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Implementation of aquaponics in education: An assessment of challenges and solutions

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ABSTRACT: Aquaponics is the combination of aquaculture and hydroponic technology to grow fish and plants together. While aquaponics can play a role in food security, it may also be a potential educational tool because of its interdisciplinary nature and required technological skills. With aquaponics, students could conduct activities involving chemistry, physics, biology and sustainability to solidify their understanding of scientific theories. The interdisciplinary nature of aquaponics may make it an appealing tool for science education, yet that same aspect may also make an aquaponics system challenging to implement and manage. Given this paradox, this exploratory research assessed challenges and solutions facing aquaponics in education with a focus on implementation. In-depth interview data were collected through phone interviews with educators (N=10) who currently, or had in the past five years, used an aquaponics system in educational settings in North America. Participants reported two challenges: technical difficulties as a result of the nature of aquaponics and restrictions as a result of school settings. Solutions given by participants were physical aquaponics system modifications and the development of community connections and support, passion for aquaponics and expertise. These findings will help educators manage their expectations for aquaponics while establishing objectives for their individual settings.

KEY WORDS: aquaponics, science education, environmental sustainability, hands-on learning, managing expectations

INTRODUCTION AND LITERATURE REVIEW

Aquaponics is a technique for food production that combines aquaculture and hydroponics in a symbiotic relationship (Bernstein, 2011), and it is emerging as a potential teaching tool for enhancing interdisciplinary science education. Aquaculture is the farming of aquatic plants and animals (Nash, 2011) and in recirculating aquaculture, water is cleaned and recycled in a closed-loop system (Timmons & Ebeling, 2007). Hydroponics is a method of growing plants, especially herbaceous leafy greens, without soil (Smith, 2000). Instead, plants are grown in a water and chemical solution from which they absorb nutrients through their

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roots (Smith, 2000). Combining hydroponics and aquaculture allows the chemical nutrients needed for hydroponic plant growth to be replaced with fish wastes that might otherwise be discharged and cause potential environmental degradation (Bernstein, 2011). In this way, it is possible to raise both fish and plants together in a balanced system that closes the aquaculture waste stream and adds a second source of income from plant harvests (see Figure 1).

Figure 1. Aquaponics combines aquaculture and hydroponics so that fish wastes provide nutrients for plant growth. University of Massachusetts Amherst aquaponics system, photo by James Webb.

As a sustainable food production technology, aquaponics can play a role in increasing the availability of nutritious food in present and future food systems. Small to medium-scale aquaponics systems require very little space and can be used in homes, backyards, basements, balconies and rooftops to increase personal and community food security (Bernstein, 2011). Consumers are becoming more aware of the impact of their food choices on both their own health and the environment, and aquaponics systems may be able to meet the needs of this growing market (Graham, 2003). Increasing consumer awareness of food choices, combined with the flexibility of aquaponics technology, places the aquaponics industry in an advantageous position for future growth.

Although aquaponics has the promise, there are also potential challenges that may limit its progress as a widespread food production technology. The highly technical nature of aquaponics is often overlooked: a balanced system must match the demands of the plant and fish species, plus the crucial nitrifying bacteria (Tyson, Simonne, White & Lamb, 2004). Aquaponics practitioners must be comfortable with the design and construction of systems, the physics of water flow, testing and troubleshooting water chemistry and the biology of both fish and plants in order to sustain a system in the long-term. Additionally, running a profitable commercial aquaponics system requires knowledge in business, finance and marketing. The rise of aquaponics systems is also threatened by external factors such as the wild versus farmed fish debate, strict regulations, cultural ignorance of tilapia (a fish commonly used in aquaponics because of its hardiness) and food safety issues (Graham, 2003). For aquaponics to overcome these roadblocks, there is a growing need for more rigorous preparation in a variety of subjects and increased public awareness.

A New York Times newspaper article that investigated the growing aquaponics phenomenon quoted Rebecca Nelson, of the U.S. aquaponics company Nelson and Pade, Inc., saying there are “perhaps […] 1,000 [aquaponics systems] bubbling away in school science classrooms” (Tortorello, 2010). This comment reflects a recent growing interest in aquaponics in education because of synergies between science education and the intrinsic nature of running an aquaponics system. Using aquaponics in education may serve the dual purpose of preparing future practitioners while giving students the opportunity for active learning, which parallels the goals of contemporary science education in the United States (National Research Council, 2012).

The rationales stated above for aquaponics in education support its use as a teaching tool to enhance learning, convey new ideas and actively engage students. We propose that aquaponics be viewed as a living teaching tool because it can be used to grow living organisms in an educational setting especially for the application of academic subjects and hands-on learning.

A list compiled by Nelson (2007) in the *Aquaponics Journal* highlighted Shrewsbury Elementary School (Pennsylvania), Canby High School (Oregon), Tunstall High School (Virginia) and seven others as examples of successful educational aquaponics systems in the U.S. and across North America. Examples of aquaponics in education have also surfaced in U.S. community, teacher and trade magazines and newspapers over the past decade. Johanson (2009) described his experience building an educational aquaponics system for approximately $500 and his success using it for secondary technology education courses in Pennsylvania. The Donald F. Harris Sr. Agri-Science and Technology Center at Bloomfield

High School in Connecticut has become well known for its culinary training program that incorporates produce from the aquaponics program (Lehner, 2008). Students at Eagle Valley High School in Colorado conceptualized and designed a 2,500 square foot greenhouse where they use aquaponics to grow vegetables for local markets (Overbeck, 2000).

Notably, Wardlow, Johnson, Mueller and Hilgenberg (2002) described the Aquaponics in the Classroom program that was developed as a component of the AgriScience Education Project at the University of Arkansas, U.S. Teachers enrolled in the program were loaned a small aquaponics system at no cost, plus an instruction manual and a set of student activities for using the system. Wardlow et al. (2002) reported that the program was very successful, with 38 classrooms using the 16 systems over a three-year period in the late 1990s. A brief survey of teachers using the systems showed that teachers had positive perceptions of the Aquaponics in the Classroom project, but Wardlow et al. (2002) reported the need for more information on how the units are actually used.

The growth of aquaponics in education is seen in the publication of teaching guides on the subject. The aquaponics company Nelson and Pade, Inc. produced a comprehensive aquaponics curriculum, which is available for a fee (Nelson and Pade, Inc., 2000). The curriculum includes eight chapters and three appendices covering topics such as system design, plant selection, fish nutrition, and experiment ideas. The curriculum is designed to accompany the implementation of a classroom aquaponics system (Nelson and Pade, Inc., 2000). A teaching guide produced through the Cornell Science Inquiry Partnerships Program by Mullen (2003) described a simpler and smaller aquaponics set up and focused on using aquaponics to study the nitrogen cycle. The teaching guide had seven specific learning objectives and encouraged teacher creativity (Mullen, 2003).

Discussion of aquaponics in education is also occurring on the Internet and an informal query of the Google search engine for “aquaponics in education” reveals approximately one million results with informational content on aquaponics, as well as ideas for lesson plans. The Aquaponic Source website has an Aquaponics in Education webpage (n.d.), which promotes aquaponics as “an extraordinary tool for educators”, lists potential lessons and offers their products for educators. Aquaponics USA also has an Aquaponics in the Classroom page (n.d.) with similar content as The Aquaponics Source and their respective products for educators. The proliferation of websites with information on aquaponics in education also suggests that it is growing in popularity.

Aquaponics in education seems to be currently attracting attention, based on the number of schools with aquaponics systems, its increased incidence on the Internet and in articles, and from anecdotal evidence. Despite this growing awareness of aquaponics, the process of planning, building, maintaining and using an aquaponics system in an educational setting has been unevenly documented and analyzed. Subsequently, peer-reviewed articles on the use of aquaponics in education are almost nonexistent and claims are not substantiated by empirical research. The purpose of this study was to explore aquaponics in formal education as a step towards addressing the lack of research on educational aquaponics, specifically focusing on the process of starting educational aquaponics systems and solutions to potential challenges. The interdisciplinary nature of aquaponics may make it an appealing tool for education, yet that aspect may also make an aquaponics system challenging to implement and manage. Given this paradox, this study used qualitative research methods to resolve the following research questions: Why are educators choosing to use aquaponics systems? (RQ1); In educational settings where aquaponics is implemented and maintained, what challenges do educators face and how have they overcome these challenges? (RQ2); Based on their experiences, what advice do educators have for others who want to begin using educational aquaponics systems? (RQ3).

METHODOLOGY

Sampling framework

Qualitative data were collected through phone interviews with educators who currently or had in the past five years used an aquaponics system in a formal educational setting in North America. Qualitative research methods were chosen in order to collect rich, descriptive data on aquaponics in education as an emerging phenomenon, which makes potential responses unknown for a close-ended survey. Furthermore, studies on aquaculture in education have found that qualitative research results can differ from quantitative questionnaire results, highlighting the importance of exploratory qualitative data collection for a holistic understanding (Conroy, 1999; Conroy & Walker, 2000).

Because there is no comprehensive list of educators using aquaponics, a purposeful sampling strategy was used to find participants in North America who currently had an educational aquaponics system or had used one in the past five years. In order to maintain comparability, the boundaries of the research study were originally set to include only educators who have or had aquaponics systems in a formal, K-12 setting in the U.S. However, over the course of the study, the boundaries were expanded to also include higher education and nonprofit K-12 organizations that use aquaponics in formal education settings in North America in order to increase the sample size. Regional differences, age and gender were not accounted for because they are outside the boundaries of the current research, although experience in aquaponics or a related field is discussed in the results.

Names of possible participants were collected from websites, published articles and the attendance list from the Aquaculture in Education session organized in 2010 by the Western Massachusetts Center for Sustainable Aquaculture. Participants were also solicited from two discussion posts on each of two aquaculture- and aquaponics-based social networking, member-only websites, AquacultureHub and the Aquaponics Association, as well as one discussion post on each of five aquaponics groups on the social networking website Facebook (Aquaponics Resource Center, Aquaponics Survival Communities, The Aquaponic Source, Aquaponics Association, Aquaponic Gardening). Additionally, possible participants were contacted through the National Aquaculture Educators Network listserv, organized by the Auburn University Department of Fisheries and Allied Aquaculture and the Alabama Cooperative Extension System. Finally, well-connected people in the aquaponics field were contacted for the names of potential participants. They were encouraged to suggest other potential participants, employing a snowball sampling strategy (Rossman & Rallis, 2012).

Audio records and textual data were collected through in-depth phone interviews over a three-month period from February to May in 2013. Phone interviews were chosen because of geographic and resource constraints. Although concerns have been raised about the quality of phone interview data in comparison to data collected face-to-face, it has also been shown that data collected through both modes are comparable (Sturges & Hanrahan, 2004) and the dispersed nature of the research population severely constrained the interview mode. As electronic mail addresses were more readily available than phone numbers, potential participants were first contacted via electronic mail with a request for participation. Once a participant confirmed that they met the eligibility requirements and agreed to contribute to the research, they chose a convenient time for a phone interview.

Interview protocol

A semi-structured interview guide was used although emphasis was placed on the interview as a “conversation with a purpose” (Kahn & Cannell, 1957, p. 149), especially because of the exploratory nature of the research. One participant requested to complete the questions in writing, which was agreed to in order to maintain their comfort and sustain their participation. Interviews were tape recorded, with permission, although two interviews were not recorded for logistical reasons (unrecorded interviews were immediately transcribed from memory and corroborated with interview notes).

The semi-structured interview guide revolved around four topics that correlated to the research questions. Each interview began with the participant describing how and why they have or had an aquaponics system in their educational setting and continued to a conversation about the challenges they may have faced while implementing their system. Participants were then asked about if and how they had overcome potential challenges. Interviews were concluded by asking about advice that the participant may have for others in similar situations.

It is important to note that the variability in participants generated differences in flow and pacing for each interview because of the individual setting, scale and use of each aquaponics system. There was some latitude with follow-up questions and probes, as appropriate to each individual participant's situation. Additionally, some participants were under time constraints, while others were willing to speak more in depth, which may affect the nature of individual responses. Finally, although a second researcher evaluated the interview questions before their use, they were not pre-tested because the small sample size made all participants valuable to the final research. However, the interview guide was updated twice with respect to order and specific phrasing over the course of the interviews but the nature of the questions remained intact.

Coding procedure and analysis

Interviews were transcribed and interview material was analyzed following standard qualitative protocol for thematic analysis (Rossman & Rallis, 2012). The research questions were used as the *a priori*, analyst-constructed categories for the data coding procedure and codes emerged within each category through the constant comparative method (CCM) (Boeije, 2002). The first two rounds of coding relied on the research questions to delineate data into broad categories. After the initial coding, excerpts were continually compared within each category to develop a more nuanced code structure based on standardized definitions that were developed. Data were managed using software for qualitative data analysis (Dedoose v. 4.5.95).

Participant descriptions

Ten participants (N=10) contributed to this research and shared their experiences with aquaponics in diverse educational settings in North America either currently or in the past five years. Phone interviews ranged in length depending on the participants' time constraints; most interviews (n=5) were between 20:01 and 45:00 minutes, while the remaining interviews (n=4) were between 5:00 and 20:00 minutes. The educational institutions represented were public (n=5), private (n=2) and nonprofit (n=3). The grade levels served by the institutions were post-secondary (n=2), secondary (n=4), intermediate (n=1), elementary (n=1), intermediate and secondary (n=1) or all K-12 (n=1). At these institutions, the research participants were teachers (n=4), professors (n=2) or held another supporting role in education, such as grant coordinator, aquaponics manager or involved community member (n=4).

FINDINGS

Why are educators choosing to use aquaponics systems? (RQ1)

The first topic of each interview was why the educator used or had used aquaponics in their educational setting and how they had become interested in doing so. Many participants reacted to this question by telling the story behind their aquaponics systems, including the person(s) or experience that had first introduced them to aquaponics. Beyond the story of their initial introduction to aquaponics, the educators gave their beliefs about why aquaponics was a desirable teaching tool. Reasons for using aquaponics emerged as five main areas that have been titled: hands-on learning, flexible, food concepts, fun and science, technology, engineering and mathematics (STEM) concepts (see Table 1).

For example, hands-on learning was interconnected with the teaching and learning of STEM concepts, as well as with fun. Janet[‡] manages two aquaponics systems at two schools for a nonprofit organization and she described why she uses aquaponics:

> I think it's important for children to experience and be introduced to the connectedness and symbiosis of earth's systems, which are exemplified in this fun and tangible way with aquaponics. (Janet, 9-11)

Table 1. Code frequency of why educators choose aquaponics in education

Code	Frequency (# excerpts)	Proportion (%)
Flexible	10	17
Food concepts	14	24
Fun	4	7
Hands-on learning	15	26
STEM concepts	15	26

In educational settings where aquaponics is implemented and maintained, what challenges do educators face and how have they overcome these challenges? (RQ2)

[‡] Most names are pseudonyms, unless permission given otherwise, and numbers following the quote are line numbers of the transcript in Dedoose v. 4.5.95.

Participants described the challenges they have faced while implementing and maintaining their educational aquaponics systems. Of the 83 excerpts in which participants described challenges, 34% related to technical difficulties resulting from the nature of aquaponics, 17% mentioned space and location and 12% described time constraints, in addition to five other challenges (see Table 2).

Table 2. Code frequency of challenges facing implementation of aquaponics in education

Code	Frequency (# excerpts)	Proportion (%)
Bureaucracy	7	8
Funding	6	7
Information gap	6	7
Other	6	7
Space & location	14	17
Summer & holiday care	7	8
Technical difficulties	28	34
Time	9	12
Total	**83**	**100**

Technical difficulties intrinsic to the nature of aquaponics were the most frequently cited challenges. Dan, a seventh grade life science teacher who uses aquaponics for teaching about populations and ecosystems, described the challenges he encountered:

> The first has been getting the water quality situated, and then second figuring out the right ratio of fish to veggies for the right amount of effluent and then third, transplanting the plants into the hydroponics section. (Dan, 23-25)

After technical difficulties, challenges as a result of space and location were most frequent, which was defined as the physical environment of the educator and/or institution. David, a community member heavily involved with building aquaponics systems at his local elementary school, mentioned location as a challenge:

> Location is tough. Certainly at [our school]. I think maybe some other schools might be less overcrowded, and that might be less of an issue. The goldfish system is about the size of a bookcase, so it can go anywhere you would put a bookcase. The new tilapia system is very long, but it is only 23 inches wide at the widest point, so it will fit along the side of the hallway. It's not the way I would set things up if I had unlimited space… (David, 76-81)

Some participants discussed the time that it takes to implement and maintain aquaponics systems as a challenge, especially given other responsibilities. Alex, who manages an educational aquaponics system at a nonprofit organization focused on aquaculture education, described her experiences with teachers and time constraints:

> We've been fortunate enough to have teachers work with us who are really motivated, and I think it's important if you're working with teachers to outline the work that's involved in it because teachers are really busy and they have a lot on their plates. (Alex, 159-162)

Caring for an aquaponics system over the summer and holidays was mentioned as a challenge in 8% of excerpts, because living plants, fish and bacteria require ongoing attention (see Table 2). Dan elaborated on the challenge of caring for an aquaponics system over the summer:

> Our original goal was to have the vegetables and the fish for some kind of dinner at the end of the year, and now we have to figure out what to do with the systems over the summer. I was thinking about having some students take it home, none of the custodians want to take care of it, I might come in and find one of the custodians fishing in my tank. But to have a student take it home it has to be all cleaned out. We don't know what we're going to do yet. (Dan, 37-42)

Some participants directly described a lack of knowledge of aquaponics as a challenge. Thomas is an environmental science professor using aquaponics in his institution's Food for Sustainability project and he coined this lack of relevant knowledge "the information gap":

> Some of the big challenges are the accessibility of information, there's not a lot of peer-reviewed studies and most of the credible information is from [Dr. James] Rakocy and the UVI [University of the Virgin Islands]. You have Aquaponics Journal, but a lot of what's out there on the Internet is hobbyist blogs and you get a lot of conflicting information. It's really hard to learn what exactly we were supposed to be doing, […] just the information gap, […] so knowledge is definitely a gap in existing publications. (Thomas, 116-129)

Challenges as a result of institutional bureaucracy were noted, which was defined as complicated administrative procedures (see Table 2). Participants also described funding as a challenge to implementing and maintaining an educational aquaponics system (see Table 2). In all, the challenges that participants reported were categorized as: technical difficulties, space and location, time, summer and holiday care, bureaucracy, information gap, funding and other.

After discussing challenges that they had faced, participants described if and how they had overcome those challenges. The solutions they described emerged in two broad categories: 16 % were coded as technical solutions and 84% as nontechnical solutions, of the 130 total excerpts (see Table 3).

Table 3. Code frequency of participants' solutions for overcoming challenges to implementing and maintaining educational aquaponics systems

Code	Child Code	Frequency (# excerpts)	Proportion (%)
Technical solutions	System modifications	18	13
	Other adjustments	4	3
Subtotal		**22**	**16**
Nontechnical solutions	Administrative support	4	3
	Community connections & support	26	20
	Expertise---mentor	13	10
	Expertise---personal experience	3	2
	Grant funding	5	4
	Other	4	3
	Outsourcing labor	10	8
	Passion	19	15
	Rewarding experience	3	2
	Self-sufficiency	10	8
	Trial & error & problem solving	11	9
Subtotal		**108**	**84**
Total		**130**	**100**

Participants described technical solutions to challenges, which were categorized as either system modifications or other adjustments (see Table 3). System modifications were defined as changes to the physical system and/or components, including adaptions from an ideal, in order to overcome a challenge. For example, Julian runs a high school aquaculture and aquaponics program and he described a change in the species used for his aquaponics system because of a problem with the previous species:

> Yeah, we tried it before with tilapia and the tilapia ate all the roots off of everything. But the crawfish they do fine with it, they stay on the bottom and the lettuce floats on the top. And everything works great so far. (Julian, 56-58)

Janet talked about how she has to make changes to the system design because of flooding:

> One of these times [a flood happened] was over a weekend, and water was coming into the table faster than it could flow out through the drain. Needless to say, we had a big mess on Monday and the table is currently offline so that I can change the size of the drainage. (Janet, 145-148)

Nontechnical solutions to challenges educators faced were also discussed, which were defined as educator and program characteristics or qualities that contributed or may contribute to overcoming challenges. Of the 130 excerpts coded as solutions to aquaponics in education, 20% mentioned community connections and support and 15% described a passion for aquaponics in education, which were the two most frequently cited solutions (see Table 3).

Community connections and support were often cited directly by educators as helpful, and evidence of community connections also emerged indirectly. Thomas described how starting an aquaponics system would have been difficult without a network:

> If we were just doing this on our own and with what we found on the Internet, it would have been very different. I would think that someone starting up would also face a challenge if they did not have a network of people to communicate and trade ideas with because I like to say that every aquaponics system is different, you're always working with different water quality parameters, different temperatures, humidity levels, different crops. There's a lot of different variables. (Thomas, 157-163)

Community connections also included partnerships and outreach with other schools, churches and businesses to exchange expertise and sometimes donate needed materials.

After community connections and support, evidence of passion for aquaponics in education emerged frequently as a nontechnical solution for overcoming challenges. The *Oxford English Dictionary* defines passion as "an aim or object pursued with zeal; a thing arousing intense enthusiasm" (Oxford English Dictionary, 2013). Some participants described passion for aquaponics in their students and other educators expressed their own passion and interest in aquaponics. Steve, a high school environmental science teacher, stated that his passion for aquaponics has driven him despite the time commitment:

> I was blissfully ignorant, if I had known all this stuff was going to happen, I probably would have panicked about how much this was going to consume, and done something that was easier. But like I said, I love it. (Steve, 246-248)

Expertise in aquaponics, or a related field like aquaculture, was also frequently mentioned as a solution to overcoming challenges, especially technical difficulties. Many of the research participants did not have direct previous experience or expertise in aquaponics, and 10% of excerpts cited a mentor with experience as a helpful asset for overcoming challenges (see Table 3).

Participants mentioned that they delegated maintenance work related to their aquaponics system to others, especially students. This characteristic was coded as outsourcing labor, and it was assumed to reduce the burden of caring for an aquaponics system (see Table 3). For example, when asked about who maintains the aquaponics system, Julian replied: “That’s what students are for” (Julian, 77).

Many participants wanted to be able to sell their aquaponics produce, while a few were currently doing so, to reinvest that money into their aquaponics system. The idea of self-sufficiency as a desirable solution to overcoming challenges emerged in 8% of excerpts from participants (see Table 3). Related to the idea of self-sufficiency, participants also mentioned that they had received grant funding to finance their aquaponics systems. After grant funding, two participants also cited administrative support as helpful to implementing an educational aquaponics system. A shared quality that also emerged as a possible solution to overcoming challenges in aquaponics in education was a willingness to problem solve and use trial and error logic (see Table 3). Overall, participants described and presented a variety of solutions for overcoming challenges to implementing aquaponics in education, which were divided into technical and nontechnical solutions.

Based on their experiences, what advice do educators have for others who want to begin using educational aquaponics systems? (RQ3)

Near the end of each interview, participants were asked if they would recommend aquaponics in education and if they had advice for other educators who wanted to start an educational aquaponics system. All participants recommended aquaponics in education and eight of the participants gave advice. Advice given directly was categorized as such and tabulated (see Appendix), although it was also cross-tagged if it was relevant to other categories.

Participants remarked on the size and scale of an educational aquaponics system both when asked for advice and throughout interviews. Three educators suggested using a small educational aquaponics system and then increasing its size, if desired, as competency increases. Two of these educators stated that educational aquaponics systems should be small to minimize complications. For example, Sally stated:

> It can be very low key, just like having a fish in a tank and growing a plant on top of it, it can be as small as that. But the bigger you try to make it, the more engineering comes in. (Sally, 91-92)

Two educators described that starting small and then growing their aquaponics project had been a successful strategy for them. One educator, however, commented that starting too small reduced the potential for learning and increased technical difficulties.

DISCUSSION AND CONCLUSIONS

Ten participants (N=10) contributed to this research, although over 200 potentially eligible participants were contacted directly through electronic mail, many of them with more personalized messages. In addition, approximately 30,000 individuals had the opportunity to view the request for participants on the social networking sites AquacultureHub, Aquaponics Association and Facebook. Despite the high number of individuals who may have viewed the request for participants, finding potential participants and eliciting their participation proved challenging, likely because aquaponics is interdisciplinary, still emerging as a phenomenon and occurs in a variety of educational settings. The discrepancy between the high number of potential participants who were contacted and the lower number of actual participants represents not only the difficulty of finding participants but also the difficulty of securing their phone number and an interview time via electronic mail. This discrepancy may be inherent to the research design (i.e., qualitative interviews versus quantitative questionnaire) but may also be related to an intrinsic quality of the population (e.g., severe time constraints). Furthermore, although a high number of individuals had the opportunity to view a request for participants, these individuals did not all have educational aquaponics systems because they were targeted from aquaculture and aquaponics industry, hobbyists and educational groups. Overall, the difficulty in finding educators who use aquaponics systems likely contributes to the lag in research on aquaponics in education. Closing this research gap will be crucial to developing appropriate training programs and curricula to advance aquaponics in education.

Why aquaponics?

In the small body of literature on aquaponics in education, reasons for incorporating aquaponics in education fell broadly into three categories: the application of academic subjects (especially science and math) (Emmons, 1998; Johnson & Wardlow, 1997; Milverton, 2010; Nelson, 2007; Overbeck, 2000; Wardlow et al., 2002); hands-on, experiential and integrated learning (Nelson, 2007; Overbeck, 2000; Wardlow et al., 2002); and connections to food, agriculture and global trends (Lehner, 2008; Milverton, 2010; Nelson, 2007; Overbeck, 2000; Wardlow et al., 2002). Participants in this study stated that they used aquaponics for hands-on teaching and learning of STEM and food-related concepts, which aligns with the categories that existed in the literature. Some participants in this study reported that they value aquaponics for its flexibility and because it is fun. Overall, these five areas fall into two broad categories: content (i.e., what students learn) and pedagogy (i.e., how educators teach). Framed in the context of these two categories, the findings of this study show that participants valued aquaponics because it represents both a method for teaching as well as content to be learned.

Challenges and solutions

When asked about the challenges they faced implementing aquaponics in education, study participants reported challenges that emerged in two broad categories: those intrinsic to aquaponics and those intrinsic to an educational setting. For example, participants most frequently reported technical difficulties as a challenge to implementing aquaponics, which included issues with nitrogen cycling, developing a well-functioning system set-up and long-term maintenance. Funding and the information gap are also included as intrinsic to aquaponics because of the resources and expertise required by the technology. In this case, the aquaponics technology presents challenges, which may also be the case for commercial and backyard aquaponics practitioners. Participants also reported challenges as a result of their school settings, such as space limitations in a classroom, time constraints because of other responsibilities and the need to care for the system over stipulated school breaks. Unlike the aquaponics industry and hobbyists, these challenges are a result of an educational setting and are unique to aquaponics in education. The results of this research show that educators who want to implement aquaponics in education likely face more challenges as a result of their educational setting in addition to technical challenges due to aquaponics technology.

Participants in this study reported the care of an aquaponics system over school breaks and summer recess as a challenge but offered few concrete solutions. Participants suggested breaking down the system over the summer or asking custodial staff to care for it. However, breaking down the system may require prematurely harvesting fish and plants if growth is slower than anticipated, which may be an uncomfortable prospect for overly attached students. On the other hand, custodial or other year-round school employees are not guaranteed to agree to help and may not be capable of adequate care. Overall, many participants stated that they or their students provided care to their aquaponics systems during school breaks. While this may be a workable solution for some educators, it may also be a difficult sacrifice for others. Additionally, it may be challenging to recruit students if there is a lack of funding to employ them. Consequently, solutions to the need for care of an aquaponics system over school breaks continues to be a challenge and exploring alternative models will be essential to the expansion of aquaponics in education.

Ultimately, challenges that emerged to aquaponics in education seem to be not only a result of aquaponics technology but also of educational settings. Stated solutions by participants included technical solutions that seem to be driven by intangible characteristics. Although participants created their own technical solutions, the development of community support, passion for aquaponics in education and expertise seem to serve as the conduit for devising unique system modifications. Overall, David summed up what is needed to implement aquaponics in education:

> You need space, you need enthusiastic people, you need some funding, you need some expertise. (David, 102-103)

System size

While giving advice, and also throughout the interviews, participants remarked on the size and scale of an educational aquaponics system. The idea of "small" as an ideal aquaponics system size was presented, however, one participant reported that too small was not ideal. This raises the following questions: Is there an ideal size for an educational aquaponics unit? If so, what is it? We would suggest that, given the variety in the results of this study, an ideal size for an educational aquaponics unit is dependent on individual educators' situations and values. For example, K-12 teachers in a traditional school setting may not have a classroom with a floor drain or the structural integrity to support two tons of water for a medium or large system. In this situation, it is more realistic for a teacher to implement a tabletop system using a 20-gallon aquarium for student observations. On the other hand, an educator who values the potential for students to conduct long-term scientific experiments would benefit from implementing a medium to large scale system because a larger system offers more research opportunities, which aligns with how the educator wants to use aquaponics. These examples suggest that educators' individual situations, especially available space and resources, as well as the reason that they value aquaponics, dictate the appropriate size for an educational aquaponics unit.

Bringing it all together

Perhaps because challenges to aquaponics in education may be intrinsic to the technology or the educational setting, every aquaponics in education situation seems to be unique. This quality makes it difficult to suggest exact, concrete solutions to every challenge. However, it seems likely that possessing a passion for aquaponics in education and cultivating a supportive community will assist educators in acquiring expertise and uncovering individualized solutions. Nevertheless, the findings of this study can provide some helpful guidelines to educators who are interested in implementing educational aquaponics systems. Broad guidelines emerged from this study that may be useful for establishing the foundations of an aquaponics in education project:

1. Reflect on passion for aquaponics in education and the factors motivating implementation of the educational aquaponics system.
2. Reach out and develop a supportive community, including other educators, administrators, local businesses, government-run fish hatcheries, universities and the aquaponics industry.
3. Cultivate aquaponics expertise, especially through community connections.
4. Establish a plan and desired goals for implementing aquaponics in education but remain flexible.
5. Explore solutions for summer or holiday care early in the process and planning.

Where do we go from here?

The qualitative results of this study on aquaponics in education represent in-depth answers to exploratory questions from ten educators in North America. It would be useful to test these results against a larger sample of educators using a quantitative questionnaire survey. Given the frequency with which participants mentioned technical difficulties related to aquaponics technology, there is also a need for more reliable information, expertise and training on aquaponics. It is worth noting that although it was not the purpose of this study, it is not known how educators actually use aquaponics for teaching and learning. 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. Research into the effectiveness of aquaponics as a teaching and learning tool, as well as how it is used, would greatly strengthen the body of knowledge on aquaponics in education and most likely allow for broader implementation.

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APPENDIX

Advice from participants

Participant	Advice
Paul (51-54)	Keep the system as simple as possible. Don't try to push production to the limits, because that's one of the problems that we had trying to feed so many people. Like when we increased the number of fish, we had die offs because we had dissolved oxygen problems. So keep it simple and stay away from the limits.
Alex (178-183)	So I think it's important for anyone that works with teachers who want to do aquaponics is to make sure that they have some sort of support system in place, because it's really easy for a teacher to get really excited about aquaponics, try it in their classroom, it doesn't work, and then they lose that motivation and they just give it up because they don't have the resources to help them out.
Alex (159-162)	We've been fortunate enough to have teachers work with us who are really motivated, and I think it's important if you're working with teachers to outline the work that's involved in it because teachers are really busy and they have a lot on their plates.
Alex (163-165)	For me, it's simple right now, but that understanding for teachers, there's a definite learning curve and I think it's really important to give them some training and to give them some support throughout the process.
Steve (290-294)	I think just knowing that it's [aquaponics] not… There are days when I go leafing through my resource books, going okay I need a 90 minute lab activity what can I find that's quick and dirty, that's not aquaponics. Aquaponics is something you just have to know is going to be, you can start easily but it's going to take a longer time to get up and running.
Thomas (275-284)	Like for example K-12 teachers face a different set of responsibilities than I do as a professor, and it takes a lot of time and patience to manage an aquaponics system. The smaller, the better, I would say at that level because you need people to be able to come in on winter break, or the summer, if that can't happen you need to be able to disassemble your system and send it somewhere. […] I would recommend for K-12 teachers it'd be a great project if it was kept small.
Dan (52-53)	Yes, I would definitely recommend aquaponics, but definitely to start at the beginning of the year.
Sally (251-254)	To start small. I think there's a ton of information out there, and there's a lot of DIY-er people. I guess the biggest thing is to start small, and grow something you want. It's not the fish that make the money, if there's money to be made, but to grow what you want to eat, and so the kids will be invested in it.
David (208-215)	Line up the funding first, because you don't want to end up paying for all that stuff yourself if that falls through. Build everything

	really solid, if a 2x6 seems reasonable, go with a 2x10. Try to make everything so it just looks really solid, way beyond what's probably necessary because if you're hoping it'll be there for 20 years in an institutional setting, hopefully kids won't be climbing on it, but it's going to take some knocks in that setting. Also, it's just key so that when anybody sees a tank in a classroom with 200 gallons of water in it, it looks like something that inspires some confidence.
David (230-237)	And that's another thing to think about when starting a system, who's going to be responsible for the day to day stuff, that hopefully the kids will do, and the more major maintenance things. Who's going to clean the pump every week, and even think about if this is a system that will need to be shut down and scrubbed out every year or two, and if so, who's going to do that. It's wise to have that sort of stuff lined up in advance, because if you don't and it ends up dirty and functioning poorly after awhile, it's a huge waste of resources and it's negative advertisement for the technology.
David (245-247)	I guess the main thing in trying to set this sort of stuff up is to plan everything out as much as possible with an A plan, a B plan and don't tell anybody, but make a C plan too, just in case.
Janet (233-235)	I would definitely recommend aquaponics to a teacher, but not every classroom is equipped with a floor drain and the structural integrity to support nearly 2 tons of water.
Janet (185-190)	I'd highly recommend for someone who is designing his own system to MAKE VIDEOS. I might show a teacher how to reset the siphon countless times, but when it comes to actually resetting it themselves, it'd be helpful if they could see it just oooone more time. This can go for everything from testing the water, to how to set the automatic feeder for short school breaks, to some basic troubleshooting (how to raise the system's pH, how to remove ammonia, etc.)