and relationships, when studying a "living" aquaponics ecosystem when compared to all other groups. Further, group 4 students asked thoughtful questions, interacted well with their peers, and seemed to be very attentive and interested in the ecological project. In addition, the researcher noticed that teacher D (group 4) supported her students to ask questions and come to their own conclusions and appeared to have an innate skill to keep students engaged throughout the class period. Group 4 had a larger number of participants who completed the curriculum in the classroom (26 total) with less class time each day (45 minutes), compared to the number of participants in group 2 (20 total), who had 61 minutes of daily class time, and to the number of participants in group 3 (15), who had 54 minutes of daily class time. It could be that teacher D had to be more efficient teaching the content and facilitating the APBI curriculum due to these challenges. Furthermore, the senior researcher observed in the classroom that teacher D (group 4) implemented more of a constructivist teaching approach when compared to the other two teachers. She allowed wait time when asking questions in class, encouraged students when working in groups to interact with each other, her, asked thoughtful, and open-ended questions, encouraged students to reflect on their experiences, and asked students to articulate their ideas about ecological concepts before she presented her understanding of the concepts. This was evident each time the researcher visited group 4 students' classroom.

Overall, group 4 teacher had an engaged and exciting class and implemented student-centered strategies.

CONCLUSIONS

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

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