Seeding the Future

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Learn how to create opportunities for young people from low-income, ethnically diverse communities to learn about growing food, doing science, and how science can help them contribute to their community in positive ways. The authors developed a program that integrates hydroponics (a method of growing plants indoors without soil) into both in-school and out-of-school educational settings.

Over the past decade, many programs have emerged that provide opportunities for students to work in the fields of farming and gardening (see Robinson-O'Brien, Story, and Heim 2009 for a good review of urban agriculture programs). Most programs have focused on outdoor urban gardening, which works well during the summer, when most students are out of school and low-income youth must find work to help support themselves and their families, rendering these students unable to participate. Because the growing season does not align well with the school year, particularly in northern climates, it can be difficult to continue outdoor gardening programs throughout the year. Further, most research has focused on students' behavioral changes in regards to their eating habits but have not carefully examined whether participation improves interest in studying science or exploring STEM (science, technology, engineering, and math) careers (Robinson-O'Brien et al., 2009; Zhang and Barnett 2014). Yet, despite the reported positive outcomes (Ozer 2007; Rahm 2002), researchers have found that in many cases outdoor urban gardening programs are often short-lived and do not impact a large number of students due to (a) teachers being “overloaded” with other duties, (b) lack of funding to maintain the program, (c) lack of support on the part of parents or volunteers, (d) lack of gardening experience by teachers, and (e) lack of space (e.g., space previously available for the garden being lost). Researchers have found that, despite these challenges, engaging youth in gardening and farming improves the attitudes, knowledge, and skills of urban youth, who typically have less direct and easy access to nature than their nonurban peers (Williams and Dixon 2013), in regards to science and their relationships with nature or food systems (Fraze et al. 2011).

Our work is the result of a collaboration between university scholars, nonprofits (STEM Garden Institute, Groundwork Lawrence, Salvation Army), educational researchers and evaluators, and classroom teachers. Our Seeding the Future project focuses on creating opportunities for young people from low-income communities to learn about growing food, doing science, and how science can help them contribute to their community in positive ways. Our programs target youth from upper elementary school through high school and are designed to solve two critical problems. First, many urban youth perceive school science as boring, irrelevant, and certainly not for them (Aschbacher and Roth 2010; Franco et al. 2009; Ozer 2007). Second, many urban youth have little knowledge of where their food comes from and little opportunity to learn how to grow their own food (Baron 2001; Fraze et al. 2011; Richardson 2011). Thus, our approach has been to build a holistic program that integrates hydroponics (which allows youth to grow produce indoors and year-round) into a variety of educational settings, including after-school environments, classrooms during the school year, and an out-of-school program for youth from urban schools. In this article, we discuss how our project team is working with teachers and community organizations to engage youth in growing produce, while learning how to use scientific practices and apply concepts from different disciplines to care for their produce.

Why Hydroponics?

In the recent National Academies report, “STEM Integration in K–12 Education: Status, Prospects, and an Agenda for Research,” (Honey, Pearson, and Schweingruber 2014) the authors note that U.S. K–12 STEM education has focused on individual subjects, particularly science and mathematics. Reform efforts, including the development of learning standards and, more recently, large-scale assessments, likewise have treated the STEM subjects mostly in isolation (NRC 20o4). However, an ever-growing number of careers in agriculture require individuals to not only have strong scientific skills, but also have a deep understanding of how concepts are connected across disciplines. Unfortunately, in most K–12 classrooms, the disciplines of STEM are isolated and distinct from each other, with little opportunity for students to make connections between them. With this concern in mind, we use hydroponics as a way to support teachers in making connections between the disciplines.

Hydroponics, a method of growing plants using nutrient-enriched water without soil, offers a gardening alternative that is not tied to external space and the growing season and can be conducted indoors year-round. Although there are many versions of hydroponics systems, most include a structure for holding the plants, a reservoir of water containing nutrients, a method for getting the water to the plants, and a light system. As such, students can be engaged in learning and applying concepts from chemistry, physics, and biology while conducting research investigations by changing variables (i.e., the time the lights are on) and observing the impact on plant growth.

A major advantage of classroom-based hydroponics is that there are a wide variety of possible systems, and the systems can easily be adapted to fit the space, resources, and needs of specific settings. Our systems were designed as a result of meetings with teachers who wanted the systems to be (1) small, (2) easily moved, and (3) capable of fitting in the trunk of a car. With those design constraints in mind, we designed a set of hydroponic systems that teachers could use in their classrooms. We were also cognizant of safety when designing. The lights that come with the system automatically shut off if they get hot or if water lands on areas that may cause a short-circuit. The water pumps are low-powered and will shut off if they get hot (i.e., if a reservoir runs low on water and the pump keeps running).

Figure 1

Our curriculum, however, starts students and teachers on a simpler and smaller system. With smaller systems (Figure 1), students can set up individual systems, and groups of students can create systems with different conditions to conduct experiments. With larger systems (Figure 2), single experiments can be conducted by the whole class by changing variables on the separate tiers. Youth can grow herbs; leafy crops such as lettuce, kale, or chard; or a range of other crops. As crops grow, youth can collect data, research variables that impact plant growth, and examine economic (i.e., how much electricity is being used), ecological (i.e., how does the ecological footprint of hydroponics compare to traditional agriculture), and social justice (i.e., where is fresh produce available and who can access it) questions related to food production.

Figure 2

In terms of curriculum and programming, hydroponics effectively integrates the strands of STEM, which is a major goal in science education (see NRC 2004). Students can engage in engineering design and problem solving through building the systems; learn chemistry and biology content to maintain the nutrient and pH levels that sustain plant growth; and use math skills and scientific practices to design, conduct, analyze, and share experiments involving their plants. The relative ease of controlling and manipulating multiple variables that impact plant growth (e.g., lights, nutrients, pH, water flow) can make hydroponics an excellent context for learning about and conducting experiments. Further, the *Next Generation Science Standards* (NGSS Lead States 2013) have as a central goal the integration science knowledge with science practices; that is, learning how to do science is as important as knowing what science has discovered. The *NGSS* therefore identify seven crosscutting concepts and eight science and engineering practices. According to the *NGSS*, practices are what scientists and engineers do as they work, through a coordination of both knowledge and skills. Thus, by engaging youth in hydroponic crop production, students can use scientific practices to learn science through an interdisciplinary approach.

Connecting Out-of-School Time With the Community

Our out-of-school program targets students who are underrepresented in STEM fields, with a focus in urban areas with large minority populations. To that end, we created the Urban HydroFarmers program. Our work focuses on using the science that the youth participants are learning to explore and solve social justice problems (i.e., food deserts). We recruit high school–age youth from three Boston public high schools. The youth work in a greenhouse and science lab on campus, where they learn about the basic science of hydroponics, science career options, and how to prepare for college. The youth are charged with managing the campus greenhouse, caring for the vertical hydroponic systems (Figure 3), and learning how to design and build their own hydroponic systems . In the past year, youth have been learning about the ecological impact of their hydroponic systems and designing solar energy arrays to power their systems. In this project, the high school youth worked closely with a school in Boston Public Schools that serves students with moderate behavioral and cognitive special needs, and they trained middle school youth to build and install solar-powered hydroponic systems. The produce that is being grown at the school will be given to a nearby nonprofit organization that trains homeless individuals in the restaurant industry and places them in jobs.

Figure 3

In-School: Curriculum, Connections, and Community

Our hydroponic project began with a small set of teachers testing and experimenting with hydroponics in their classroom. While developing the curriculum with teachers during this pilot phase, a question arose: “What to do with students while the food is growing?” In hydroponics, once the seedlings are transplanted, there is little maintenance unless a problem arises with pH, lighting, or the nutrient solution. Therefore, we have focused our curriculum around conducting scientific research by asking questions regarding the impact of different variables on food production. In this way, teachers will be able to engage students in the design of experiments, monitor results, and then analyze the results in-depth upon harvesting the food. This approach allows teachers to guide students in asking questions and conducting experiments while connecting the experiments to the existing science curriculum. Fortunately, hydroponics is ideal for integration into most teachers' curricula because it uses principles and concepts from economics, physics (light, electrical conductivity), biology (plant physiology), and chemistry (nutrients). To that end, our hydroponic curriculum projects are not intended to be an "add-on" but to serve as an integrated project that can be used in conjunction with teachers' current curriculum. The current curriculum can be downloaded online.

The development of our curriculum and resources relied heavily on input from classroom and after-school teachers. In working with teachers, we identified a set of research questions that often serves as the starting core component of our curriculum. However, we have also learned that it will be necessary to develop a set of introductory materials around hydroponics and materials that guide students through the economic analysis of their food production, as well as content-specific curriculum material around physics and chemistry (as of this writing, our biology curriculum is still under development and will be added to the curriculum website as it is completed). These modules are designed to be flexible in that they can be used as a stand-alone unit; however, most teachers choose from the lessons and activities and integrate the ones that suit their students' research investigations (see Tables 1 and 2 for curriculum units and example research questions).

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Support for Teachers

We host a summer institute for our teachers as well as call-back workshops. The purpose of the institute is to introduce new teachers to the curriculum and the hydroponic systems for their classrooms. The follow-up workshops are both a chance to update teachers on new developments with the curriculum, and for our project team and evaluator to learn from the teachers about their successes and challenges.

Figure 4

Figure 5

Cost of Implementation

We have worked to reduce the cost of the systems for a classroom teacher. As of this writing, all of the systems that are in classrooms are provided through support from the National Science Foundation (DRL: #1312073 and DRL: #0833624) and a U.S. Department of Agriculture/National Institute of Food and Agriculture grant (NIFA #2015-05553). As a part of their professional development training, teachers put the systems together and learn how to maintain and troubleshoot them (design specs, including where to purchase materials, can be downloaded online). If individuals wish to build their own hydroponic system, the complete system (similar to the one in Figure 2) would cost approximately $400. However, the more expensive components (i.e., lights, aluminum, trays) should last 15 to 20 years; the other materials are relatively inexpensive. The ongoing expenses of the hydroponic systems include the *grodan* (or *grow medium*, inert cubes of spun rock that support the seeds), which is $10 for a sheet that will allow for the starting of 92 plants; the nutrient solution (one bag of nutrient solution will last for years and is about $20); and the *pH up* and *pH down* (buffering compounds that adjust the pH of the nutrient solution), which are about $17 per bag and last for three to four years. The most expensive replacement parts are the T5 grow lights. The T5 lights are approximately $12 per bulb and each tier uses four bulbs. However, the T5 bulbs usually last one to two years under normal use. The only other ongoing expense is the purchase of seeds. We recommend that teachers purchase their seeds from Johnny's Selected Seeds, because one can purchase a wide variety of both organic and heirloom seeds.

Safety

Operating a hydroponic system in a classroom is quite safe. The lightbulbs can get hot and should not be touched if they have been operating for several hours at a time. The nutrient solution is not toxic and, although it should not be eaten, it can be handled directly without safety gear. The manufacturer recommends that the pH up and down powders be handled using gloves and safety goggles, but once the powder is added to the nutrient solution, these are unnecessary. Lastly, we recommend that power strips be elevated off the floor just in case of a water spill.

Examples of Implementation From Classrooms

An external evaluation of the project provided rich descriptions of the ways in which teachers use the materials, the successes and challenges they face, and their anticipated and observed outcomes for students. Before sharing the evaluation findings, to better understand how and what teachers do with the curriculum in their classrooms and how they implement it with their students, we identified two partner teachers and requested that they write brief summaries of their work with their students.

Case 1: English Language Learners: Deborah Jose, Newton North High School

Jose works with English language learners with limited formal education in a large suburban school. Some of her students have not been in school for several years and are learning school skills such as listening to others, along with English language skills and the curriculum content.

This year, Jose is building her curriculum around hydroponics. Because her classroom focuses on developing English language abilities, most lessons and activities are centered on language. The hydroponics program has become a great motivator for using language across the four domains (reading, writing, speaking, and listening). Students started the year by building the systems, planting seeds, and making observations over the first weeks as the plants grew. Students were proud of what they had built and excited to watch the transformation of the seeds into plants. Working in teams, they developed presentations about building the structure, planting the seeds, what plants need to grow, and their plants' growth. They then shared this information with the school's culinary arts teacher. The culinary teacher was excited to buy "all the product you can give me," and students will be growing cycles of lettuce, basil, arugula, and herbs this year. This also prompted students to develop a brand name and logo, and decide how much to charge for their produce based on prices at local stores. Beyond academics, the project has provided the students, who are newcomers to the community, with opportunities to connect with the culinary teacher and other students, and gain confidence in themselves as learners and contributing members of the school community. Although the connections developed by these two classes have been within the school community (at least so far; there is talk of selling produce at community farmers markets, similar to the out-of-school program with high school–age youth), the hydroponics program has enabled connections to form outside of individual classrooms.

Case 2: Special Education Students: Andrea Aeschlimann, Revere Middle School

Aeschlimann, a special education teacher in a diverse urban school, has been using hydroponics in her classroom for the past year. During the last school year, her classes connected hydroponics to lessons about data collection, plant growth, systems, energy, light and waves, cells, measuring, and the water cycle (see her class hydroponics blog). They used prisms to break down the components of the grow lights, looked at cells in plant leaves under a microscope, found the mass of basil leaves, and diluted solutions to make the appropriate nutrient balance for the plants. Students loved watching the plants grow and put in requests to grow the foods that were important in their different cultures. The Iranian students grew fennel, the Guatemalan students grew cilantro, the Italian paraprofessionals in the school requested basil, and city officials from the community put in a request for cabbage for St. Patrick's Day. Students grew six crops of herbs and vegetables over the course of the school year. Some of this produce was sent home to students' parents and used to make their family's favorite dishes. The rest was sold to teachers around the school. A small group of students with autism became engaged in the process of caring for, selling, and delivering the plants, so Aeschlimann made a "hydroponics team" that took care of the money and distribution of the crops. Through that team, students learned many skills beyond science and formed connections with teachers around the school. Plant sales over the year raised more than $400, which paid for the supplies for all 50 projects students in the class developed for the science fair.

Findings From External Evaluation

The evaluation across all years of the project also revealed information about the ways in which classroom teachers and out-of-school instructors implement the hydroponics materials and curriculum. Through focus groups, individual interviews, and observations, we determined that during the initial years of the project, teachers were concerned about logistic issues related to space and time, similar to those described by Ozer (2007) and Rahm (2002). However, more recently, teachers across disciplines and grade bands described the successes and the ways in which they are able to embed hydroponics into their classrooms, integrating it with their own curricula and aligning it with standards and inquiry practices. Teachers described how they can quickly and easily provide opportunities for students to conduct simple experiments using the hydroponics materials. The interdisciplinary nature of the curriculum provides numerous connections to standards and classroom for students across grade levels and abilities. Teachers also described the ways in which the hydroponics resources support goals for their English language learners and students with individualized education plans, including increasing students' vocabulary and understanding of science practices, developing vocational skills, connecting them to culinary programs or science fairs, and increasing their engagement, confidence, and interest in science. Finally, teachers' insights throughout the development of the project resources also provided valuable information about the ways in which they have adapted to challenges. Teachers also stated that in contrast to previous years of the project, administrators value the materials, and issues such as space, lighting, and troubleshooting the systems are less of a concern.

Closing Thoughts

Beyond teaching specific topics, hydroponics can encourage personal, community, and real-world connections. For many urban students, science course offerings in middle and high school are often perceived as neither interesting nor relevant (Atwater, Wiggins, and Gardner 1995; Kahle 2004; Kahle and Lakes 2003; NRC 2004; NRC 2011). Our program, with its focus on engaging students in growing food to share with their community, makes science relevant by framing learning around improving the plants they will share as food. Lastly, our work has found that students whose first language is not English and students with special needs particularly benefit from hydroponics in their classroom. Many of the immigrant youth in our program came from rural or agricultural regions in their home countries, and growing plants offers them an opportunity to talk to their parents or caretakers about a science topic they have in common. For youth with special needs, hydroponics offers an opportunity to develop personal ownership over a science project by caring for "their" system and "their" plants. As the entry-level science that impacts plant growth in hydroponics is relatively easy, youth can initially focus on a single concept or variable and, through that, develop content knowledge, language skills, and an interest and appreciation for the process of science.

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