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School gardening with a twist using fish: Encouraging educators to adopt aquaponics in the classroom

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ABSTRACT
To evaluate the willingness of teachers to incorporate aquaponics in the classroom, we engaged teachers in a 6-week project. Participants in the experimental group maintained small-scale aquaponic systems. All teachers completed pretests and posttests, and exit surveys. Both groups (experimental and control) scored significantly higher on the posttest, but there was no significant score difference between groups. In the exit surveys, participants from the experimental group expressed a greater likelihood to use an aquaponic system at home or in the classroom, believed the system was easy to maintain, and strongly agreed it would help students with math and science.

Introduction

During the past two decades, school gardens have emerged as valuable sites for experiential learning at elementary, middle, and high schools throughout the United States (Graham, Beall, Lussier, McLaughlin, & Zidenberg-Cherr, 2005; Skelly & Bradley, 2000; Williams & Dixon, 2013). As fun and engaging hands-on projects, school gardens provide an effective, low-cost means of facilitating experiential learning through exploration, synthesis, and application of scientific principles to solve new problems (Andreasen, 2004; Kolb, 1984; Williams & Brown, 2013). In addition, garden projects may help instill responsibility toward long-term goals, pride in physical work, and leadership skills (Williams & Dixon, 2013). Further, school gardens often provide urban students with their first exposure to agriculture and an appreciation for fresh food (Louv, 2008). The experience encourages engagement with broader food-system issues including ecological sustainability and urban hunger.

Recently, interest has grown in applying aquaponic gardening as a teaching tool (Hart, Webb, Hollingsworth, & Danylchuk, 2014). Developed following ancient

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farming techniques (e.g., Aztec *chinampas* 1150–1350 BC), modern aquaponics integrates fish farming (aquaculture) and hydroponic crop production through recirculation of water (Bernstein, 2011; Lewis, Yopp, Schramm, & Brandenburg, 1978; Naegel, 1977; Rakocy, Masser. & Losordo, 2006). Water containing nutrient-rich fish waste fertilizes plants, and by removing nutrients the plants provide clean water recycled to the fish tank (Buzby & Lin, 2014). The integrated system eliminates agricultural runoff, conserves water through treatment and recirculation, and conserves space through higher crop yields per unit area (Rakocy et al., 2006; Shafeena, 2016). Aquaponics is particularly well-suited to urban areas, especially where uncontaminated fertile soil is scarce (Orsini, Kahane, Nono-Womdim, & Gianquinto, 2013).

The first time students encounter an aquaponic system, they are often full of questions: "How do plants grow without soil?" and "What are the fish doing?" As a model for agronomic and aquatic systems, aquaponic systems encourage curiosity, critical thinking, and creativity while affording opportunities for experiential learning in ecology, biology, chemistry, mathematics, and agriculture (Hart et al., 2014; Wardlow, Johnson, Mueller, & Hilgenberg, 2002). Despite these benefits, teachers may hesitate to incorporate aquaponics in their lesson plans because of a lack of requisite knowledge and impressions that aquaponic systems are complex, costly, and difficult to maintain (Hart, Webb, & Danylchuk, 2013). Indeed, successful implementation of an aquaponics project requires planning, technical understanding, cooperation, and commitment; and these challenges should not be understated (Hart et al., 2013). Therefore, there is a need for teachers to gain familiarity with aquaponics if they are to feel confident in proposing and implementing aquaponics projects at their schools.

We engaged 14 teachers in a 6-week aquaponic project that included introduction to key principles and first-hand experience with design, construction, and maintenance of small aquaponic systems, to gauge educators' responses in terms of knowledge gains and changes in attitude toward incorporating aquaponics in the classroom or at the school garden. Our study provides a framework for teacher training, implementation of a low-cost classroom-scale aquaponic system, and an exemplar of lab exercise that encourages STEAM (Science, Technology, Engineering, Art, and Math) education and the claims-evidence-reasoning (CER) discussion framework (Zembal-Saul, MacNeill, & Hershberger, 2013). The objectives of this 6-week project were to examine the educators' content development and understanding, interest, and motivation in establishing aquaponic systems in educational settings.

Methods

Study sites

Fourteen participants convened at a central location in Cutler Bay, Florida (25.5864, −80.3347). Seven participants maintained an aquaponic system at their place of residence for the duration of the project.

Participants

Alpha Delta Kappa (ADK) is an international honorary organization of women educators dedicated to educational excellence, altruism, and world understanding (ADK, 2015). Fourteen active members in the ADK International Honorary Organization (local Miami-Dade Alpha Lambda chapter) participated in the 6-week aquaponic project.

Experimental protocol

Participants were administered an aquaponics content pretest to record prior knowledge about aquaponics systems, gardening, sustainability, and water conservation. As participants completed the pretest, the instructor randomly distributed numbered (1 or 2) data collection notepads. Participants recorded the number on their pretest before pretests were collected. Seven participants (assigned no. 1 notepads) were placed in the experimental group; the other seven participants (assigned no. 2 notepads) were placed in the control group. Participants were not informed whether they were in the experimental or control group.

After pretests were collected, an interactive PowerPoint® lecture (30 min) was presented to all participants. The lecture covered information on aquaponic systems, solar power, sustainability, urban gardening, and water conservation. Afterward, participants designed a model aquaponic system indoors before assembling an actual aquaponic system outdoors. They were divided into groups and assigned different tasks: (a) obtain fish from the lake, (b) gather edible plants from a prepared garden bed on site, (c) assemble the components of the aquaponic system, and (d) piece together the solar panels and battery to power the water pump. Upon completion, the instructor and participants concluded with a group discussion and reviewed the aquaponic system activity. The following day, half of the participants (those who received specially marked no.1 notepads, the experimental group) were invited back at a later date to construct an aquaponic system to be maintained at their place of residence.

The experimental group worked together to construct and assemble their personal aquaponic systems (95 L; Fig. 1). Each teacher was required to conduct a scientific experiment using the CER Framework (Zembal-Saul et al., 2013) by investigating the effects of varied fish feed on plant height (stem elongation). Participants were divided into three groups and assigned a feeding schedule that varied the amount of fish feed for the experiment (Al-Hafedh, Alam, & Beltagi, 2008; Medina, Jayachandran, Bhat, & Deoraj, 2016). Each teacher was assigned 10 juvenile fish (*Herichthys cyanoguttatus*) purchased from an ornamental fish farm in Miami. They also received eight edible plants (four were red amaranth plants [*Amaranthus tricolor*] used in the study) grown from seed at the Florida International University greenhouse. Each group fed their fish once a day in the evening. Group one (two participants, n = eight plants) administered 1/8 ounce of feed, group two (three participants, $n = 12$ plants) administered 1/4 ounce of feed, and group three (two participants, n = eight plants) administered 3/8 ounce of feed

Figure 1. Finished aquaponic system constructed by the participants in the experimental group.

during the experiment. Participants measured temperature and only red amaranth stem elongation (in cm) every Friday for 4 weeks.

After the fourth week, participants reported their data to the instructor via e-mail. All participants (experimental and control group) reconvened for the final meeting. First, all participants were administered an aquaponics content posttest and an exit survey. Then, the instructor provided data collected by the experimental group and led an interactive workshop demonstrating data analysis techniques using Excel appropriate for late elementary and middle school classes.

Aquaponic system supplies and design

Constructing an aquaponic system requires more imagination and creativity than materials specific for the actual system. Most components can be recycled materials used for other purposes such as storage containers and PVC pipes. During the first meeting, all participants assembled a demo aquaponic system and powered the water pump and fluorescent grow light through a battery charged by solar panels (Fig. 2).

Supplies used to construct basic indoor aquaponic systems are listed in Table 1. As a team, participants in the experimental group constructed seven aquaponic systems (95 L) to maintain at their place of residence.

Data analysis

Teachers in the experimental group measured individual red amaranth plant growth (stem elongation) for each treatment during their 4-week experiment. A simple linear regression was used to examine the relationship between the amount of fish feed (explanatory variable) and stem elongation (response variable) using the program Microsoft Excel® (Microsoft Corp., Redmond, WA). A paired two-sample *t*-test was performed using Microsoft Excel® to compare content pretest and posttest scores. A two-sample t-test was also performed to compare score differences between groups.

Table 1. Supply list for each classroom—Scale indoor aquaponic system.

Aquaponic system supply list		
Item	Quantity	Cost
Plastic storage containers	2	Reuse old containers
Stand	1	\$15.00
Water pump	1	\$15.00
Clay pellets (substrate)	10 L	\$20.00
Aquarium safe silicone sealant	1	\$5.00
Uniseals (3/4 inch)	1	\$2.00
Thermometers	1	\$7.00
Flexible subing (OD 3/4 inch)	3 m	\$7.00
PVC pipe (3/4 inch)	0.5 m	\$10.00
Clamp lamp and fluorescent grow light	1	\$30.00
Total		\$111.00

Results

Fish feed and edible plant growth experiment

An increase in fish feed led to taller plants (stem elongation, Fig. 3). Red amaranth stem elongation for each treatment: Group 1, 1/8 ounce fish feed treatment, plant growth $\bar{x} = 2.019$, $s = 0.265$; Group 2, 1/4 ounce fish feed treatment, plant growth

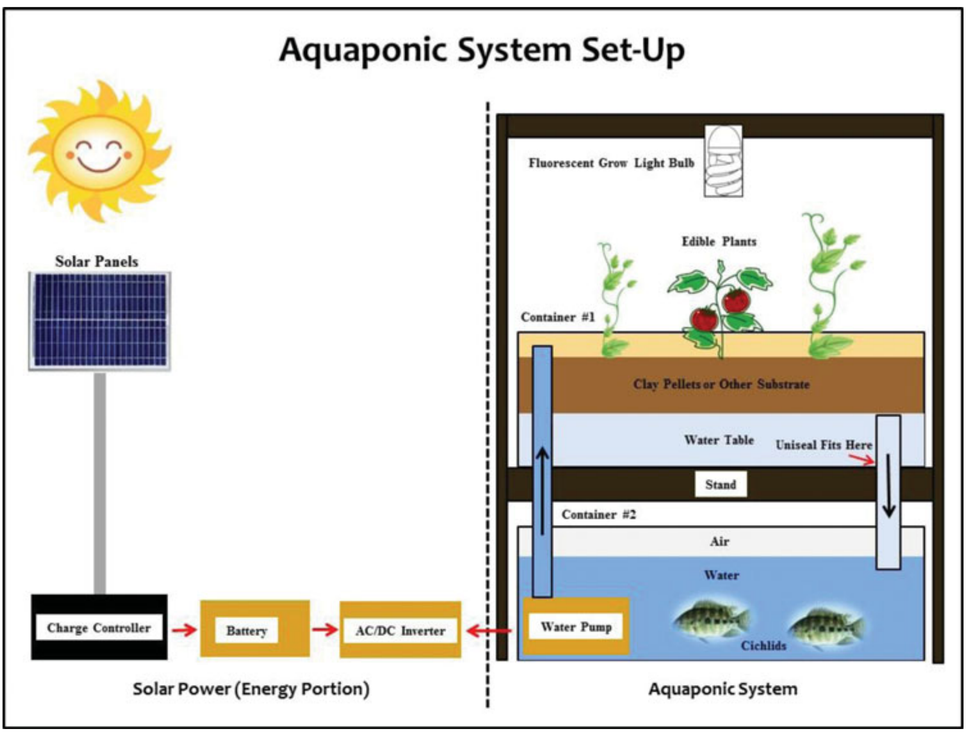

Figure 2. Visual diagram depicting components of an aquaponic system. Electricity to power the water pump and fluorescent grow light can be provided through a battery charged by solar panels (renewable resource practice); otherwise, the traditional power outlet can also be used.

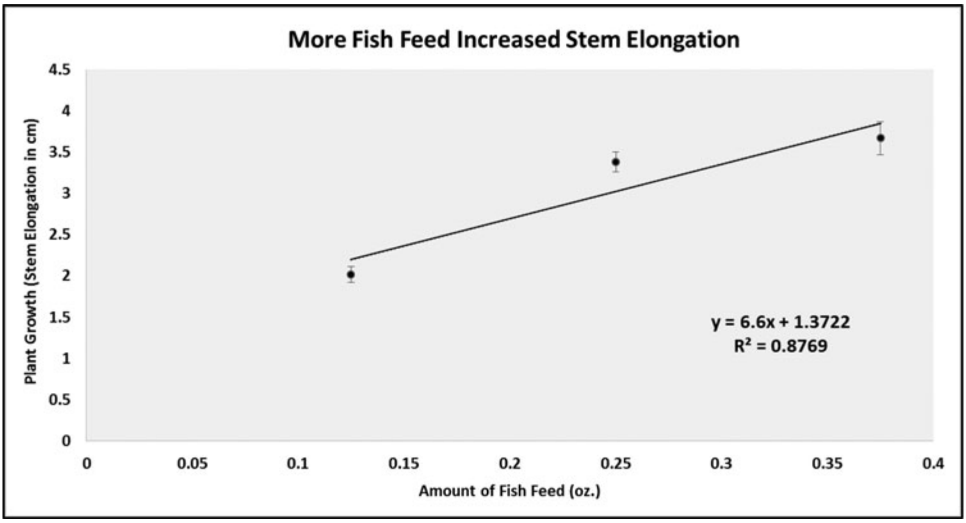

Figure 3. This graph displayed a positive relationship between fish feed and plant growth (stem elongation). An increase in the amount of fish feed led to an increase in stem elongation.

$\bar{x} = 3.379$, $s = 0.425$; Group 3, 3/8 ounce fish feed treatment, plant growth $\bar{x} = 3.669$, $s = 0.557$.

Content pretest and posttest scores

Content posttest and pretest scores differed significantly for all participants (Paired t-Test, $df = 13$, t-statistic $= -2.699$, $p < .018$). Participants, as a group, averaged a higher score on the content posttest than pretest (pretest [$\bar{x} = 0.620$, $s = 0.149$], posttest [$\bar{x} = 0.800$, $s = 0.155$]) (Fig. 4). Change in score between groups (experimental and control) was not significantly different (Two sample t-Test, $df = 13$, t-statistic $= -0.606$, $p < .556$). The control group had a higher change in score than the experimental group, though, it was not significantly different (experimental group [$\bar{x} = 0.138$, $s = 0.185$], control group [$\bar{x} = 0.220$, $s = 0.308$, Fig. 5]).

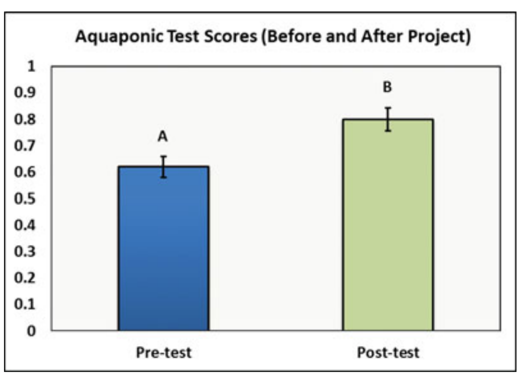

Figure 4. Aquaponic content pretest and posttest score averages were statistically significant. Different letters indicate significance (Paired t-Test, $p < .018$).

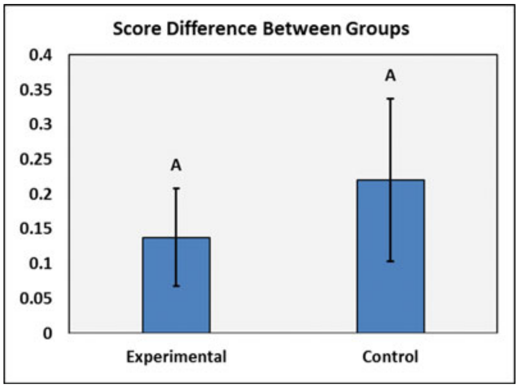

Figure 5. Participants in the experimental group (maintained aquaponic systems) did not demonstrate a statistically significant score difference from the control (did not maintain an aquaponic system) (Two-sample *t*-Test, $p < .556$).

Exit survey responses

Participants in the experimental group demonstrated a stronger interest and more support toward establishing an aquaponic system (Table 2). More participants in the experimental group than control group strongly agreed in the following statements: no. 1–I am more interested in learning new ways to become sustainable ($0.67 > 0.00$), no. 2–I would recommend aquaponics to other people ($0.83 > 0.00$), no. 4–Family and friends have shown interest in your aquaponics system at home or

Table 2. Responses in percent by all participants from the exit survey statements (Con = Control Group, Ex = Experimental Group).

Exit survey statements	
No. 1	I am interested in learning new ways to become sustainable.
No. 2	I would recommend aquaponics to other people.
No. 3	I will incorporate aquaponics into my life.
No. 4	Family and friends have shown interest in your aquaponic system at home or classroom.
No. 5	Aquaponics would help Math and Science teachers engage students in the classroom.
No. 6	Aquaponics is a lot of work.
No. 7	Aquaponics is worth dealing with despite all the work.

Exit survey results					
	Strongly disagree (1)	Disagree (2)	Neutral (3)	Agree (4)	Strongly agree (5)
No. 1 (Con)	0.00	0.00	0.42	0.57	0.00
No. 2 (Con)	0.00	0.00	0.43	0.57	0.00
No. 3 (Con)	0.00	0.29	0.57	0.14	0.00
No. 4 (Con)	0.00	0.00	0.57	0.43	0.00
No. 5 (Con)	0.00	0.00	0.00	0.57	0.43
No. 6 (Con)	0.00	0.00	0.14	0.86	0.00
No. 7 (Con)	0.00	0.00	0.29	0.57	0.14
No. 1 (Ex)	0.00	0.00	0.00	0.33	0.67
No. 2 (Ex)	0.00	0.00	0.00	0.17	0.83
No. 3 (Ex)	0.00	0.00	0.50	0.50	0.00
No. 4 (Ex)	0.00	0.00	0.17	0.50	0.33
No. 5 (Ex)	0.00	0.00	0.00	0.17	0.83
No. 6 (Ex)	0.00	0.50	0.17	0.33	0.00
No. 7 (Ex)	0.00	0.00	0.33	0.50	0.17

classroom (0.33 > 0.00), and no. 5–Aquaponics would help Math and Science teachers engage students in the classroom (0.83 > 0.43). Participants, in both groups, had similar responses on statement no. 7–Aquaponics is worth dealing with despite all the work.

Discussion

The aquaponic project modeled a practical way to incorporate an educational gardening experience with limited space in an urban area, worked through the challenges of assembling and maintaining an aquaponic system, and applied scientific inquiry for the classroom. Participants in both groups (experimental and control) demonstrated enthusiasm and scored significantly higher on the content posttest than the pretest. However, participants did not demonstrate significant differences in pretest/posttest scores between the experimental and control groups. Therefore, participation in the interactive aquaponic project lecture and working together to assemble a model aquaponic system was enough to significantly increase content posttest scores of both groups.

The experimental groups' additional participation with aquaponic system maintenance for 4 weeks generally led to more favorable views on the use of aquaponics systems at school and at home. For example, while all respondents agreed aquaponics would help students become more engaged with math and science, the fraction who strongly agreed with the statement was nearly double among participants in the experimental group (83% > 43%). While only 14% of those in the control group agreed with the statement, "I will incorporate aquaponics into my life," half of the experimental group respondents agreed. A large fraction of participants in the control group (86%) agreed that aquaponics was a lot of work, while half of the experimental group respondents disagreed and only one third agreed. All experimental group participants agreed (17%) or strongly agreed (83%) they would recommend aquaponics to others, while 57% of the control group participants agreed and 43% responded neutrally. Therefore, the exit survey results suggest teachers' interest and motivation for aquaponics systems grew as a result of their hands-on experience maintaining them at home. The majority of the study's 14 participants agreed or strongly agreed aquaponics is worth the effort, statement no. 7. Surprisingly, however, agreement was slightly higher among the control group participants (71% > 67%). We believe all participants understood aquaponic systems in the classroom provided hands-on learning applicable to lessons taught at school. Both groups (experimental and control) knew their students would be enthusiastic and eager to experiment with the aquaponic system including general maintenance; therefore, delegating most of the work on students. Participants were also encouraged to write responses regarding the aquaponic project. The first question asked, "What did you like about the Aquaponic Project?" Responses from the control group were: (a) "Seeing the fish and plants"; (b) "Self-contained"; (c) "I liked the concept and study"; (d) "Circulating air, water, wastes, good idea"; and (e) "Learning how to set up and its function." Responses from the experimental group were: (a) "Interesting, doable gardening system for the average person, Convenient and adequate size for a classroom"; (b) "Great way to get students to think outside the box of the usual ways to get food"; (c) "Watching the plants thrive"; and (d) "I liked the simplicity of the system and its obvious purpose and results." The second question asked, "What did you not like about the Aquaponic Project?" Responses from the control group were: (a) "It appears to require too much work, but I learned a lot"; (b) "Juggling where to place in a house or classroom, space requirements"; (c) "Amount of room required is a burden"; (d) "Good concept, but requires expense in establishment"; and (e) "I would not want to maintain the system." Responses from the experimental group were: (a) "I thought it was a great idea"; (b) "Wish the tank was clearer to see fish better"; (c) "Lot of work initially"; and (d) "Difficult (for me) to remember to turn the light on/off and feed fish at a specific time. Definitely better in a classroom with kids being responsible for the system."

Participants in the experimental group performed a simple plant growth study with their aquaponic system at home. Participants varied the amount of fish feed to determine if a specific amount of fish feed would lead to taller plants. They concluded 3/8 ounce of fish feed produced the tallest plants; however, they noted the average height difference between 1/8 ounce and 1/4 ounce was greater than the average height difference between 1/4 ounce and 3/8 ounce, thus a longer study period could have led to more conclusive results. The purpose of the plant growth study was implementation of the CER framework (using data collected from the experiment) as a scientific procedure for the classroom. The scientific nature of this experiment demonstrated a pragmatic way of applying core subjects taught in the classroom (Al-Hafedh et al., 2008; Bernstein, 2011; Hart et al., 2014; Medina et al., 2016). The experiment helped participants gain an understanding of the system and served as a demonstration for teachers to integrate aquaponics in the classroom incorporating biology and mathematics.

Conclusion

The vertical component of aquaponics favors assembly inside the classroom (an additional benefit if outdoor logistics constrain routine class time). Integrating aquaponic systems into classrooms utilize every component of STEAM-related ingenuity (Fig. 6). The CER Framework helps structure conceptual learning and understanding by modeling the scientific method performed by scientists thus allowing teachers and students to conduct participant-centered, inquiry-based projects (Zembal-Saul et al., 2013).

Aquaponic systems are emerging as more efficient alternatives to conventional agriculture practices (Francis et al., 2003; Lehman, Clark, & Weise, 1993; Rakocy et al., 2006). Traditional methods for gardening will have to adapt to climate change (e.g., drought, water deluge) as humans face a challenging future. The urgent paradigm shift can begin in the classroom when educators, teachers, and students

Figure 6. Fifth graders conduct experiments using aquaponic systems in the STEM classroom at North Hialeah Elementary School (Hialeah, Florida). The original system used during this study can be identified with the red arrow.

integrate sustainable gardening techniques through the use of aquaponics systems. Application to current aquaponics research and future careers can propel momentum toward the paradigm shift.

Student participation in the design and construction of a small-scale aquaponic system may reinforce concepts from physics, hydrology, and engineering, while maintenance of the system may complement lessons in chemistry, biology, ecology, and agronomy (Fig. 7). Laboratory exercises may provide first-hand experience with the scientific method through the formulation and testing of hypotheses and the collection and analysis of data. We believe these experiences can substantially contribute to students' academic development in preparation for higher education in agriculture, engineering, and the sciences. Further, more specialized educational outcomes may be realized by integrating aquaponics with other school programs such as culinary courses. Teachers can integrate aquaponic systems into lesson plans and address pressing societal issues like global hunger, water conservation, habitat loss, and sustainability in a world with shrinking resources (Klinger & Naylor, 2012; Turcios & Papenbrock, 2014).

Figure 7. Fifth graders at Key Largo School (Key Largo, Florida) assembled an aquaponic system in their classroom. The students decided to incorporate salt-tolerant plants and marine fish and invertebrates in their aquaponic system. Photo Credit: Emily Magnaghi.

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