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Implementation of Aquaponics in Education: An Assessment of Challenges, Solutions and Success

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IMPLEMENTATION OF AQUAPONICS IN EDUCATION:
AN ASSESSMENT OF CHALLENGES, SOLUTIONS AND SUCCESS

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DEDICATION

To my summer 2012 students, for inspiring this research.

Mahalo nui loa.

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ABSTRACT

IMPLEMENTATION OF AQUAPONICS IN EDUCATION: AN ASSESSMENT OF CHALLENGES, SOLUTIONS AND SUCCESS

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Aquaponics is the combination of aquaculture and hydroponic technology to grow both fish and plants together in a closed-loop system. While aquaponics can play a role in increasing food security, it may also be a potential educational tool because of its interdisciplinary nature and required technological skill set. With aquaponics, students could conduct hands-on activities involving chemistry, physics and biology to solidify their understanding of a range of theories. Beyond standard science, technology, engineering and mathematics (STEM) principles, aquaponics may be related to projects on sustainability, environmental science, agriculture, the food system, health, economics, business and marketing. The interdisciplinary nature of aquaponics may make it an appealing tool for education, yet that same aspect may also make an aquaponics system challenging to implement and manage. Given this paradox, this exploratory research assesses challenges, solutions and success of aquaponics in education with a specific focus on implementation. Qualitative data were collected through phone interviews with educators (n=10) who currently, or had in the past, used an aquaponics system in an educational setting in North America. The most frequently described uses for aquaponics were flexible, hands-on teaching and learning of STEM and food-related concepts. Participants reported two broad challenges to implementing aquaponics: technical difficulties as a result of the nature of aquaponics and restrictions as a result of their school settings. Solutions given by participants were physical aquaponics system modifications and the development of intangible characteristics, especially community connections and support, passion for aquaponics and expertise. In this study, success in aquaponics in education emerged as a cyclical pattern: participants valued the overall learning experiences of aquaponics and the continued application of these learning experiences. Ultimately, these exploratory findings will help educators manage their expectations for aquaponics while establishing objectives for their particular educational settings.

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CHAPTER 1

POTENTIAL FOR AQUAPONICS IN EDUCATION

Science Education, Reform and Theory

Science is a body of knowledge about the natural world produced by a global community of researchers making use of systematic methods. It has been recognized that science plays a crucial role in society and in everyday life. As a result, there are many reasons to teach and learn science, including: helping citizens in decision-making on science-related issues, giving consumers a broad understanding of science and technology-related products, increasing the number of students entering careers in science fields and giving all people a general appreciation for the wonders of science (National Research Council [NRC], 2012).

Science is included alongside technology, engineering and mathematics in the STEM acronym. The push for STEM education in United States schools has accelerated in the recent decade, mainly to produce career scientists and increase economic prosperity (Breiner, Harkness, Johnson & Koehler, 2012). Funding has increased for STEM-related endeavors and federal allocation for STEM policy, research and education is in the billions (Breiner et al., 2012). However, STEM is a broad acronym with variable conceptualizations (Breiner et al., 2012; Brown, 2012), and there are many avenues for teaching and learning STEM concepts.

To guide STEM education in the current scholastic environment, the National Research Council (NRC) has laid out an updated, cohesive framework to guide science standard development and state level decision-making: “A Framework for K-12 Science Education: Practices, Crosscutting Concepts, and Core Ideas” (2012). The NRC designed the framework specifically to give students an interdisciplinary science background and to experience the realities of doing science (NRC, 2012). The framework emphasizes crosscutting concepts, such as patterns and systems, and their application to learning core ideas with the goal of preparing informed citizens and career scientists (NRC, 2012). The NRC also maintains that it is important to build the science curriculum across many years of school, spend less time on details, draw interdisciplinary connections and engage students with concepts that interest them.

The NRC science framework is rooted in the concepts of non-traditional education, education reform and constructivism (Thomson & Gregory, 2013). In traditional education, learners are expected to learn and memorize facts through didactic lectures by the instructor, also called direct instruction (Thomson & Gregory, 2013). In contrast, non-traditional, progressive education uses learning theories based in studies of human development and advocates for a more holistic learning process (Dewey, 1938). The theory of constructivism, which is related to non-traditional education, defines learning as a process of constructing and creating our own knowledge, not just receiving it (Marlowe & Page, 2005). Ultimately, the theories of non-traditional education and constructivism have driven educational reform and permeate the current education climate.

The rise of non-traditional education, along with the implementation of associated theories, has been a result of education reform advocates and movements. John Dewey, a key historical figure in education reform, championed experiential education in his classic book "Experience and Education" (1938). Experiential education includes experiential learning and is a philosophy advocating the importance of direct experience and reflection to the educational process (Dewey, 1938). Related non-traditional instructional theories include active learning (Bonwell & Eison, 1991) and project-based learning (PBL) (Thomas, 2000). The goal of such instructional theories is to increase learner interest while strengthening critical thinking, gaining knowledge and developing skills for lifelong contributions to society, which parallels the aims of the current NRC framework.

Definition, History and Applications of Aquaponics

Aquaponics is a relatively new technique for food production that combines recirculating aquaculture and hydroponic technologies in a symbiotic relationship (Bernstein, 2011). 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 roots (Smith, 2000). Combining hydroponics and aquaculture allows the chemical nutrients needed for hydroponic plant growth to be replaced with fish wastes that would otherwise be discharged and cause potential environmental degradation (Bernstein, 2011) (Figure 1). In recirculating aquaculture systems, naturally existing nitrogenous bacteria are the initial consumers of fish-produced ammonia, and they produce nitrate as a byproduct of nitrification. Without the addition of plants, built-up nitrate is diluted by the addition of more water or by a denitrification process (van Rijn, 2007). In an aquaponics system, the plants become part of the filtration equation by absorbing the nitrate byproduct, which is their preferred form of nitrogen (Bernstein, 2011). In this way, it is possible to raise both fish and plants in a balanced system that closes the aquaculture waste stream and adds a second source of income from plant harvests.

As a 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). These small systems can be constructed from recycled materials and within the constraints of a limited budget (Bernstein, 2011). Aquaponics technology can also be used in a variety of climates. In cold climates, an aquaponics system can be located inside, or in a greenhouse, while it easily exists outside in tropical areas. 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 promise, there are also potential challenges that may limit its progress as a widespread food production technology. In a SWOT assessment

(Strengths, Weaknesses, Opportunities and Threats) to explore the possibilities for commercial aquaponics in Alberta, Graham (2003) lists potential weaknesses, including high consumer willingness to pay (WTP), required start-up capital, high marketing needs and the requirement of technical knowledge. The highly technical nature of aquaponics is often overlooked; to keep a system balanced, water levels, temperature, pH and nutrients must match the demands of both the plant and fish species, as well as the crucial nitrifying bacteria (Tyson, Simonne, White & Lamb, 2004). Crops and fish must also be managed at a ratio of nutrient inputs to outputs for optimum production, which varies according to species, system size and cropping system (Rakocy, Shultz, Bailey & Thoman, 2004). Additionally, the rise of aquaponics systems is 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.

Potential Intersections of Aquaponics With Education

Rationales for Aquaponics in Education

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 can require knowledge in business, finance and marketing. The ongoing care required of aquaponics systems may also encourage responsibility, leadership and teamwork, while fostering a sense of community and social equity.

This range of related topics may make aquaponics an effective tool for STEM education, plus many other topics, in both formal and non-formal educational settings. Using aquaponics in education may serve the dual purpose of preparing future practitioners, as well as giving students the opportunity for active learning, which parallels the goals for science education in the NRC framework. Ultimately, aquaponics may be an ideal platform for teaching and learning because of its interdisciplinary nature, required technological skill set and applications to real-world issues.

Given the anecdotal and limited empirical evidence, as well as personal experience, the potential uses of aquaponics for STEM, sustainability and business make conceptual sense. In articles about using aquaponics in education, reasons for its use fall into three broad categories:

1. The application of academic subjects (especially science and math) (Emmons, 1998; Johnson & Wardlow, 1997; Milverton, 2010; Nelson, 2007; Overbeck, 2000; Wardlow, Johnson, Mueller & Hilgenberg, 2002).

2. Hands-on, experiential and integrated learning (Nelson, 2007; Overbeck, 2000; Wardlow et al., 2002).

3. Connections to food, agriculture and global trends (Lehner, 2008; Milverton, 2010; Nelson, 2007; Overbeck, 2000; Wardlow et al., 2002).

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. Examples of teaching tools include computer-based technologies (Roschelle, Pea, Hoadley, Gordin & Means, 2000) and popular films (Champoux, 1999). Similarly, aquaponics may 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, hands-on learning and connections to global trends, including food and agriculture.

History and Examples of Aquaponics in Education

A New York Times article that investigated the growing aquaponics phenomenon quoted Rebecca Nelson, of recognized 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. A list also 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 North America.

Examples of aquaponics in education have also surfaced in 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 et al. (2002) described the Aquaponics in the Classroom program developed as a component of the AgriScience Education Project at the University of Arkansas. 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 Agriscience Education Project was unique because it loaned out systems, which may reduce the burden on teachers to build and maintain a system for the long-term. However, loaning systems at no-cost may have other negative tradeoffs, perhaps causing teachers to undervalue the aquaponics system and the commitment that may accompany true ownership.

Older articles have showcased prototype designs for different aquaponics systems. Johnson and Wardlow (1997) briefly described a $600 system that includes a culture tank, water treatment tank, packed column aerator and a nutrient film technology (NFT) hydroponics unit. Johnson and Wardlow (1997) then lay out educational activities that can be done with the system, including studying water quality, fish responses to stimuli and diffusion of chemicals across various growing media. The list of potential activities is detailed in this article but there is a lack of detailed instructions for assembling the system. Another prototype system produced by Emmons (1998) described an aquaponics system and its potential educational uses, although there is not enough detail to replicate the design. In these older articles, aquaponics is also referred to as aquaculture-hydroponics, which reflects the recent development of the aquaponics field in general.

The growth of aquaponics in education is also seen in the publication of teaching guides on the subject. The aquaponics company Nelson and Pade, Inc. has produced a comprehensive aquaponics curriculum, which is available for a fee (Nelson and Pade, Inc., 2000). The curriculum includes both an educator's guide and a student's guide with 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) also describes a simpler and smaller aquaponics set up and focuses 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.

Mismatch Between Research and Practice

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 the potential possibilities for aquaponics as a living teaching tool, peer-reviewed articles on the use of aquaponics in education are almost nonexistent. The lag between the use of aquaponics in education and research into the topic is likely because aquaponics in education is a recent phenomenon and it may be challenging to find those who are using educational aquaponics systems. As a result, claims that aquaponics is an appropriate and effective teaching tool are not substantiated by empirical research. This suggests that educators who implement and use aquaponics systems may face unknown challenges, and their realities may not match up to expectations formed from advertised and anecdotal claims. Additionally, there are no studies that assess student learning before and after using an aquaponics system, as compared to a control group. Thus, it is helpful to compare aquaponics to other living teaching tools, especially aquaculture, hydroponics and soil gardens, to gain a deeper understanding of the potential for aquaponics in education.

Comparisons to Similar Living Teaching Tools: Aquaculture, Hydroponics and School Gardens

Aquaculture Education

As a food production technique, aquaponics is nestled within the larger fields of agriculture and aquaculture. There is a long tradition of agricultural education in the United States (True, 1929), which more recently includes aquaculture in education. Aquaculture education has expanded in order to create a more skilled workforce, raise awareness and increase knowledge of aquaculture (Brown, 1995). In addition to these aims, aquaculture has been postulated to be an effective teaching tool for science, math and business concepts (Cline, 2011; Conroy, 1999; Lovett, 1999; Wingenbach, Gartin & Lawrence, 2000a). Because of the overlap and similarities between aquaculture and aquaponics as living teaching tools, I will briefly discuss the status of aquaculture in education.

In the early 1990s, The National Council for Agricultural Education published a set of curricula to be used by teachers, as well as manuals on building and maintaining aquaculture systems with different species (Wingenbach et al., 2000a). Consequently, researchers set out to evaluate by region the number of teachers using aquaculture, the factors affecting their decision to use aquaculture, teacher, student and school demographic information, and barriers to implementing aquaculture in the classroom (Conroy, 1999; Conroy & Walker, 2000; El-Ghamrini, 1996; Lovett, 1999; Wingenbach et al., 2000a).

In the initial study of aquaculture education, El-Ghamrini (1996) looked at commitment, perceptions, attitudes and demographics towards adoption of aquaculture as an educational innovation, as well as characteristics of schools and environments. The author studied factors that negatively or positively contribute to technological innovation (e.g. formal training, school size, etc.), and found that the most important predictor was some form of communication (e.g. visit to research center, courses, posters, face-to-face communication). El-Ghamrini (1996) also found that connections between high schools and local communities were important because high school activities for community economic development explained 4% of aquaculture technological innovation. Ultimately, El-Ghamrini (1996) recommended more technical assistance and training, as well as realistic budgets and business plans, before embarking on educational aquaculture programs.

As a continuation of El-Ghamrini's (1996) discussion, Conroy (1999) also produced a study on the adoption of aquaculture as an innovation in education. The explicit purpose of this study was to identify barriers to implementation of aquaculture education as part of secondary agriscience curricula. The study used a mixed methods approach, employing a close-ended survey, interviews and focus group discussions. The themes that came up from the qualitative data were: availability of instructional materials is not a barrier; aquaculture can be implemented at many different budget levels; and the time it takes to manage the system is a serious barrier to enlarging aquaculture education programs. Importantly, Conroy (1999) found discrepancies between the qualitative interview data and the quantitative survey data. The qualitative data showed that the greatest barrier to aquaculture education was time, which contradicted the survey data, where time was ranked as the fourth most serious barrier. Conroy (1999) called for more mixed method approaches because of these possible discrepancies. Finally, Conroy (1999) stated that possibly the most important message from this study was that teachers adopted aquaculture despite the serious barriers because they believed in it and internalized this commitment.

In a companion publication from the same study, Conroy and Walker (2000) examined the integration of vocational agriculture programs with academic subjects such as science and math. The authors specifically focused on aquaculture as a vehicle for integration and its implementation into agriscience. They specifically examined aquaculture because it is an example of “where hands-on experiences complement theory in science and a variety of other disciplines” (Conroy & Walker, 2000, p. 55). Using the same mixed methods approach described above, Conroy and Walker (2000) explored how teachers and students define integration and how aquaculture was being successfully implemented. Conroy and Walker (2000) found that agriculture teachers may not have had enough science background to teach an integrated course, which should be addressed in teacher education programs. Nevertheless, students who were interviewed reported that aquaculture helped them to better understand science and math principles. The authors concluded that there is potential for integration of academic and vocational subjects but that successful integration is difficult. Most importantly, Conroy and Walker (2000) pointed out that successful integration happens when individual teachers are committed to it and high levels of administrative support make successful integration more likely.

In light of Conroy’s (1999) call for more mixed method and qualitative studies, it is appropriate that Lovett (1999) used focused interviews to gather the experiences of eight teachers using aquaculture in West Virginia during the 1998-1999 school year. The teachers reported that the greatest payoff of aquaculture was the diversity of students enrolled but the biggest drawback was the amount of time required from the teacher (Lovett, 1999). The teachers also reported that teaching science concepts and skills was their main focus for teaching aquaculture (Lovett, 1999). Lovett (1999) recommended that teachers wanting to start aquaculture programs reflect on their time and space constraints, as well as the opportunity cost. Lovett (1999) also called for additional research into how much time aquaculture actually requires of teachers, the costs involved in set up and maintenance and the extent to which aquaculture can reinforce science and math concepts.

Wingenbach et al. (1998, 2000a, 2000b) produced a trio of studies on aquaculture education that parallel the goals of Lovett (1999), as well as the study conducted by Conroy (1999). The goal of the initial study by Wingenbach et al. (1998) was to collect baseline data on all northeastern secondary agricultural education programs that had an aquaculture program or component in the total curriculum during the 1996-1997 school year. The authors assessed teachers' perceptions of aquaculture information and training, technologies used, community linkages and teachers' attitudes on aquaculture programs using a survey instrument based on El-Ghamrini (1996). Wingenbach et al. (1998) found that northeastern agriculture teachers thought practical information sources like training programs, courses, conferences, symposiums, other agriculture teachers, workshops, field days and tours were very important to their aquaculture programs. A majority of teachers had attended formal training programs in aquaculture technology and/or curriculum and thought that training was very important (Wingenbach et al., 1998). Wingenbach et al. (1998) found limited linkages and communication about aquaculture between school districts but teachers believed linkages would be beneficial. Wingenbach et al. (1998) also found that teachers relied on external contributors for help, especially colleges and universities. Interestingly, Wingenbach et al. (1998) noted that the Internet would change how teachers access information on aquaculture, but that they were unsure of the reliability or existence of online information (note that this study is 15 years old).

In another publication from the same study, Wingenbach et al. (2000a) discussed the factors affecting teachers' decisions to teach aquaculture and barriers to teaching aquaculture in vocational agriculture programs in the northeastern region. According to the teachers surveyed in the study, the most important factors behind the decision to use aquaculture in the classroom were its relation to environmental conservation, student motivation and a natural segue between aquaculture and traditional vocational agriculture subjects. However, Wingenbach et al. (2000a) reported that the lowest ranked factors in teachers' decisions to implement aquaculture were college attendance and the effect on local economies. Wingenbach et al. (2000a) found the top three barriers to be "limited facilities to house the program, need to care for fish on holidays/weekends and high cost of equipment to teach aquaculture" (p. 7). Ultimately, Wingenbach et al. (2000a) report that aquaculture programs are expensive and resources are limited.

As part of the same study, Wingenbach et al. (2000b) also interviewed students at northeastern secondary school agricultural programs to collect their perceptions of aquaculture education. Wingenbach et al. (2000b) found that students were interested in aquaculture classes for hands-on experiences related to the natural world and environment. Students reported that aquaculture participation had positively affected their science and math abilities, and Wingenbach et al. (2000b) found that math and science concepts were more easily understood in the practical way that aquaculture requires. Practical life skills learned included teamwork, responsibility, problem solving, leadership, communication, engineering, system design and the scientific research process (Wingenbach et al., 2000b). Students said that starting and maintaining an aquaculture system was hard work for teachers, requiring a dedicated teacher and help from other schools. However, students highly recommended aquaculture and reported it as one of the best educational opportunities they had had in high school (Wingenbach et al., 2000b). Wingenbach et al. (2000b) stated that more awareness of aquaculture programs in the northeast was needed, as well as collaboration and integration with other teachers and subjects. They recommended linkages for sharing teachers and facilities, in addition to more research on the community effects of teaching aquaculture. Ultimately, Wingenbach et al. (2000b) called for a longitudinal study to look at the long-term benefits of aquaculture education.

The studies described above produced a wealth of information about aquaculture in education but they are over a decade old. The only recent study on aquaculture in education was produced by Cline (2011) in Alabama. The purpose of the research was to evaluate Alabama's aquaculture course of study in order to help teachers use aquaculture more effectively as a teaching tool. The research population was the science and career/technical teachers qualified to teach one of four aquaculture classes in the

Alabama Aquaculture Science course of study. Using electronic questionnaires, Cline (2011) compared the discrepancies between what teachers thought was important, what they know and the quality of the materials to find that different standards are important to teachers in different groups. Cline (2011) found that high discrepancy scores between importance and knowledge showed that teachers think a concept is necessary but have little background knowledge to actually teach it. High discrepancies between importance and materials showed that there is a need for increased training and teaching materials. Ultimately, teachers thought the available materials were poor (Cline, 2011). Overall, Cline (2011) recommended more effective training and materials, as well as an investigation into how science teachers infuse aquaculture into science courses.

Although there are few articles on aquaponics in education, the studies on aquaculture in education help to frame aquaponics in education within a broader context. It is possible that the barriers, challenges, goals, successes and perceptions of aquaculture in education can also apply to aquaponics because they incorporate similar technologies. However, aquaponics in education is a newer idea and it may also be similar to other educational models. Adding plants using hydroponic technology may also add a new level of complexity for system operation and management.

Hydroponics in Education

Hydroponics, the soilless cultivation of plants in a nutrient solution, was developed in the 19th century and first used to produce crops in 1929 (Hershey, 1994). More recently, it has been used as a teaching tool for hands-on plant biology (Hershey, 1994), as well as science and sustainability (Carver & Wasserman, 2012). Because hydroponic technology is intrinsic to aquaponics, it is helpful to explore the potential and status of hydroponics as a living teaching tool.

In the mid-1960s, Syrocki (1966) described hydroponics as "a valuable instructional resource" (p. 271) and a worthwhile classroom activity for hands-on student experiences. Syrocki (1966) gave detailed instructions on a sand culture technique that can be used so plants do not require care over weekends and holidays, a challenge facing the use of living teaching tools. In another early article on educational hydroponics, Steucek and Yurkiewicz (1973) described their hydroponics project in detail and stated that hydroponics is a flexible, interdisciplinary project that can be modified for different needs and classes.

More recently, hydroponics as a living teaching tool has captured imaginations because of its relevance to space exploration and settlement (Karpeles, 2000; Silberstein & Brooke, 1994). The National Aeronautics and Space Administration (NASA) produced lesson plans for students to explore hydroponics, based on the premise that it is a necessary technique for agriculture in space (Beatty, n.d.). Teachers at a middle school in California received grant funding to build a simulated space center in their classrooms (Silberstein & Brooke, 1994). The teachers taught science classes centered on space technology and invention, with a hydroponics set-up growing lettuce and tomatoes (Silberstein & Brooke, 1994). Students participated in planting and caring for the crops, and recording data (Silberstein & Brooke, 1994). Ultimately, the teachers suggested that hydroponics is a convenient teaching tool because of its flexibility and tangible results (Silberstein & Brooke, 1994). A teacher at an elementary school in Chicago also started a hydroponics project in his fifth grade classroom based on the question: “If space is to be colonized, how will humans grow their necessary food while living in space stations?” (Karpeles, 2000, p. 284). The project was so successful that students started a small business selling their basil to a local restaurant and to community members. After a few years of trial and error, the teacher had built four hydroponic beds that were used by teachers and students throughout the school (Karpeles, 2000).

Besides its relevance to space exploration, hydroponics is also applicable to agriculture, botany, chemistry, ecology and history in one module (Peckenpaugh, 2001). It can be geared towards different age groups for the application of real world concepts and exposes students to food production techniques (Peckenpaugh, 2001). To this end, several articles have described the basics of hydroponics, its relevance to education, simple designs to get started and potential uses (Carver & Wasserman, 2012; Hershey, 1992; Hershey, 1994; Peckenpaugh, 2001; Sell, 1997). Hershey (1994) gave instructions for building hydroponics systems at different scales using easily available materials like plastic soda bottles and film cans. Sell (1997) also outlined considerations for different types of hydroponics systems and listed advantages of hydroponics, including: no need to water plants over weekends/breaks, little maintenance after installation, opportunity for cross-curricular projects and its status as “the technology of the future” (p. 73). After the construction and establishment of a hydroponics system, class experiments can be conducted to reinforce class concepts. For example, Hershey (1992) gave an in-depth description of an advanced class project to explore pH changes in the nutrient solution of hydroponically grown plants. Other possible class projects to explore plant biology and general science include conducting nutrient deficiency experiments (Hershey, 1994).

In a contemporary example of hydroponics in education, Carver and Wasserman (2012) used a long-term, inquiry-based hydroponics lesson derived from the work of NASA biologists. This lesson combined the space exploration element with sustainability concepts on water scarcity and agriculture. The goal of the lesson was for students to explore hydroponics, design an experiment using hydroponics (e.g. effect of temperature on plant growth) and then carry out the experiment. The authors evaluated the project with pre/post-tests, surveys and concepts maps and found that there was a positive change in student understanding and attitudes towards science (Carver & Wasserman, 2012). To conclude, Carver and Wasserman (2012) discussed the great potential for hydroponics in cross-curricular activities and inquiry-based student experiments.

Similar to aquaponics in education, there are relatively few examples and guidelines for hydroponics in education, especially as compared to aquaculture and agriculture. However, the experiences of educators may be similar because both hydroponics and aquaponics are living teaching tools.

School Gardens

School gardens are a final example of a living teacher tool and they parallel aquaponics in education in many ways. As a result of these similarities between school gardens and aquaponics in education, it is valuable to examine the current status and issues facing school gardens. Gardens can be implemented in schools at multiple scales, from containers to raised beds to greenhouses, and there are a variety of different types, including flower, butterfly, herb and vegetable gardens. Like aquaponics systems, gardens are multidisciplinary. Rationales for school gardens include their relevance to: ecosystem complexity, place-based learning, food systems, environmental attitudes and experiential education (Blair, 2009), as well as student achievement and psychosocial development (Ozer, 2007). Gardens also benefit children's nutrition by positively affecting their attitudes and behaviors towards vegetables and fruits (Ozer, 2007; Robinson-O'Brien, Story & Helm, 2009). Additionally, researchers have reported that gardens improved attitudes towards school, strengthened community connections and ultimately excited students (Blair, 2009).

School gardens have received widespread attention more recently because of their positive effects on children's nutrition knowledge and preferences for vegetables and fruits (Langellotto & Gupta, 2012). It has been argued that higher consumption of fruits and vegetables in children will combat childhood obesity and accompanying diseases (Robinson-O'Brien et al., 2009). National attention has thus been focused on decreasing childhood obesity rates through healthy eating and school gardens (Ozer, 2007). The focus and increased spending on childhood obesity can be compared to the increased attention on STEM education, and both school gardens and aquaponics in education may play a role in these issues.

Like aquaponics in education, there has been a lag in the amount of research on the prevalence, effectiveness and benefits of school gardens (Blair, 2009). Although research on school gardens is ahead of research on aquaponics in education, there is still a strong call for well-designed studies to evaluate the school garden movement (Robinson-

O’Brien et al., 2009; Ozer, 2009; Blair, 2009). Researchers in the past decade have worked to empirically analyze the effects of school gardens through multiple approaches. An early study by Skelly and Bradley (2000) looked at elementary school teacher perceptions of the importance of school gardens in Florida. Skelly and Bradley (2000) found that the schools had gardens, but they were not being used very often. However, teachers reported using gardens for environmental education and experiential education, and they felt gardens helped students learn better. Teachers cited lack of materials, knowledge, comfort and time as possible reasons for not using the gardens as much (Skelly & Bradley, 2000). Also, Skelly and Bradley (2000) reported that funding might be a barrier. Ultimately, Skelley and Bradley (2000) advocated for integrating gardens and garden activities into classroom lessons to increase usage and enhance learning.

The state of California is recognized for its school gardening initiative “A garden in every school” (Graham, Beall, Lussier, McLaughlin & Zidenberg-Cherr, 2005). In a study on the status of school gardens in California, Graham et al. (2005) surveyed the entire population of California public school principles on their school gardens. The authors found that the most frequent purpose for having a school garden was to enhance academic instruction, also for extracurricular activities and to provide edible produce. Most frequently taught subjects included science, environmental studies and nutrition. Responsibility for taking care of the garden resided predominantly with teachers, then parents and lastly students. Most principals thought the garden was moderately to very effective at enhancing science, but principals thought curriculum materials and lessons linked to the garden would help the garden to be used for academic instruction. Principals agreed that the biggest resource needed was funding to sustain the garden and the greatest barriers to having school gardens were time constraints, lack of relevant curriculum materials and lack of teacher interest, knowledge, experience and training. For schools without gardens, the three largest barriers were lack of funding, time constraints and lack of gardening supplies. Also, principals perceived gardens as being not to slightly effective at enhancing the school meal program (Graham et al., 2005). Ultimately, Graham et al. (2005) suggested that greater awareness of available materials, funding, assistance and training would be helpful in increasing school gardens.

As the studies above have shown, school gardens may face barriers, including: lack of time, funding, materials and knowledge (Skelly & Bradley, 2000; Graham et al., 2005). As a result, a recent study by Hazzard, Moreno, Beall & Zidenberg-Cherr (2011) reported the best practices of schools that had implemented or sustained instructional school gardens, in order to provide models for other schools. Hazzard et al. (2011) found that it was essential to have people committed to the school garden, especially a combination of administrators, teachers, parents, community members, garden coordinators and students. Grants were a common form of funding, as well as sponsorships, and schools found free or reduced cost materials to reduce the costs of implementing and sustaining the garden. Of the ten schools, nine had a part-time or full-time garden coordinator who spends their time taking care of the garden and facilitating its use. Master Gardeners, who provide free, high-quality volunteer service, were also essential. As far as actually using the garden for academic instruction, Hazzard et al. (2011) found that collaboration between garden coordinators, teachers and administration was key, and that quick, easy lessons based on state standards would be the ideal curriculum. Barriers reported included lack of time, funds, uncooperative administration, burned-out teachers, lack of committed volunteers and not having a paid full-time garden coordinator (Hazzard et al., 2011). However, Hazzard et al. (2011) state that schools that are able to overcome barriers and sustain gardens have a part- or full-time garden coordinator who collaborates with teachers to create and implement standards-based garden lessons, as well as support from the principal and administration. Ultimately, Hazzard et al. (2011) concluded that their findings fall into four areas that are key for sustaining instructional school gardens: people, funds, materials and instruction. The main recommendation made by Hazzard et al. (2011) to schools is to form a dedicated committee made up of different school and community members to avoid burnout and work together.

Summary of Comparisons to Similar Living Teaching Tools

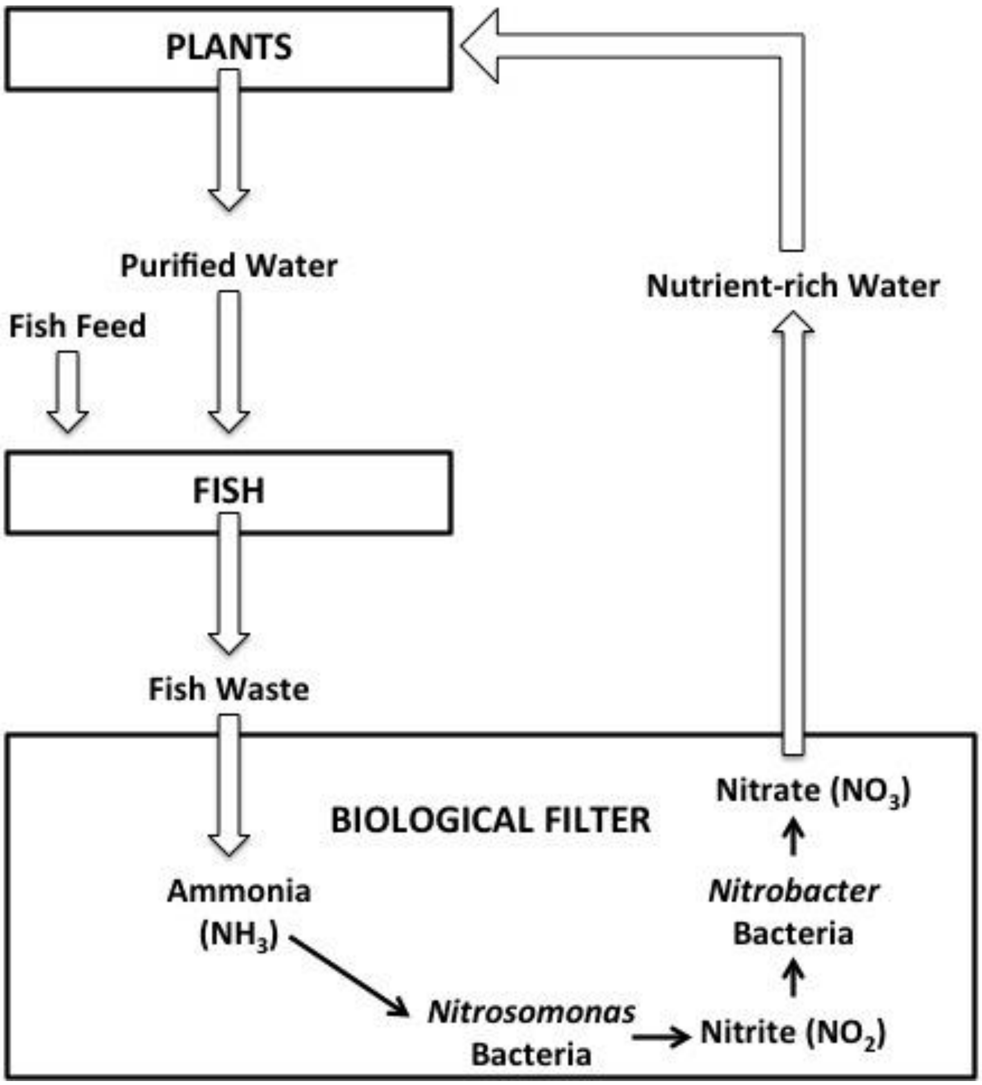
The literature on aquaponics in education is not comprehensive, making the exploration of aquaculture, hydroponics and gardens in education especially relevant to further understanding the current status of aquaponics in education. The above discussion of the literature on aquaculture and hydroponics in education, as well as school gardens, demonstrates the parallels to aquaponics in education. Each of the teaching tools described have a living component, which requires long-term care in order to thrive. Intrinsic to their definition, aquaculture, hydroponics, soil gardens and aquaponics also each requires space, building materials, funding, time and knowledge (Conroy, 1999; Hazzard et al., 2011; Hershey, 1994; Wingenbach et al., 2000a). Acquiring these resources may be challenging, as often described above, but the literature on aquaculture, hydroponics and school gardens also describe some solutions, including commitment (Conroy & Walker, 2000; Hazzard et al., 2011; Wingenbach et al., 2000b) communication and community (El-Ghamrini, 1996; Hazzard et al., 2011). Although there are differences between these teaching tools, it is possible to hypothesize that similar challenges and solutions may apply to aquaponics in education.

Thesis Objectives

Given the large potential for aquaponics in education, this exploratory research will reduce the current mismatch between research and practice. Using data collected through qualitative interviews with educators who use, or have used, aquaponics in education, this thesis research will investigate challenges to the implementation of aquaponics in education and possible solutions. This thesis research will also assess the success of implementing educational aquaponics systems by exploring why educators choose to use aquaponics and the outcomes of implementing aquaponics systems.

Ultimately, the findings of this study will be used to formulate broad guidelines for implementing aquaponics in education.

Figure 1: Nitrification in aquaponics (modified from Goodman, 2011)



CHAPTER 2

AN ASSESSMENT OF CHALLENGES, SOLUTIONS AND SUCCESS OF AQUAPONICS IN EDUCATION

Introduction and Purpose

The push for science, technology, engineering and mathematics (STEM) education in United States schools has accelerated in the recent decade, mainly to produce more career scientists, increase economic prosperity (Breiner et al., 2012) and combat declining student interest levels (Osborne et al., 2003). Concurrently, the National Research Council (NRC) has updated its vision for K-12 science education in the United States, producing “A Framework for K-12 Science Education: Practices, Crosscutting Concepts, and Core Ideas” specifically to give students an interdisciplinary science background and to experience the realities of doing science (NRC, 2012). The framework emphasizes crosscutting concepts, such as patterns and systems, and their application to learning core ideas (NRC, 2012). Given this emphasis on interdisciplinary science and STEM education, educators are exploring strategies of teaching and learning that align with the current goals.

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 living teaching tool for enhancing STEM 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 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 (Figure 1).

As a 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). These systems can be constructed from recycled materials and within the constraints of a small budget (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 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; to keep a system balanced, water levels, temperature, pH and nutrients must match the demands of both the plant and fish species, as well as the crucial nitrifying bacteria (Tyson et al., 2004). Crops and fish must also be managed at a ratio of nutrient inputs/outputs for optimum production, which varies according to species, system size and cropping system (Rakocy et al., 2004). Additionally, the rise of aquaponics systems is 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* article that investigated the growing aquaponics phenomenon quoted Rebecca Nelson, of the recognized 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 parallels between the goals of science education and the intrinsic nature of running an aquaponics system. 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 ongoing care required of aquaponics systems may also encourage responsibility, leadership and teamwork, while fostering community. These aspects of aquaponics reflect the skills needed in STEM fields as well as the goals of the NRC framework: crosscutting concepts, such as patterns and systems, and their application (NRC, 2012).

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 North America. Examples of aquaponics in education have also surfaced in 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 et al. (2002) described the Aquaponics in the Classroom program that was developed as a component of the AgriScience Education Project at the University of Arkansas. 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 Agriscience Education

Project was unique because it loaned out systems, which may reduce the burden on teachers to build and maintain a system for the long-term. However, loaning systems at no-cost may have other negative tradeoffs, perhaps causing teachers to undervalue the aquaponics system and the commitment that may accompany true ownership.

The growth of aquaponics in education is also 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 the potential possibilities for aquaponics as a living teaching tool, peer-reviewed articles on the use of aquaponics in education are almost nonexistent. As a result, claims that aquaponics is an effective and appropriate teaching tool are not substantiated by empirical research, and there are no studies that assess student learning before and after using an aquaponics system, as compared to a control group. The potentially complicated process of building and maintaining an aquaponics system may also present challenges that preclude its educational use in the first place.

The purpose of this research is to explore aquaponics in formal education, specifically focusing on the process of starting educational aquaponics systems, solutions to potential challenges and the conceptualization of success. 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 exploratory research uses qualitative research methods to address 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); What were the original goals of the educators for their aquaponics system and how do these compare to the current reality and/or actual outcome of the educational aquaponics system? (RQ3); Based on their experiences, what advice do educators have for others who want to begin using educational aquaponics systems? (RQ4).

Methods

Sampling Framework

This study was designed to explore aquaponics in formal education, specifically focusing on the process of starting educational aquaponics systems and factors that contribute to successful implementation and maintenance. Qualitative data were collected through phone interviews with educators who currently or had in the past used an aquaponics system in an 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 multiple types of 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 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 United States. 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 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 and participants were encouraged to suggest other potential participants, employing a snowball sampling strategy (Rossman & Rallis, 2012).

Additionally, it is important to note that potential participants who may have had negative experiences with aquaponics in education may not have felt comfortable participating, despite the stated value of their experiences to the current research. As a result, data from those who may have had more negative experiences with aquaponics in education may not have been collected and this aspect of the purposeful sampling strategy may be reflected in the research findings.

Interview Protocol

Names and contact information of potential participants were collated into a Microsoft Excel database. Potential participants were then contacted via electronic mail to elicit participation and confirm their eligibility as an educator who used or had used aquaponics in an educational setting in North America. Electronic mail was used as the communication medium because those addresses were more readily available than phone numbers and participants could respond at their convenience. Pre-written templates were used to send electronic mail to maintain consistency but all correspondence was personalized. Before negotiating an interview time with qualifying participants, a letter outlining the research study, as well as measures to ensure confidentiality and anonymity, was sent via electronic mail (Appendix A). After confirming participants' eligibility and willingness to participate, a convenient time was found to conduct a phone interview. 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.

A semi-structured interview guide was used (Appendix B) 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 (Table 1). 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 also asked to briefly describe the system that they had, although that is outside the bounds of the current research, in order to more fully engage them. Participants were then asked about if and how they had overcome potential challenges. Interviews were concluded by asking about the goals of the project, if they had been met, and advice that the participant may have for others in similar situations. Following each email, participants were thanked via electronic mail. Each participant was assigned an identification number and a pseudonym, unless they allowed their real name to be attached to their data.

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. It is also well known that there are biases inherent to interviewing, such as respondents' possible desire to answer positively to please the interviewer, i.e. courtesy bias, which may also affect the data collected. Finally, although the interview questions were evaluated by a second researcher before 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 (Appendix C). Data were managed using software for qualitative data analysis (Dedoose v. 4.5.95).

Results

Participant Descriptions

Qualitative data were collected through phone interviews with ten educators (n=10) who currently or had in the past used an aquaponics system in an educational setting in North America. The difficulty in finding participants is illustrated in Table 2, which shows the discrepancy between potential participants who were contacted and those who actually participated in the study. Interestingly, the use of the popular social networking website Facebook produced no relevant responses or potential participants, despite the high level of potential participants who may have viewed the request. While similar discussion posts on the AquacultureHub and Aquaponics Association community websites also did not produce any actual participants, they did produce the connection with the National Aquaculture Educators Network listserv, which was invaluable.

The ten participants who contributed to this research use or have used aquaponics in diverse educational settings. The educational institutions represented were public (n=5), private (n=2) and nonprofit (n=3) (Figure 2). The age levels served by the institutions were post-secondary (n=2), secondary/grades 9-12, (n=4), middle/intermediate/grades 6-8, (n=1), elementary/grades K-5, (n=1), middle/intermediate and secondary (n=1) or all K-12 (n=1) (Figure 2). At these institutions, the research participants were teachers (n=4), professors (n=2) or held another supporting role, such as grant coordinator, aquaponics manager or involved community member (n=4) (Figure 2).

Qualitative data were collected via phone interviews over a three-month period from February to May, 2013. Most participants responded during the first month (n=6), and then responses slowed to three during the second month (n=3) and one during the last month (n=1) (Figure 2). The number of emails sent by the researcher to the participant to negotiate their participation and an interview time (excluding the thank-you email and phone calls) was also collated. Most participants received 3-5 emails (n=8), while one received 6-8 emails (n=1) and one received 0-2 emails (n=1) (Figure 2). The participant who received the most emails was also the last respondent. Most interviews were between 20:01-30:00 minutes in duration (n=4), while two were between 10:01-20:00 minutes (n=2), two were less than 10:00 (n=2) and one was greater than 30:00 minutes (n=1) (Figure 2). The participant who required the fewest emails to establish an interview also had the longest interview.

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. For example, Steve[1] described a "random conversation" with a friend that led to his introduction to more people doing aquaponics in the community, which prompted him to decide it would be a fun classroom project (Steve, 11-17). Beyond the story of their initial introduction to aquaponics, educators gave their beliefs about why aquaponics was a desirable teaching tool in response to this question, as well as unprompted throughout the course of the interview. The beliefs and reasons for using aquaponics emerged as five main areas that have been titled: hands-on learning, flexible, food concepts, fun and STEM concepts. Of the 58 excerpts in which participants described why they use aquaponics, 26% (n=15) were coded as hands-on learning, 26% (n=15) as STEM concepts, 24% (n=14) as food concepts, 17% (n=10) as flexible and 7% (n=4) as fun (Table 3).

The hands-on aspect of aquaponics in education was seen as desirable by participants, exemplified in this statement by Thomas, an environmental science professor using aquaponics in his institution's Food for Sustainability project:

> It's served as a platform for students to have a hands-on experience and explore some topic that they're interested in. (Thomas, 331-332)

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)

Another main reason cited by participants for their use of aquaponics was its status as a food production technique. Many participants wanted students to learn more about food production, introduce sustainable food production strategies and produce some of their own food. Julian introduced aquaponics to his existing aquaculture program because of its connection to sustainable food production and seafood, as well as to the larger community:

> We're on the coast and we have families who have been doing that [fishing] for generations. So it fits in well with what we're doing. A lot of them are having a pretty tough time. Most of the oysters have disappeared, with the hurricanes and oil spill. Fishing's getting harder, they keep changing the loading limits on fishing the Gulf. So we were trying to find something for them to diversify into. (Julian, 83-87)

Aquaponics was also viewed as a flexible teaching tool that can be used for a variety of lessons and situations. Alex, an educator at a nonprofit organization that specializes in aquaponics and aquaculture for youth education, described the interdisciplinary uses of aquaponics:

> It's just a great system that you can really integrate writing, math, science, really anything into it. (Alex, 215-216)

In all, research participants stated that they used aquaponics for flexible, hands-on teaching and learning of STEM and food-related concepts. Some participants also stated that they used aquaponics because it was fun.

<u>In Educational Settings Where Aquaponics is Implemented and Maintained, What Challenges do Educators Face and how Have They Overcome These Challenges? (RQ2)</u>

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% (n=28) related to technical difficulties resulting from the nature of aquaponics, 17% (n=14) mentioned space and location and 12% (n=9) described time constraints, in addition to five other challenges (Table 4).

Technical difficulties intrinsic to the nature of aquaponics were the most frequently cited challenges (n=28). 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)

Thomas also described some of the other technical challenges that he faced when implementing his first system:

> We purchased a glass 55 gal tank and some plastic floating rafts, net pots and rockwool and spent a summer just trying to figure out how to make the thing work. The entire first summer was just a failure in terms of growth. We were killing our bacteria with chlorinated water, we had algal bloom problems with black hair algae because we were in a greenhouse getting a lot of sun exposure, and we wound up having to cover our tank up with a shower curtain. (Thomas, 78-84)

The technical difficulties described by the research participants (e.g. ratios of fish to plants, algae growth, nitrogen cycling, maintenance) are inherent to aquaponics technology.

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. Two participants stated that they had problems with their aquaponics system in the hot environment of a greenhouse. Sally, an interdistrict grant program manager who has been heavily involved in her agriscience high school's aquaculture and aquaponics program, commented on the greenhouse environment:

> When it's boiling hot in the greenhouse it doesn't grow, so we discovered that. (Sally, 172-173)

Two other participants discussed challenges as a result of their school or classroom environments. 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)

Steve commented on space in his classroom:

> My classroom is not a particularly big classroom, it's probably 24 by maybe 28 or 30 feet, so it's not small but it's not huge. If I were building a commercial system, I would certainly be using round or oval tanks, never an aquarium. But aquariums are the right shape to fit nicely along a classroom wall. I have grow lights that are on a cart so I can move those around, so if I need more space I can move those things. I think, to me saying that you can't do an aquaponics system in a classroom is more of an excuse than a reality. (Steve, 209-215)

Some participants discussed the time that it takes to implement and maintain aquaponics systems as a challenge, especially given other responsibilities. Alex 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)

David also discussed the time constraints that can exist for teachers, especially in relation to standardized testing:

> I don't know if this is true at nicer schools in posher towns, but I suspect it's the case everywhere, that the teachers are so focused on standardized tests and the curriculum that they're required to go through, I think they don't feel like they have much time to be concentrating on something else, and they don't really have the flexibility, even when they're teaching something math or science related. (David, 122-126)

Caring for an aquaponics system over the summer and holidays was mentioned as a challenge in 8% of excerpts (n=7), because living plants, fish and bacteria require ongoing attention (Table 4). Alex summarized this aspect of aquaponics in education:

> Things to consider as a teacher, what happens over vacation, over the summer, who's going to take care of it, those are some challenges… (Alex, 218-221)

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)

Challenges as a result of institutional bureaucracy were also noted in 8% of excerpts (n=7), which was defined as complicated administrative procedures (Table 4). Janet described how the school policy influences her ability to access the aquaponics systems for critical care (e.g. when oxygen levels drop unexpectedly and endanger fish health) and maintenance of her two aquaponics systems:

> These systems can only be observed on school days during relatively normal business hours (7AM-6PM), unless special permits are obtained, or special relationships are established with the school building management staff […] so coming to perform maintenance procedures in a timely fashion can be difficult, especially in the event of true emergencies. (Janet, 161-167)

Some participants directly described a lack of knowledge of aquaponics as a challenge in 7% of excerpts (n=6), which were coded as information gap (Table 4). For example, Steve touched on how he was “totally ignorant of nitrogen cycling” (Steve, 264), and Thomas 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)

Participants described funding as a challenge to implementing and maintaining an educational aquaponics system in 7% of excerpts (n=6) (Table 4). Steve explained his experience with funding for his aquaponics systems:

> I would say that’s the other big thing, especially because the dollars involved, it’s pretty easy to get five hundred, a thousand, couple thousand dollars tied up in a small system. […] I don’t mind buying small stuff, I don’t mind paying for the fish and the fish food, but if I’ve got to go buy another 250 gallon stock tank, my wife frowns on that money coming out of our bank account. (Steve, 328-335)

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 % (n=22) were coded as technical solutions and 84% (n=108) as nontechnical solutions, of the 130 total excerpts (Table 5). Often, participants described their challenge and their solution in the same explanation. It is also important to note that some participants described solutions that they would like to undertake but had not yet at the time of the interview. These solutions have been coded into the appropriate category because of their potential for helping educators to overcome challenges facing aquaponics in education.

Participants described technical solutions to challenges, which were categorized as either system modifications (13%, n=18) or other adjustments (3%, n=4) (Table 5). 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 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)

Steve illustrated his experiences with fitting a system into his classroom:

> I've got a five channel NFT system that's about 95% done in my classroom, and we have all of the pieces, we're just actually scouring right now Craigslist and eBay looking for an aquarium that will fit into a cabinet space that we've got available. (Steve, 72-75)

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% (n=26) mentioned community connections and support and 15% (n=19) described a passion for aquaponics in education, which were the two most frequently cited solutions (Table 5).

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)

Steve discussed the positive energy generated through a community of aquaponics practitioners:

> Certainly one person can do it, the synergism that comes with having two teachers in the same building that are doing it, everything that comes with that is positive. […] I think one person on an island can start, but over the long haul, two people, three people, ten people just makes the journey that much more fun. (Steve, 499-505)

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 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% (n=13) of excerpts cited a mentor with experience as a helpful asset for overcoming challenges (Table 5). Alex described how she was fortunate to learn about aquaponics from an experienced mentor:

> I started working here two years ago, and I was lucky enough to overlap my time with the woman who had been working in aquaponics for awhile. (Alex, 78-80)

Thomas also discussed how working with a local fish farmer was helpful:

> Luckily we worked with a local [fish] farmer who had actually attended the UVI [University of the Virgin Islands] summer course, he is doing aquaponics as an extension of his koi farm. He taught us a lot, just about how these things work and what you have to look for, and after awhile we became experts within our own community, just sharing information. (Thomas, 125-129)

A shared quality that emerged as a possible solution to overcoming challenges in aquaponics in education was a willingness to problem solve and use trial and error logic (9%, n=11). Thomas summed up this process:

> After that first summer though we got a handle, we made enough mistakes that we became experts in what not to do, so there was only what to do correctly left (Thomas, 84-86)

Participants mentioned that they delegated maintenance and work related to their aquaponics system to others, especially students. This characteristic was coded in 8% of excerpts (n=10) as outsourcing labor, and it was assumed to reduce the burden of caring for an aquaponics system (Table 5). For example, when asked about who maintains the aquaponics system, Julian replied:

> That's what students are for. (Julian, 77)

Steve also mentioned that students are involved in maintaining his aquaponics systems, but only during the school year:

> I would say that when school's in session, the students are pretty actively involved in the maintenance. During summer time and vacation periods, for the most part it's me. (Steve, 429-431)

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% (n=10) of excerpts from participants (Table 5). Sally discussed how she would have liked to be able to sell their produce:

> And I think also the ability to sell the stuff, I wish we had had that in place. To be able to sell that stuff and make a little bit of money would have been an interesting addition. (Sally, 132-134)

Related to the idea of self-sufficiency, participants also mentioned in 4% of excerpts (n=5) 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 in 3% of excerpts (n=4). In 2% of excerpts (n=3), participants described a rewarding experience with aquaponics that made it enjoyable for them and balanced out more negative experiences (Table 5).

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. Most frequently coded nontechnical solutions were community connections and support and a passion for aquaponics. Technical solutions presented were various system modifications.

What Were the Original Goals of the Educators for Their Aquaponics System and how do These Compare to the Current Reality and/or Actual Outcome of the Educational Aquaponics System? (RQ3)

The purpose of this question was to inquire into the success of participants with aquaponics in education, assuming that success could be measured by the achievement of a participant's original goals. Of the ten participants, four stated that they had met their intended goals, which included large-scale food production and student-run businesses. Of these, one participant stated that the original goals had been vague and another described how they had achieved their goals on a smaller scale than intended. Thomas described how their goals had been achieved, although not exactly at the scale they want to reach:

> Right now, it seems like we're doing what we wanted to do, maybe at a smaller scale. So instead of at the community level, we're doing this mostly on the campus level. But still we've realized all of the goals originally that we set out to accomplish. (Thomas, 217-220)

Two educators described how a portion of their goals had been achieved or changed. For example, Sally discussed how the goals for her aquaponics in education project had changed over time and how she perceived the process to be important:

> Yes, as with every project you end up somewhere else where you didn't expect to be. We were supposed to be growing lettuce but we ended up growing basil, and the basil was very successful and I still have people asking for pesto. People were offering to buy it. And we had the culinary students make it, so it was totally in house. So you always get something unexpected, you know you're not really sure where you're going with it. Did we meet our goals? Not as written, but we did achieve something and we learned something and it will help us move forward. (Sally, 291-297)

One participant commented that he/she had not met the original goals as stated and a second participant had an educational aquaponics system in progress. A third participant did not describe original goals but had multiple aquaponics systems and the long-term goal of building a large greenhouse. Finally, one participant did not discuss goals because of time constraints but was in the process of expanding the aquaponics system.

When asked about the goals for their educational aquaponics systems, and over the course of the interview, some participants valued the overall experience of implementing aquaponics in education even if they had not achieved their goals. Participants also described how they were applying the knowledge they had gained to future projects whether or not they realized their original goals as intended. Excerpts from participants that expressed value for the experience and process of implementing aquaponics in education were categorized as learning experiences (n=11). Steve summed up this sentiment when he stated that:

> We're certainly not doing it right or best or as efficiently as we could, but we're stumbling along every day making mistakes and we're learning along the way. (Steve, 326-328)

Ultimately, there was variety in participant responses on the original goals, current realities and project outcomes of participants' educational aquaponics systems, although some participants expressed value for the overall learning experience.

<u>Based on Their Experiences, What Advice do Educators Have for Others who Want to Begin Using Educational Aquaponics Systems? (RQ4)</u>

Near the end of the 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 (Appendix D), 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. Janet stated:

> I've found that aquaponics on these smaller scales are a lot more delicate and sensitive to changes in the environment – and, changes in the environment have much more drastic effects on the smaller systems – and implementing successful solutions has proven a bit more difficult. […] You can certainly have a small, tabletop aquaponics system, but I feel information gets lost when you simplify this much and minimize interaction with the system. (Janet, 59-62, 236-238)

Overall, participants gave advice to other educators and many commented that "small" might be an ideal size for an educational aquaponics system, although one participant disagreed about "small" as an ideal size.

Discussion

This exploratory research used a qualitative approach to assess challenges, solutions and success as described by ten educators who have implemented and used educational aquaponics systems in North America. The most frequently described uses for aquaponics were flexible, hands-on teaching and learning of STEM and food-related concepts. Participants reported two broad challenges to implementing aquaponics: technical difficulties as a result of the nature of aquaponics and restrictions as a result of their school settings. Solutions given by participants were physical aquaponics system modifications and the development of intangible characteristics, especially community connections and support, passion for aquaponics and willingness to problem solve. In this study, success in aquaponics in education emerged as a cyclical pattern: participants valued the overall learning experiences of aquaponics and the continued application of these learning experiences.

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 contribution. This may be inherent to the research design. For example, in studies on aquaculture in education and school gardens, researchers contacted participants through one comprehensive existing organization (Conroy, 1999) or sampled all public schools in a state (Graham et al., 2005). However, there is no national organization for aquaponics in education and educators using aquaponics are geographically widespread, making it challenging to establish an inclusive study on aquaponics in education using established methods. The discrepancy between potential and actual participants may also be related to an intrinsic quality of the population. For example, educators using aquaponics may be unable to participate in a study because of severe time constraints, which would exemplify the challenge busy educators face implementing aquaponics. 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.

Although some study participants used aquaponics as a student-run business or aspired to do so, none of the participants mentioned that they used aquaponics in education explicitly to strengthen the existing aquaponics industry. In contrast, a central goal of aquaculture education is to create a more skilled workforce, raise awareness and increase knowledge of aquaculture (Brown, 1995). This discrepancy may be because aquaculture is currently a larger industry than the newer, smaller aquaponics industry. However, the use of aquaponics in education will be crucial for the expansion of the industry in order to familiarize students and produce career aquaponics practitioners.

Hands-on learning and the relation to STEM concepts were the most cited reasons for using aquaponics in education in this study. However, 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. As Wardlow et al. (2002) suggested, there is still a need for more information on how educational aquaponics units are used in the classroom. For example, it is not known if the implementation and maintenance of aquaponics is the learning experience unto itself, or if students are also conducting long-term experiments or academic activities. Documenting the actual use of aquaponics as a teaching and learning tool will be critical for the development of appropriate aquaponics-based curricula and the expansion of aquaponics in education.

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.

An examination of the literature on other living teaching tools reveals that the challenges reported by participants in this research are similar to those previously reported. Trouble with nitrogen cycling and system set-ups have been listed as challenges to aquaponics by Johanson (2009), and the aquaculture and school garden literature also report technical and nontechnical challenges as a result of the need for money, time, equipment, space, expertise and weekend/holiday care (Conroy, 1999; Graham et al., 2005; Hazzard et al., 2011; Lovett, 1999; Wardlow et al., 2002). Ultimately, most of the challenges to aquaponics in education reported by the study participants have also been reported for other living teaching tools.

However, the most frequently reported challenge in this study was technical difficulties as a result of aquaponics technology. This challenge may be accounted for in the literature as a need for expertise and knowledge but it is not as explicitly stated as in this study. The reasons for the technical difficulties may be because of the combination of both aquaculture and hydroponics, which can be logistically challenging (Rakocy, Masser & Losordo, 2006). Additionally, maintaining water chemistry for healthy growth and biological filtration can be complex, requiring a balance between temperature, pH, oxygen and alkalinity (Rakocy et al., 2006). Combined, the technology and fundamentals of aquaponics seem to present some of the most crucial challenges to implementing aquaponics in education.

Exploration of challenges facing the implementation of aquaponics in education would not be complete without subsequent investigation into potential solutions. In this study, participants made physical system modifications to overcome technical difficulties and also reported intangible characteristics such as community connections and support for overcoming challenges. Although the solutions reported by study participants fell into technical and nontechnical categories, I postulate that it is the intangible characteristics that drive the development of technical solutions. For example, replacing the plumbing in an aquaponics system to mitigate flooding is a physical, technical solution to a technical problem. However, replacing the plumbing requires expertise, which may be sourced from a knowledgeable community, and a desire to make the aquaponics system more effective in the first place, which embodies a passion for aquaponics in education. Overall, it seems that solutions to challenges reported by the study participants can be divided into two categories with intangible characteristics motivating the development of other, often technical, solutions.

The literature on living teaching tools, especially aquaculture in education and school gardens, offers similar solutions. El-Ghamrini (1996) reported the importance of connections between high schools with aquaculture systems and the local communities, concluding that communication is necessary for technical innovation. Wingenbach et al. (2000b) found that hard work, dedication and outside help were necessary for aquaculture in education, while Conroy (1999) concluded that teacher commitment and administrative support facilitated successful aquaculture implementation. In the literature on school gardens, Hazzard et al. (2011) reported that commitment to the garden from multiple parties was key to long-term success. The findings from the literature on living teaching tools support the results of the present study: that the development of intangible characteristics, such as passion and a supportive community, are helpful for overcoming challenges facing aquaponics in education.

Community connections and support emerged most frequently as a potential solution to challenges faced by educators implementing aquaponics in education.

Participants in this study described ties with other energizing teachers in their schools and helpful businesses who gave donations of time and resources, as well as networks of aquaponics practitioners that offered guidance. Participants reported that these connections helped to support their aquaponics project and also drove them to do aquaponics in order to positively contribute to a larger community. For example, Thomas and his university students developed a small program where they managed aquaponics systems in local K-12 classrooms and used them for hands-on science teaching (Thomas, 49-64). In this example, the connections between the university and the nearby schools enabled aquaponics to be used in local K-12 classrooms and alleviated some of the responsibility that would otherwise be placed on the K-12 teacher. Steve also talked about how the owners of the local business who inspired him to start an aquaponics project volunteered to spend time teaching his students about aquaponics (Steve, 120-124). In this example of community connections, Steve reached out to his local community to gather more information on starting and running aquaponics systems, minimizing the information gap. The importance of community that emerged in this study is similar to the results reported by El-Ghamrini (1996): communication and connections between high schools and the local community accounted for positive growth of aquaculture in education. It is clear that these connections with other educators, business owners and community members were important to many of the study participants. Ultimately, the results of this study show that cultivating community connections is helpful to overcoming challenges to implementing aquaponics in education.

The theme of passion for aquaponics in education frequently emerged as a nontechnical solution. In this study, a personal passion and interest in aquaponics is assumed to drive dedication and commitment to overcoming challenges. Similarly, Conroy (1999) stated that possibly the most important message from her study on aquaculture in education was that teachers adopted aquaculture despite the serious barriers because they believed in it and internalized this commitment. The results of this study show that passion for aquaponics, similar to other teaching tools like aquaculture, can be essential to motivating the development of solutions.

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. Although summer and holiday care for educational aquaponics systems lacks definitive solutions, this challenge also presents opportunities for the development of alternative models of aquaponics in education. For example, a mobile aquaponics system may be shared between teachers at the same school who then split the responsibility over the summer. It may also be worthwhile to explore a loan model, where aquaponics systems are contracted out to schools by a central organization (e.g. nonprofit) that collects or manages them over the summer. 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 (Figure 3). 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)

Success: Goals and Current Realities

Participants were asked about the original goals for their educational aquaponics system and if they had achieved these goals. The purpose of these questions was to inquire into the successful implementation of aquaponics in education, assuming that success could be measured by the achievement of a participant's original goals for their educational aquaponics system. It is important to state that the concept of success in this study focused on the functioning of the physical aquaponics system and not on measuring success in student learning. Although some of the participants did not have concrete original goals or had goals that were unachieved, many still stated that their goals for aquaponics in education had been achieved. Even participants who had accomplished what they had originally intended still discussed how they wanted to achieve more or how their goals had changed over time. Ultimately, participants' achievement of success for their educational aquaponics systems appeared secondary to the value participants placed on the overall experience of implementing and using aquaponics in education.

Although a common definition of success of aquaponics in education has been elusive, a central theme that emerged in this study was the value of the overall learning experience of aquaponics and the continued application of these learning experiences. In this framework, success is not a linear concept. Instead, success is cyclical: set goals; either achieve them as intended, achieve changed goals or realize a different outcome entirely; then set more goals using the learning acquired and repeat. However, a key component in this cycle of success is the motivation to continue and apply learning, even if a less than favorable outcome is realized. For example, an educator may build a classroom system but face an unexpected fish die-off; they may not be motivated to restart and apply the learning they may have gained. As a result, motivation, dedication and commitment, which stem from passion for aquaponics in education, can be assumed to be essential to this cyclical framework of success. Overall, successful implementation of aquaponics in education, as seen in this study, can be assessed through the value and application of learning experiences, not necessarily the achievement of original goals.

Despite the reported value of the learning experience to cyclical success in aquaponics in education, a perceived contradiction has emerged from this study. In defining success as a cyclical framework of applied learning, the actual, physical outcome of an aquaponics project may be irrelevant. This implies that the formation of original goals may not be necessary, if goals are assumed to shift or change entirely. However, one participant advocated strongly for having a plan, as well as multiple back-up plans, when undertaking aquaponics in education. Additionally, project plans are essential to grant applications, task delegation and responsible project management. As a result, it appears that there must be a balance between planning ahead for an aquaponics in education project and valuing the learning experience regardless of the achievement of original goals.

System Size

Participants in this study were offered the opportunity to give advice to other educators who would like to explore aquaponics in education. This advice varied and is tabulated in its original form in Appendix D so that those who are interested can access it directly. 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? Participants were not asked for a numerical response to explain what they meant by "small", but it may be worthwhile to further explore in future research.

I 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. On the other hand, an educator who values the potential for learning finance and management through running an aquaponics system as a business would benefit from implementing a medium to large scale system, rather than a tabletop system. A larger system would produce more and the ability to harvest produce on a regular production schedule is necessary for running an aquaponics business, 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 unique solutions. Nevertheless, the findings of this study can provide some helpful guidelines to educators who are interested in implementing educational aquaponics systems. For example, Figure 4 shows how solutions reported by participants in this research may be applied to challenges facing aquaponics in education. Additionally, 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, 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/holiday care early in the process and planning.

6. Continue to apply learning gained from implementing educational aquaponics systems in a cyclical framework.

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. Given this information, it would be useful to test these results against a larger sample of educators using a quantitative questionnaire survey. Conducting a large-scale survey of educators who use aquaponics in education would require coordinated and sustained outreach in order to find and reach a significant sample of the population. However, a large-scale survey would contribute more information on the current status of aquaponics in education, such as an ideal size for an educational aquaponics unit.

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. Additionally, streamlining and further developing aquaponics technology could reduce technical difficulties and advance the industry as a whole.

As mentioned in the discussion, there is no existing research on how educational aquaponics systems are actually used. 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. Additionally, there have been no controlled trials that measure student learning before and after using an educational aquaponics unit. 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.

Finally, there are many other avenues for creative qualitative, quantitative and mixed methods research on aquaponics in education. For example, mixed methods could be used to investigate the quality and accuracy of information on aquaponics in education, focusing on digital media such as videos and social networking forums. A participatory action research (PAR) project could bring together community youth around aquaponics and long-term community agriculture revitalization. Ultimately, a large-scale PAR project could link educators using aquaponics who will create a web-based social networking forum to foster community, gain expertise and encourage passion for aquaponics in education.

Conclusions

It is important to keep in mind that this study employed qualitative methods with a small sample of diverse educators using aquaponics. As a result, the data collected were rich and descriptive, but cannot be broadly generalized to all educators using aquaponics in education. Nevertheless, patterns emerged on the importance of passion, community and expertise in overcoming challenges, especially technical challenges, to aquaponics in education. Successful implementation of aquaponics in education also emerged as a cyclical pattern: participants valued the overall learning experiences of aquaponics and the continued application of these learning experiences. Most importantly, educators who use or want to use aquaponics in education can take these exploratory results into account in their unique situations.

Table 1: Four main topics covered during interviews with educators

Topic 1: Introduction	**Topic 2: Challenges & Solutions**	**Topic 3: Success**	**Topic 4: Advice**
Why did you start using aquaponics?	Describe the largest barriers and challenges involved in implementing and maintaining your aquaponics system.	What goals did you have for your aquaponics system?	Would you recommend aquaponics to other educators? Why or why not?
Can you tell me about your aquaponics system(s)?	Did you overcome these barriers and challenges? How?	Did you meet your original goals for your aquaponics system? How?	What advice do you have for others who want to use aquaponics?

Table 2: Discrepancy between potential participants contacted and actual participants

Source	Potential participants contacted (#)	Actual participants (#)
Aquaponics Association	66 views*	0
AquacultureHub	90 views*	0
Aquaponics Facebook groups	31,696 subscribers*	0
Total views + potential views	**31,852**	**0**
National Aquaculture Educators Network listserv	210	4
Referred by others	18	4
Websites and articles	6	1
Western Massachusetts Center for Sustainable Aquaculture	6	1
Total contacted directly	**240**	**10**
Total	**32,092**	**10**

*As of 6/6/13

Table 3: 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
Total	**58**	**100**

Table 4: 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**

Table 5: 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**

Figure 2: Characteristics of study institutions and participants using aquaponics in education (n=10)

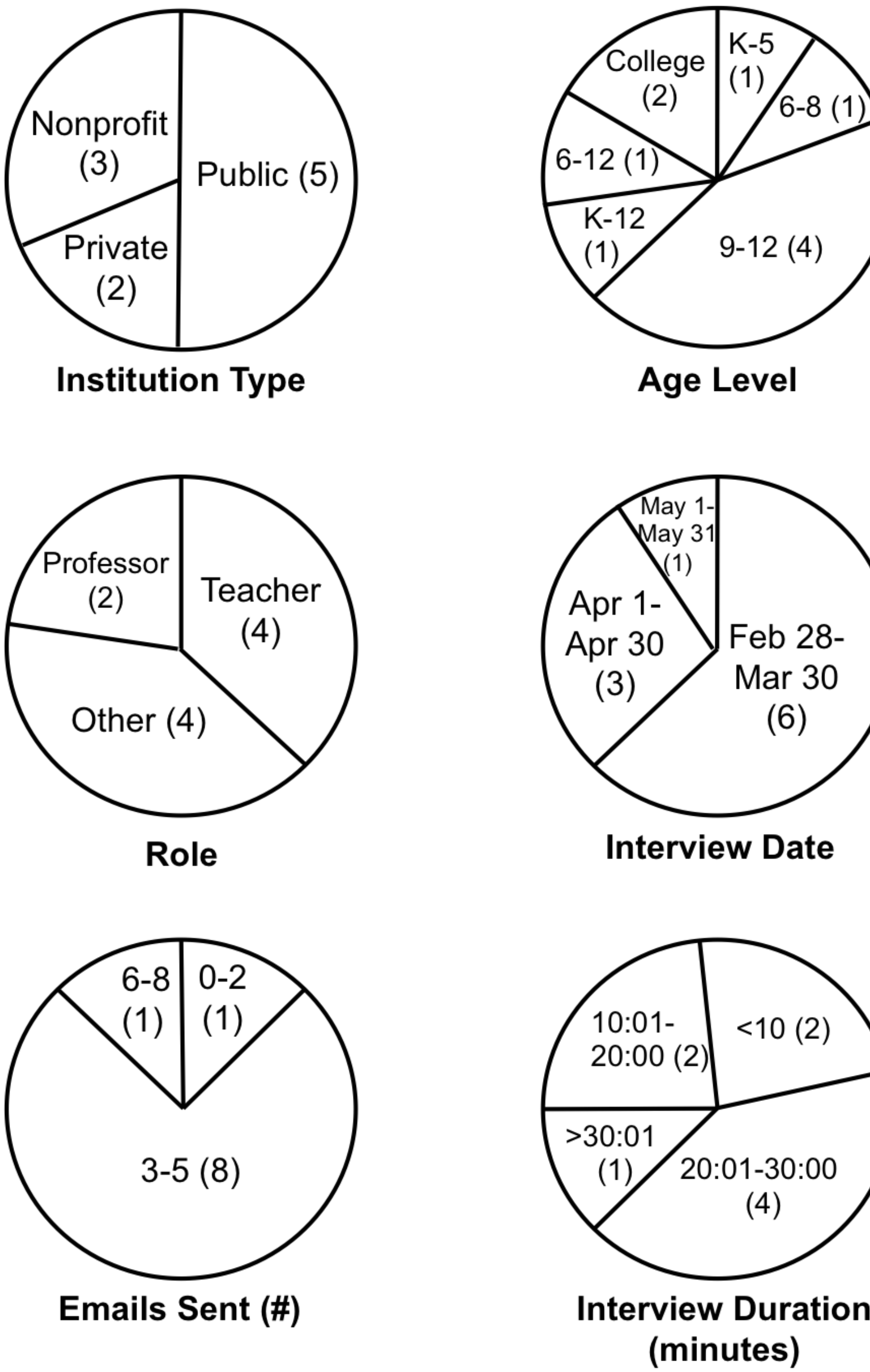


Figure 3: Community support, passion for aquaponics and expertise drive the development of individual system modifications to solve technical difficulties intrinsic to aquaponics

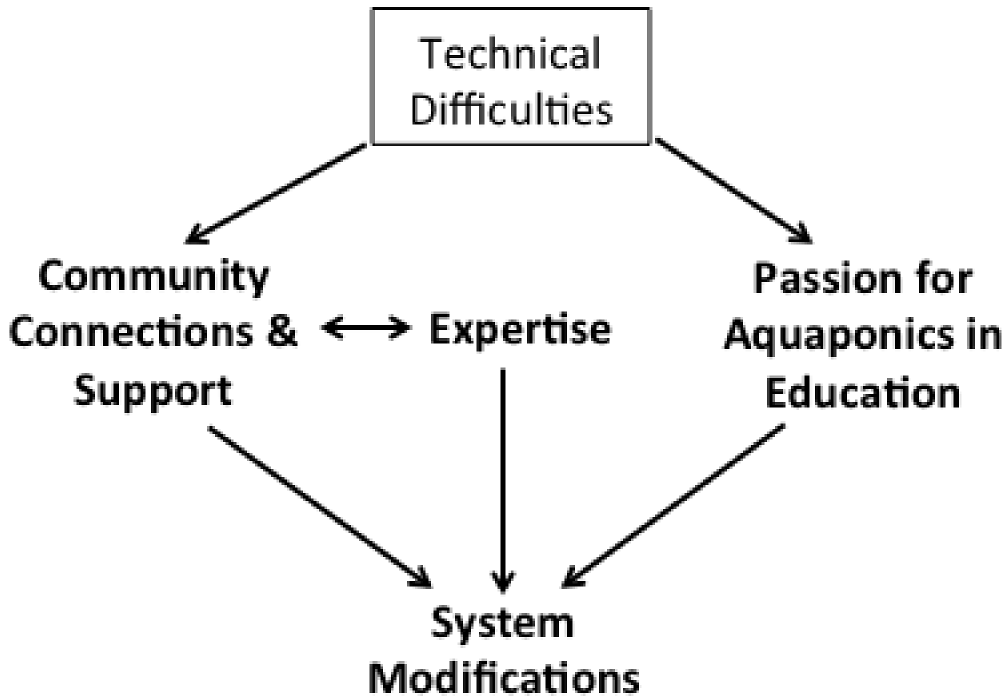
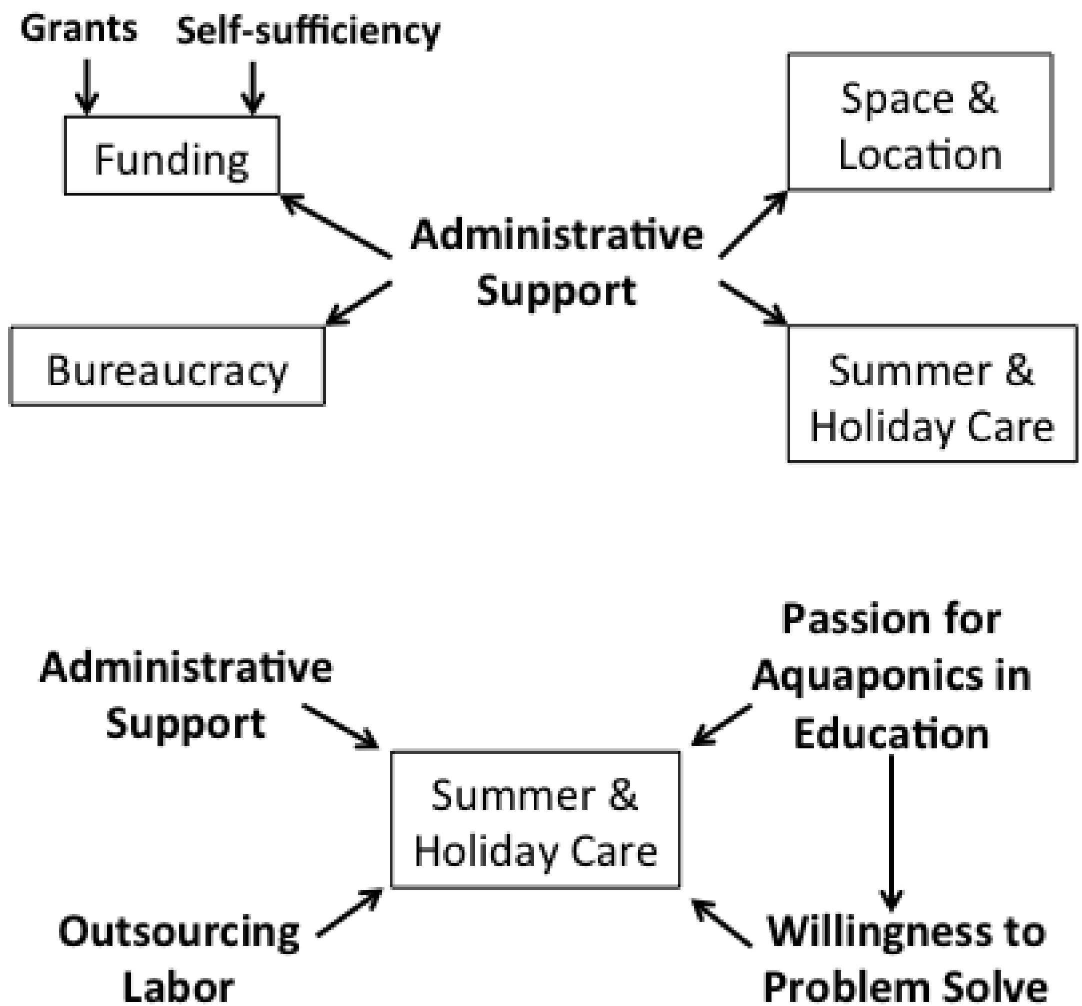


Figure 4: Two examples of how solutions suggested by study participants (bold) may be applied to challenges facing aquaponics in education



APPENDIX A

OFFICIAL INVITATION TO PARTICIPATE

Current Date

Dear Participant,

You are invited to participate in a research study on aquaponics in education. The purpose of this study is to explore the process of implementing and maintaining aquaponics systems in educational settings. After collecting information through conversations with educators, I hope to develop flexible guidelines for educators who want to use aquaponics in their schools and classrooms. This research is being conducted by Emily Hart, a Master of Science student, under the supervision of Dr. Andy Danylchuk, Assistant Professor of Fish Conservation, in the Department of Environmental Conservation at the University of Massachusetts Amherst.

Your participation is completely voluntary. If you choose to participate, you will have a conversation with me for about 20-30 minutes, via phone or possibly in-person. I will ask if you will allow me to record our conversation, solely for my research records. The information you provide will help me develop checklists and decision trees for educators who are considering starting an aquaponics system. I am happy to share my results and final paper with you if you are interested.

If you change your mind about participating at any time, I will permanently delete the records of our conversation and remove your information from my study. To protect your privacy, I will use pseudonyms to keep your identity and location anonymous, unless you ask me to use your real name and school. Our conversations will be kept confidential, although I may use your exact words in my final paper and any future publications. If you have questions about this study, please contact Emily Hart or Andy Danylchuk.

After reading this letter, please decide if you would like to participate in this research study. If you would like to participate, please contact me via email or phone to schedule a conversation at a time that is convenient for you. Thank you very much for your time.

Sincerely,

Emily Hart

M.S. Candidate in Environmental Conservation

APPENDIX B

SEMI-STRUCTURED INTERVIEW GUIDE

Hi ---- this is Emily Hart calling about my aquaponics in education project.

Is this still a good time to talk?

Pleasantries/questions about my project

Before we get started, can I record this conversation, just for my records?

How did you find out about aquaponics?

Why did you want to get into aquaponics at your school? What subject/grade do you teach?

Can you tell me about the system(s) you have?

When did you start the process of using/building a system?

Can you tell me about the process of setting up your system(s)?

What was that like for you and your students?

What were some of the challenges you faced in this process?

If you had to pick, what were the 3 biggest hurdles/limitations you came up against?

How did you (and your students) work through these?

How do you handle system maintenance? What has that been like?

Now, I’m wondering how your experiences with your system compared to your original expectations?

Can you tell me about your original goals/expectations/hopes for your system?

Would you say that your goals for the system have been met? How/why?

Would you recommend aquaponics to another teacher? Why? What advice might you have advice for them?

I will assign you a pseudonym to produce your privacy, unless you’re comfortable with me possibly using your name and school. What do you think?

APPENDIX C

QUALITATIVE CODE STRUCTURE DEVELOPED FOR ANALYSIS OF

AQUAPONICS IN EDUCATION INTERVIEW MATERIAL

Table 6: Code definitions and examples for RQ1: Why aquaponics? (continued onto next page)

Root code: Why aquaponics?		
Child code	Description	Example of coded data
Flexible	Aquaponics can be used for a variety of different topics and age levels	Over the course of about five years, I have managed to integrate it into my verbal education course, as a service learning project, I've integrated it into my junior seminar on sustainable development as an interdisciplinary business plan/campus sustainability there's a lot of umbrellas that it fits under, and I've done some of my own research with it as well. (39:28-32)
Food concepts	Aquaponics as a tool to teach/learn where food comes from and/or produce food	But I do it thinking that maybe one of them will, or two of them, or half a dozen, will jump into either environmental or some aspect of food production, that this will be a meaningful thing. The kids love to watch stuff grow, they love to be able to pick and eat stuff from a plant that they've started as a seed. I love it. (30:257-261)
Fun	Aquaponics is used because it's an enjoyable experience	It's been really fun overall. (39:317)
Hands-on learning	Aquaponics is used for hands-on, inquiry-based, real world learning/teaching	So I taught the class once, and I was thinking okay so what can I do to give the students an experience to use these tools we talk about in class and do a meaningful analysis, real world type of thing. (27: 124-126)
Other	Other reasons for implementing an educational aquaponics system	It's also important for young people to feel responsible for other living organisms, whether it's a plant or a fish. This sense of responsibility can have a profound influence on a young person's desire to participate and ask questions. "Maybe putting soap in the aquaponics system is a bad idea; it will hurt the fish. But I wash soap down the drain all of the time. Does that hurt fish, too?" They start to CARE about what they are doing and the possible consequences of their actions, and this often carries over into their everyday lives outside of the classroom. (53: 11-18)
STEM concepts	Aquaponics is used to learn science, technology,	Yes, it's definitely a great tool for science curriculum and biology. (05: 47)

	engineering and mathematics concepts, including research	

Table 7: Code definitions and examples for RQ2: Challenges (continued onto next page)

Root code: Challenges to implementation and maintenance		
Child code	Description	Example of coded data
Bureaucracy	Challenges because of institutional bureaucracy (def: excessively complicated administrative procedure, seen as characteristic of such a system)	These systems can only be observed on school days during relatively normal business hours (7AM-6PM), unless special permits are obtained, or special relationships are established with the school building management staff. I have been lucky for the most part in that the building manager for one school tends to let me come and go as I please. The other school is much more by the book, so coming to perform maintenance procedures in a timely fashion can be difficult, especially in the event of true emergencies (air pump failure). (53: 161-167)
Funding	Challenges related to securing funding to build and maintain the system	But getting funding took awhile because we had to think about how this was going to be integrated so we could explore research and educational opportunities, and then get the equipment to actually support all that. Like I described, it was really slow and we started with a small amount of money and we eventually increased, but it took awhile to do that. So that was probably another barrier. (39: 139-144)
Information gap	Lack of knowledge, expertise and/or information as a challenge to implementing and maintaining an aquaponics system	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. (16:163-165)
Other	Other challenges that don't fall into previous categories	You know, I think the biggest challenge, at least from what I've seen, is trying to get the students all on the same page. You talk about here's how you analyze a system, system x or system y, but then actually having them get there. Oh, one team forgot to measure something, or another team forgot to measure something else, or they measured everything right, they accounted for the right number of fish, the growing cycle of the fish, or oh they were totally in left field of the costs of materials, or the price they can get for their basil. Things that seem simple, but I guess aren't. So maybe they need a little more specific direction next fall. (27: 238-245)
Space and location	Challenges to using aquaponics as a result of the physical environment of the educator	Well they moved me from my original classroom that's carpeted, into a classroom that's tiled. So that when it leaks we just mop instead of steam clean the carpet. (30: 207-209)

	and/or institution	
Summer and holiday care	Challenges as a result of the need for care and maintenance of the aquaponics system over weekends, holidays and summer break	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. (40: 37-42)
Technical difficulties	Challenges as a result of the nature of aquaponics (including need for ongoing care of live organisms) and the system set-up	At first, they had a lot of trouble with biofilter maintenance. Solids were building up in it and they had to take it apart it and clean it, and one time they didn't get it back together in time and there was a bacteria die off. (05: 32-34)
Time	Time constraints as a challenge to implementing, maintaining and using aquaponics	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. (16: 159-162)

Table 8: Code definitions and examples for RQ2: Nontechnical solutions (continued onto next page)

Root code: Overcoming challenges to implementation and maintenance			
Child code	Grandchild code	Description	Example of coded data
Non-technical solutions		Educator & program characteristics & qualities that may contribute to overcoming challenges	
	Administrative support	Support expressed from the institution's administration	Yeah, I have both a principal, and because I'm at a private school, a headmaster that are, I won't say that they've given me a blank check, but everything I've gone to them and asked for, I've been pretty blessed to get. (30: 315-317)
	Community connections and support	Connections to a larger community, including those that create support and energy for the aquaponics project/system	I think it'd be difficult for someone in the K-12 setting to maintain a commercial operation, even though there are plenty of examples of schools around the country that are doing that, it would take some support though. It wouldn't be something a classroom teacher could do on their own, but rather it probably would need to be part of a larger program with a little bit of support. (39: 284-289)
	Expertise	Mentor: Expertise from someone other than the educator	I started working here two years ago, and I was lucky enough to overlap my time with the woman who had been working in aquaponics for awhile. (16: 78-80)
	Expertise	Personal expertise: The educator implementing and maintaining the aquaponics system has personal expertise	I have a master's in marine science and I worked in industry for about 20 years before I became a teacher, so I wanted a chance to do aquaculture. So I saw it as an opportunity for everybody to do what I wanted to do. (76: 12-14)
	Grant funding	Funding to implement and/or maintain the aquaponics system is from a grant	I got a grant to get four systems in four seventh grade classrooms. (40: 17-18)

	Other	Other examples of non-technical solutions for overcoming challenges	So we've been involved for a couple of years now, very much flying by the seat of our pants. Probably more lucky than good about the things we're doing, myself and another colleague Gary. (30: 18-21)
	Outsourcing labor	System labor is outsourced to students or other people, reducing burden on the educator	So I employ students to feed, monitor water quality, take care of removing solids from the system, replace water loss, breed fish, germinate seeds, harvest. (39: 200-202)
	Passion	Personal passion and interest in aquaponics, assumed to drive dedication and 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. (30: 246-248)
	Rewarding experience	A rewarding experience is valued because it outweighs negative experiences with aquaponics	Some days might be more overwhelming than others for the teachers because they have so many other systems to be responsible for, but other days I know are very rewarding (like when one school had their first generation of fry!). (53: 215-217)
	Self-sufficiency	The aquaponics system pays for itself (either fully or partially) by producing products that are sold or educators want to achieve this self-sufficiency	And I think also the ability to sell the stuff, I wish we had had that in place. To be able to sell that stuff and make a little bit of money would have been an interesting addition. If we were able to carry this on throughout the year as we had hoped we would, by this spring we'd know what we could grow, like we might be growing lettuce now instead of basil and have the market for it so we could make it self-sustaining. (42: 132-137)
	Trial and error and problem solving	Evidence of a willingness to explore solutions through trial and error and problem solving in order to overcome a challenge	So at the very beginning we had about a $500 budget. We purchased a glass 55 gal tank and some plastic floating rafts, net pots and rockwool and spent a summer just trying to figure out how to make the thing work. The entire first summer was just a failure in terms of growth. We were killing our bacteria with chlorinated water, we had algal bloom problems with black hair algae because we were in a greenhouse getting a lot of sun exposure, and we wound up having to cover our tank up with a shower curtain. After that first summer though we got a handle, we made enough mistakes that we became experts in what not to do, so there was only what to do correctly left. (39: 78-86)

Table 9: Code definitions and examples for RQ2: Technical solutions

Root code: Overcoming challenges to implementation and maintenance			
Child code	Grandchild code	Description	Example of coded data
Technical solutions		System modifications and adjustments to the physical environment and components to overcome a challenge	
	Other adjustments	Other physical adjustments to overcome challenges	We also had problems with our hot environment, so we tried to create a cool microclimate so we could actually get the lettuce to grow. (05: 34-36)
	System modifications	The physical aquaponics system and/or components are changed to solve a technical problem or challenge, including adaptations from an system ideal (e.g. square aquariums instead of round tanks)	One of them ended up, just before I was there, and one of them ended up leaking on the floor, and a bunch of the floor tiles had to be replaced. That really soured the teachers, the custodians and the administration on weird science projects, and on letting outside people come in and build things. So it did take quite awhile to rebuild that trust. I certainly go far beyond the minimum necessary to build everything so it looks like really solid furniture. (48: 181-187)

Table 10: Code definitions and examples for RQ3: Original goals and current realities

Root code: Original goals and current realities			
Child code	Grandchild code	Description	Example of coded data
Original goals		What were educators' original goals for their aquaponics system?	We were trying to grow greens, we did actually, for a local food kitchen. (42: 47-48)
Current reality and/or project outcome		The current status of the educator's aquaponics system	
	Achieved goals	Goals as stated were achieved	So the main goals were food production. We started small, about a 4x8 hydroponic set up, and then kept growing as we were more and more successful. At the point that I was there, we were harvesting 10lbs of lettuce every day and feeding about 125 people tilapia once a week. (05: 18-21)
	Learning experience	Outcome is different than original goals, but participant values the learning experience and process	Yes, as with every project you end up somewhere else where you didn't expect to be. We were supposed to be growing lettuce but we ended up growing basil, and the basil was very successful and I still have people asking for pesto. People were offering to buy it. And we had the culinary students make it, so it was totally in house. So you always get something unexpected, you know you're not really sure where you're going with it. Did we meet our goals? Not as written, but we did achieve something and we learned something and it will help us move forward. (42: 291-297)
	Unachieved goals	Goals as stated were not achieved	For us up here right now, it would be great if we could find some funding to do a large scale masters or PhD research project, but right now it hasn't been forthcoming. We've tried, but we're just not there so it's primarily been used as an undergraduate tool. (27: 190-193)

Table 11: Code definitions and examples for RQ4: Advice from educators

Root code: Advice from educators			
Child code	Grandchild code	Description	Example of coded data
Advice from educators		Based on their experiences, what advice do educators have for others who want to begin using educational aquaponics systems?	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. (48: 245-247)
	Scale of system	Ideas relating to the scale and size of an educational aquaponics system	Regardless of how invaluable I think the learning experience is of having and operating an aquaponics system, I have an issue with scaling down. You can certainly have a small, tabletop aquaponics system, but I feel information gets lost when you simplify this much and minimize interaction with the system. It's advantageous to be able to SEE and work with all of the parts to better connect them to their functions. (53: 235-240)

APPENDIX D

ADVICE FROM PARTICIPANTS ON AQUAPONICS IN EDUCATION

Table 12: Advice from participants (continued onto next page)

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.)

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Notes

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