

## WHAT WILL KEEP THE FISH ALIVE? EXPLORING INTERSECTIONS OF DESIGNING, MAKING, AND INQUIRY AMONG MIDDLE SCHOOL LEARNERS

Scott Wallace<sup>1</sup>, Tarrance Banks<sup>1</sup>, Mishael Sedas<sup>2</sup>, Krista Glazewski<sup>2</sup>, Thomas Brush<sup>2</sup>, & Christian McKay<sup>2</sup>

<sup>1</sup>The Project School; <sup>2</sup>Indiana University

We can see why educators are drawn to making; maker environments hold tremendous potential for engaging learners in both (a) building and representing their knowledge and (b) fostering opportunities for seeing the world in new ways. This potential reflects what our team of middle school teachers, university professors, and graduate students observed during a year-long project in which students built aquaponic systems while simultaneously asking questions about food, food systems, and sustainability. Their systems took a variety of forms, supporting everything from bluegill to aquatic frogs and growing a variety of flowers and vegetables. However, together we all also experienced struggle and moments of doubt. *How much guidance is enough? Too much? How do we build knowledge and not just “do projects”? How do we connect the doing and the building with our community? With the world? And, perhaps most practically, how do we fix what we just messed up?*

**Scott Wallace** is a middle school teacher at The Project School in Bloomington, Indiana.

**Tarrance (Tarrey) Banks** is a middle school teacher at The Project School in Bloomington, Indiana.

**Mishael Sedas** is a doctoral student in Learning Sciences at Indiana University.

**Krista Glazewski** is an associate professor of Instructional Systems Technology at Indiana University.

**Thomas Brush** is a professor and the Barbara B. Jacobs Chair in Education and Technology in Instructional Systems Technology at Indiana University.

**Christian McKay** is the coordinator of RedLabs in Intelligent Systems Engineering at Indiana University.

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### BACKGROUND

The Project School (TPS) is a locally-chartered public school founded by a group of community-based educators with established core beliefs that include empowering students and their families, valuing all members of the school community, creating individualized educational experiences, teaching for heart, mind, and voice, and creating educational equity. TPS couples social justice and environmental sustainability with educational excellence in all aspects of the curriculum. The school serves a wide range of students with the following demographics:

- 277 total students, Kindergarten through Grade 8, from Bloomington, Indiana and surrounding area.
- 95% annual enrollment retention rate.
- 36% of students are eligible for free or reduced lunch.
- 22% of students have Individual Education Plans (IEPs) to support special learning needs.

### Classroom Structure, Makerspace, and Partner Support

Our classrooms are fully inclusive for students of all abilities and needs and are designed as multi-age, co-teaching spaces to allow for peer leadership and mentorship. In this context, TPS' middle school classrooms (grades 7 and 8) have an open configuration with an integrated makerspace. This makerspace has a tool station, textile screen printing machine, 3D printer, and laser cutter (see Figure 1). In recent years, we have partnered with faculty and graduate students from the Indiana University (IU) School of Education. The collaboration has yielded not just tools and materials to create a makerspace for our school through grant-writing efforts, but innovative practices and support with implementation and professional development with design and fabrication technologies.



**FIGURE 1.** TPS middle school classrooms and makerspace.

### **P3 Curricular Framework: Problem, Project, and Place-Based Learning**

TPS employs a uniquely designed curricular framework: problem, project, and place-based learning (P3). P3 ties together the sciences, social sciences, history, and civics with interdisciplinary reading, writing, and mathematics that targets a goal to connect to issues in the local and global communities. Students, teachers, families, and community members work together to arrive at school-wide topics and essential questions that guide individual, group, and community projects. One primary goal is for students to understand that they can make a difference in their communities. In turn, the community sees the school as a force for social justice.

### **The TPS–Indiana University Partnership**

During the spring semester prior to the start of the project, several Indiana University educators partnered with the teachers, Scott and Tarrey, on developing the plan for this project. Together they subsequently submitted a grant proposal for funding through the IU School of Education. The ideas that resulted were to work in collaboration with the combined grade 7 and 8 teachers to guide students to plan, design, prototype, and make sustainable aquaponic systems as they learned targeted content knowledge through design problem solving. The intended outcomes of our efforts included (a) fostering student scientific, mathematics, and design problem solving ability; (b) building teacher capacity for maker-based approaches; and (c) disseminating models

of digital fabrication design practice in the form of a video-case for use in the teacher education program at IU.

Toward these ends, the project involved all students in grades 7/8 in a year-long endeavor to plan, design, model, build, test, and refine a working aquaponic system. During this project, students were to focus on multiple aspects of sustainability and design, including understanding large-scale sustainability and human rights issues, and how design processes might lead to sustainable solutions. The aquaponic project was also intended to provide a vital context for understanding food security issues in the local and global community.

The efforts behind this collaboration were built on a four-year relationship between one of the IU partners and the teachers and school administrators. This collaboration has involved guidance to the school, assisting teachers in developing the makerspace, supporting the use of various tools and resources, and helping guide instructional and curricular activities in collaboration with the teachers.

### **Designing and Making Self-Sustaining Aquaponic Farming Systems**

During the 2015–2016 school year, 60 middle school students (grades 7 and 8) supported by our team of teachers and collaborators from IU, engaged in the year-long P3 exploration of sustainable food systems and aquaponic farming. We asked the students a broad question: *What do sustainable and resilient food systems look like?* In this context, we posed the following design problem: *Design*

a self-sustaining, closed-loop aquaponic farming system that takes up the footprint of a classroom tabletop (see Figure 2).

## Teams and Roles

Ten teams of four to six students each designed and constructed aquaponic farming systems. At the beginning of the project, each student submitted a request for a specific job or role within their team based on their strengths and interests. The teachers considered their requests based on our knowledge of their interests, strengths, and potential for further development. For example, if a student expressed interest in designing but did not view self as “good at electronics,” we encouraged the student to assume an automation role despite lack of experience. We decided on these roles based on the core tasks and key components of the project since we needed roles that could serve the long-term and authentic needs of the project and the group (see Figure 3):

- **TEAM LEADER**

We asked each team leader to assume the responsibility of managing and organizing the overall group processes. The team leader also helped team members when they were struggling. This job required strong personal skills, organization, and ability to handle multiple tasks at once.

- **FLORA/FAUNA**

This group member was responsible for monitoring and tracking the health of the plants and animals in the aquaponic ecosystem. This involved observing plants and animals, collecting data on overall health, and harvesting the plants and animals at the appropriate time.

- **WATER QUALITY**

This group member was responsible for monitoring and tracking the water quality of the system through chemical tests. Additionally, if the water quality needed to be improved, this person was in charge of implementing the changes through chemical means.

- **AUTOMATION/MAINTENANCE**

This group member was a designer and tinkerer! Once each aquaponics system was up and running, we hoped to automate as many of the tasks as we could. This required programming software and hardware that was incorporated into the system. This person was also the first to troubleshoot problems with the automation systems.

- **HISTORIAN**

This group member was responsible for documenting the process of the year-long aquaponic project. This included creating a team blog and capturing work samples and artifacts throughout the process to be shared at the end of the project.

## Project Phases

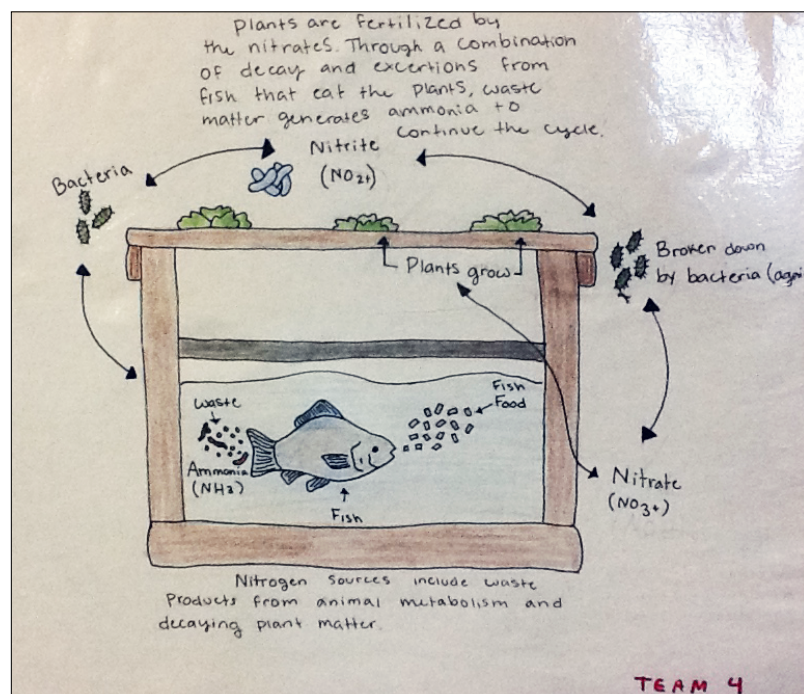
The support for planning and facilitating the daily activities was guided by the four phases developed in the initial project plan.

Phase 1 (September–October): During the first phase, students began their investigations. They created research-based plans, designs, and sketches for small-scale aquaponic systems to be built and housed in the school.

Phase 2 (November–December): In the second phase, students built models of their designs at the IU School of Education’s (SOE) Make Innovate Learn Lab (MILL) makerspace. This phase of the project included multiple tests, retests, prototype builds, and design modifications. At this event, students were supported onsite by SOE graduate students and faculty, who helped with materials, cutting, feedback and discussion about ideas.

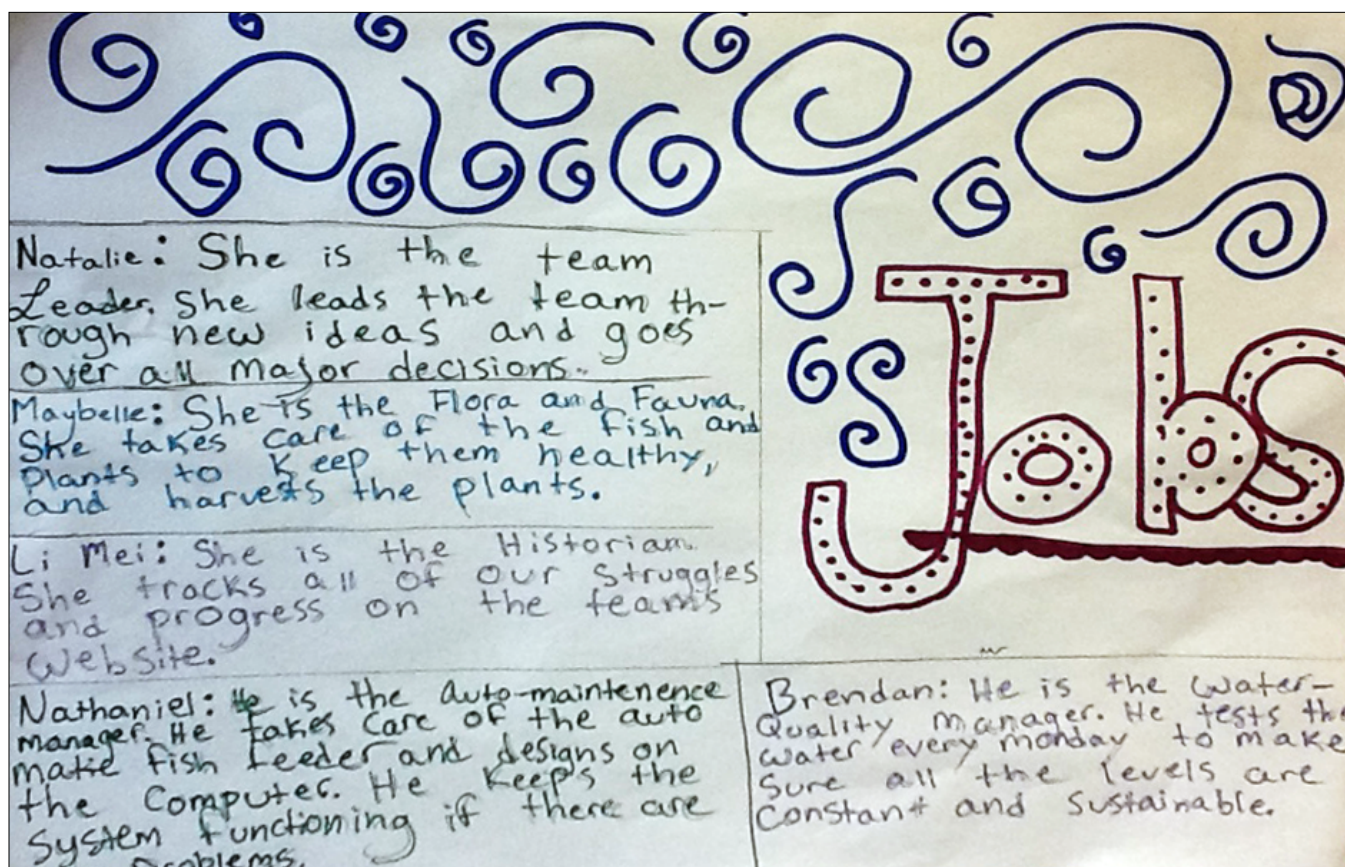
Phase 3 (January–April): In the third phase, students carried their designs and models into the production of working aquaponic systems. These systems would then be unveiled in a public event for parents, MILL affiliates, and the broader community. It was during this phase that the primary onsite involvement and support—highlighted earlier—took place between supporting IU partners, teachers, and students.

Phase 4 (March – June): In the final phase of the project, students applied what they had learned



**FIGURE 2.** System sketch.





**FIGURE 3.** Defined team members' roles.

thus far in the project to create plans for scaling up their models to large-scale food production systems.

## RESOURCE GUIDANCE

One resource that guided our knowledge and, in turn, students' knowledge, was a technical paper from the Food and Agriculture Organization of the United Nations on small-scale aquaponic production (see Somerville, Cohen, Pantanella, Stankus, & Lovatelli, 2014). From this resource, we gained basic principles to guide our project, from construction to installation to maintenance. This foundational text provided students with a primary source from a reputable institution that provided an opportunity for students to build technical reading skills while also reinforcing the design challenge as one that was both important and relevant.

## ORGANIZING THE INSTRUCTION

Collaboratively, we organized the experiences for the students along two tracks: (a) the aquaponics system and (b) the study of sustainability, food production, and labor.

### Track 1: Design and Construction of the Aquaponic System

This design project developed along two tracks: (a) the design/make track that targeted primarily math, science, and technical writing goals; and (b) the humanities track, which targeted primarily social studies and literacy goals. This project was multidisciplinary in nature and connected to a larger year-long study of food systems and solutions. We introduced students to the concept of aquaponic farming as well as compared and contrasted it to more traditional methods of farming. Students considered and discussed the effect that food choices have on the environment as well as how to mitigate those effects.

The teachers began thinking about aquaponics after Tarrey visited school gardens in Arizona. They had spent some time talking about issues of food in the classroom but had never devoted the time we desired to the topic, and aquaponics seemed like the right approach. They began guiding the students toward the in-depth study of aquaponics followed by multiple design iterations that included sketches, conceptual models, technical drawings, and fabrication of working systems in our makerspace. Students were provided with a set of constraints and guidelines regarding how they could design their systems and what materials they could use. Teacher decisions were driven primarily by project and

learning goals, budget, and feasibility. Given that there were 60 students in 10 teams, the teachers also had to consider constraints of space and cost. Accordingly, students could not build anything bigger than a “tabletop” design, which would take up the footprint of a small classroom table (approximately 20 by 30 inches), but could also be built vertically. However, the systems needed to reflect original designs for each team, rather than a replication of one design that did not foster research and choice. Thus, materials and decision parameters included the following:

#### COMMON TO EACH TEAM:

- 20-gallon tank, pump, tubing, water, and grow bins
- Lumber and other building supplies
- Paint
- General hardware: screws, nails, glue, tape
- Community tools (e.g., hammer, pliers, saw, drill)

#### NEGOTIATED TEAM OPTIONS:

- Fish selection
- Plant selection
- Grow material

- General system design (i.e., one grow bed or two, vertical or horizontal, etc.)
- Team names
- Team purpose/vision

The negotiated options enabled each team to design a different system that met the criteria in very diverse ways, enabling choice and ownership. While most systems were vertical with the tank at the bottom and the plants growing in upper bins, variations included the number of bins (some had two while others had one) and the types of growing configurations—cups or gravel (see Figure 4). Throughout the year, students maintained, modified, and problem-solved their aquaponic systems to improve their yields and keep their systems fully functional.

#### Track 2: Questions on Sustainability Problems, Food Production, and Labor

For this track, the teachers focused on exploring the question: *Can DIY aquaponic systems solve sustainability problems associated with the industrial food system at home and abroad?* To make an authentic connection between the hands-on design work with aquaponic systems and the larger sustainability and social justice issues related to food systems and supply chains, Scott and Tarrey made a fairly bold decision



**FIGURE 4.** A sampling of team aquaponics projects.



to fully integrate all core subject work, including English / Language Arts and Humanities. Using text resources like Michael Pollan's book *The Omnivore's Dilemma* (2009), they were able to frame the curricular work around food systems while embedding skill work related to developing strategies for close reading of challenging non-fiction texts and multimedia. They made multiple curricular decisions to facilitate this integration including structuring micro-research projects on the history and root causes of one specific problem connected to food systems, couching that problem within sustainability, and asking students to pose their own potential solutions to the problem. This was completed during the fall semester of 2015.

During the spring semester of 2016, Scott and Tarrey engaged students in concepts of labor, labor organizing, and immigration as it relates to our industrial food system. This curricular decision was based on a desire to connect students to social justice issues related to food supply chains that could easily have gone unexamined in a strictly design-based project. Through exploring César Chávez and other labor movements throughout U.S. history, the teachers were able to frame an experience for students to critically analyze the people responsible for producing the food in this system and how those people are treated.

### **Learning Goals and State Academic Standards**

The overarching project goals were for students to design a close-looped, self-sustaining aquaponic system and describe the practice of aquaponics as a solution to food supply issues. However, Scott and Tarrey also had to address, practice, and assess multiple learning goals and state prescribed academic standards during this year-long project. We list here a sampling of those learning goals from each of the major subject areas and/or disciplines. All students would meet the following standards:

#### **IN ENGLISH / LANGUAGE ARTS (ELA):**

- Acquire multiple strategies for critically analyzing non-fiction texts.
- Effectively use multiple forms of text in their writing to construct a compelling argument or position.

#### **IN HUMANITIES:**

- Understand and be able to articulate pros and cons to each of the major food supply chains in the United States (industrial, industrial-organic, local-sustainable, hunter-gatherer).
- Identify multiple food systems related issues, trace those issues to theory their source, offer ideas around cause and effect, and identify potential solutions to those issues.

- Understand the connection between labor rights, wage disparity, immigration and migrant-workers to the industrial food supply chain in the United States.

#### **IN SCIENCE:**

- Compare and contrast the nitrogen cycle in both traditional and aquaponic farming methods.
- Understand and be able to identify the complex systems within living things (including fish dissection when fish died) and the interactions among them (digestive, circulatory, etc.).
- Observe and explain the process of photosynthesis central to the energy cycle of animal ecosystems.
- Begin to develop an understanding of basic chemistry due to the central principle of converting ammonia to nitrite and nitrate for plant uptake in aquaponics.

#### **IN COLLABORATION:**

- Identify the skills and dispositions of an effective team member and reflect on themselves as team members.
- Develop problem-solving strategies for effective teamwork.

### **DESIGNING THE AUTOMATION: LEARNING FROM FAILURES**

Once all the aquaponics systems were functioning (around the beginning of the second semester), we posed another design challenge: *How can we automate critical tasks for keeping our fish alive?* In previous years, the school offered elective classes, which provided resources such as LilyPad Arduino circuit boards with microcontrollers for a wearable textiles class. Arduino is an open-source software and program-mable circuit board used by a growing global community creating a wide variety of electronic artifacts. The software is called Arduino Integrated Development Environment (IDE), but we will simply call it the "Arduino software." The Arduino boards can be paired with sensors that detect the physical world and actuators that respond to the inputs like motors or small light-emitting diodes (LED) as indicators. Sensors are the inputs of the system and actuators are considered the outputs. For example, temperature sensors read the water temperature, and servos are examples of actuators as they move based on a met condition. We began by looking at what we had on hand and reached out to our IU partners for ideas. We brainstormed by looking online at the variety of Arduino products and what we hoped the automation system to accomplish. For example, we looked at one Arduino circuit board that would broadcast information from our aquaponic system to the Internet. However, not only the cost was an important factor, but considering the fact of having students code when they had little or no prior experience with programming. We initially thought we could

monitor the water acidity or basicity (i.e., pH) of each system with a sensor, but quickly found that pH probes cost more than \$100 for each team and provided unreliable data. We also decided that in order to finish the automation system on time, we were not going to use the LilyPad Arduino boards because the system used conductive thread to make the connections between the LilyPad Arduino board with the microcontroller and different sensors. Thus, using the LilyPad Arduino would have required all students to learn and develop hand sewing skills. In the end, we found it more time and cost efficient to purchase the product called *SparkFun RedBoard*—a modified Arduino board—and the following less expensive components: color LEDs, connecting jumper wires, small buzzers, water temperature probes, ultrasonic distance sensors, small servos, and a real-time clock (RTC) module.

Each automation systems kit consisted of one RedBoard microcontroller board (subsequently swapped out for Arduino UNO boards for reasons discussed later), one ultrasonic distance sensor (to continually monitor the water level of the system), a waterproof temperature sensor (to monitor water temperature specific to the species of fish), and a continuous servo (to drive a student-designed automatic fish feeder). The system also had an alarm subsystem and a backup clock with current date and time. The alarm subsystem consisted of one small buzzer and four small lights (LEDs). If the water temperature passed predetermined values, the red (too warm) or blue (too cold) lights would light up, and the buzzer would sound alerting the students. Otherwise, temperature values in the acceptable range were indicated by the green light. Similarly, if the water level was beyond predetermined height values, the buzzer would sound, and a yellow light would turn on. Another important subsystem was the backup clock or real-time clock (RTC) module, which would maintain the current time and date regardless of the microcontroller losing power. The RTC was vital to allow the fish feeder to pour the food into the fish tank at the exact time, every day.

However, this automation part of the aquaponics system did present some challenges and learning experiences for all. The main challenges were (a) selecting the sensors and/or actuators; (b) learning how to program the automation system of sensors and actuators; (c) determining the simplest and most effective methods to teach the automation in class; and (d) troubleshooting without jeopardizing the students' level of achieved interest in the automation portion of the overall project.

### **Challenge 1: Selecting Types of Sensors and/or Actuators**

We faced the first challenge of this automation project when deciding on the types of sensors and actuators to use, as described earlier. This issue was a challenge because of

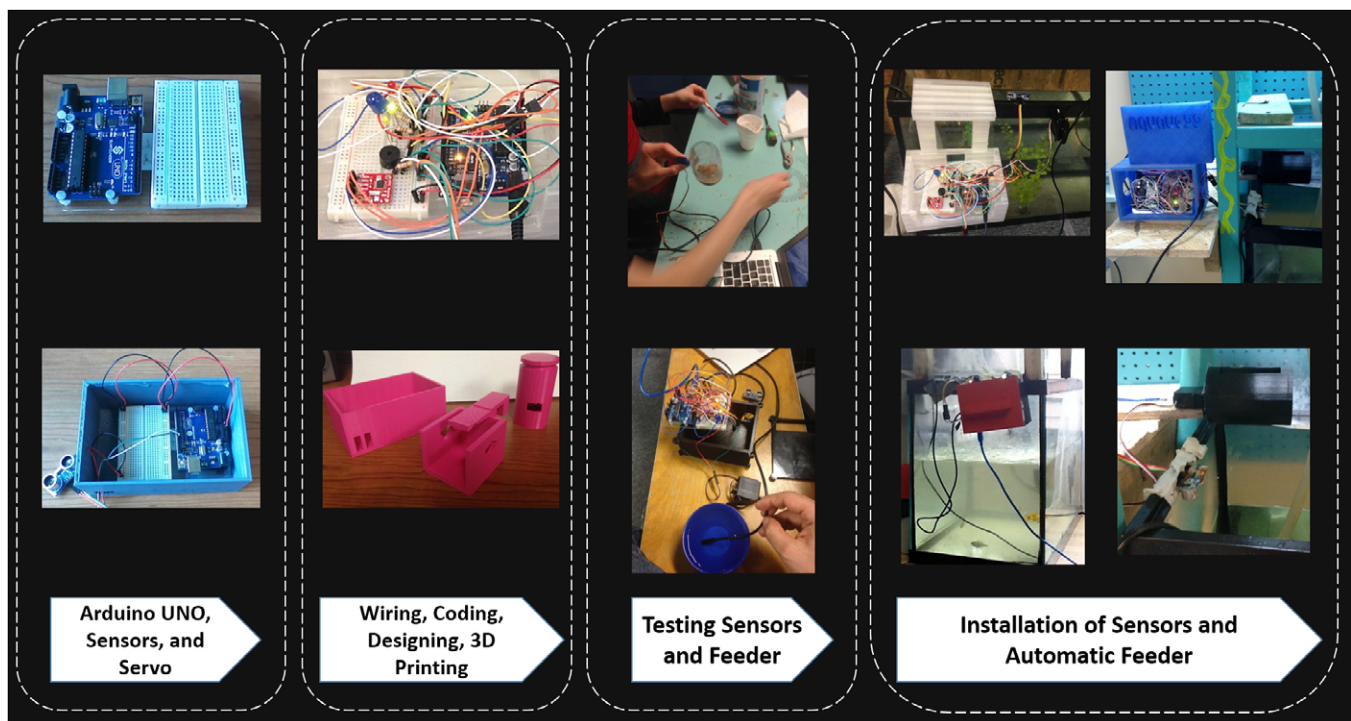
three factors: cost, complexity of coding, and simplicity for learning how to use all of the electronic components in the limited class time. We purchased sensors and actuators with a cost between \$4 and \$15 in addition to the Arduino boards that cost around \$20. Funds and components were provided through a mini-grant in collaboration with the School of Education at IU.

### **Challenge 2: Learning How to Program the Automation System (Arduino, Sensors, and Actuators)**

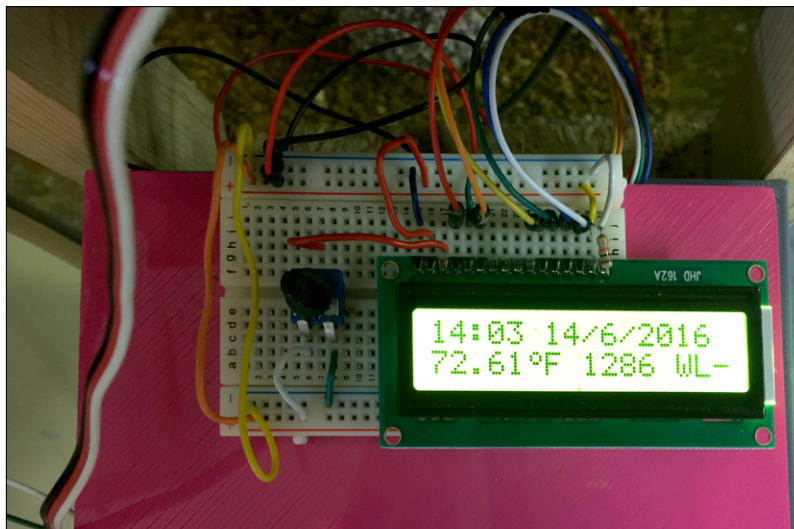
One of our IU partners and co-author, Mishael, a graduate student in the School of Education, worked on the coding of each of the components while building a working prototype. Mishael had some experience with Arduino boards but did not have advanced experience with the types of sensors and actuators we selected. He did some research on public online forums and textbooks to learn how to code each of the components and modify public open-source codes to meet our design requirements. Sometimes codes for one component would conflict with another component's code. For example, the code for the real-time clock and the code for the servo controlling the feeder were in conflict, so we had to search online for additional ways to code the servo to also be able to use the date and time provided by the RTC. Mishael started working on the final prototype approximately two months ahead of time. Having someone working a bit ahead of us and our students was incredibly helpful because he could detect potential pitfalls early enough to troubleshoot them ahead of time so that the students were not paralyzed and discouraged by problems they did not feel capable of solving. If we had students who were passionate about programming and felt capable of doing this work, we would have involved those students. However, this level of sophistication and troubleshooting required someone with more experience to help make the experience rewarding for adolescents with limited expertise in this area.

### **Challenge 3: Deciding the Most Effective Way to Teach the Automation in Class**

We made the decision that students would not be required to create the code for each sensor and subsystem from scratch, but would work from public open-source codes. Every automation leader was exposed to the basic concepts of programming in the Arduino software as well as the open-source code. Each automation leader was able to locate and change various parameters in the code, such as entering any acceptable values for the water temperature or water level ranges. Finally, each team's design leader used SketchUp™ or Tinkercad™ to design the fish feeder and a case or box to house the automation system. These were subsequently printed in 3D. Figure 5 depicts the various phases of the automation process from the initial instruction to the installation, while Figure 6 depicts an installed automation system.



**FIGURE 5.** Phases of automation.



**FIGURE 6.** Installed system display.

#### Challenge 4: Building on Failure During Troubleshooting

When faced with problems during our teaching, we worked collaboratively on troubleshooting in order to not jeopardize students' level of achieved interest in the automation part of the project. For example, early in the project we realized that the selected RedBoards were not compatible with the Arduino software (the prototype had worked well on a Windows laptop). Some students showed frustration at this or when the code that was provided to them seemed to not work the first time, thus requiring more troubleshooting.

When students saw their teachers were also confused at times, it reassured them that it was not "just them." Subsequent conversations with students involved explaining to them that we were all members of a team dedicated to solving the problems, but that we had never done this specific project before, so we did not yet know the solutions.

Ongoing troubleshooting and research into the problem by the team of teachers and IU partners revealed that there was an incompatibility between the RedBoard, Apple's USB serial port drivers for OS X, and the Arduino software. This issue prevented the serial port the RedBoard was connected to from being read by the Arduino software. While we located the serial port driver patch that could restore functionality between the RedBoards and Arduino software it would have required installing it on all of the classroom laptops at a significant time cost. On evaluating that time cost to benefit ratio the team made the decision to return the RedBoards and purchase new Arduino boards. Those new boards arrived quickly, and student projects proceeded with a smooth start.

#### Making Sense of Students' Struggles

To support the students who were their team "automators," we also had each team send one of their team leaders to the workshops. We knew that with absences, different abilities,



and limited adult support, it would be important for teams to have multiple students that could work on the project and seek/provide support as needed.

To maximize results, we also employed the use of other students who had been successful with the specific step we were working on. If a student pair got their Real Time Clock calibrated, for example, they became support systems for other groups who were struggling with that portion of the project. This allowed us to triage who really needed the adult support the most.

The most important part of this support was that as teachers, when we found the problem with a team's setup, we fought the urge to just fix it ourselves. It allowed us to present the team with another learning opportunity to explain how circuits work, or why the LED keeps burning out. This, in theory and in practice, supported students in solving their own problems the next time they encountered them.

One tension we continually faced was balancing the "get-it-built" impulse of students with the level of guidance we wanted to provide them. That is, we found that, at least initially, most students preferred to work quickly and without much attention to planning and forethought. This approach tended to result in more troubleshooting later--whether that meant shimmying up their built aquaponics systems or checking the programming code line-by-line for the problem area. It was difficult to know when to slow student efforts and when to encourage their freedom of exploration and realization of their ideas. One solution was in the form of a structure we called "Progress & Struggles," in which teams documented both accomplishments and setbacks (see Figure 7).

Given that two teachers were supporting ten teams, this system helped students articulate their milestones and provided specific platforms for teacher feedback, assistance, and help. Furthermore, teachers could see who had mastered certain skills and direct them to other teams struggling in similar areas.

## OVERALL, WHAT DID THE STUDENTS THINK?

Following the project, we collected student perspectives through interviews and

focus groups to inform how we might refine our approaches with regard to engaging students in meaningful design and inquiry through making. More specifically, we wanted to know what students identified as important to their work and what they wanted other teachers to know. The students were forthcoming in their reflections and ideas. Broadly speaking, they included three primary themes:

### Students Believed That Structured Group Work was a Critical Element of the Work.

Students identified connections between the importance of group work and the skills related to working effectively with a team to success later in school and life in general. They discussed group work nearly unanimously in terms of what worked for them during this project and had strong opinions on nearly every aspect of the group work elements of this project from group size, how to assemble teams, and the role of specialized jobs. In short, the way in which we structured

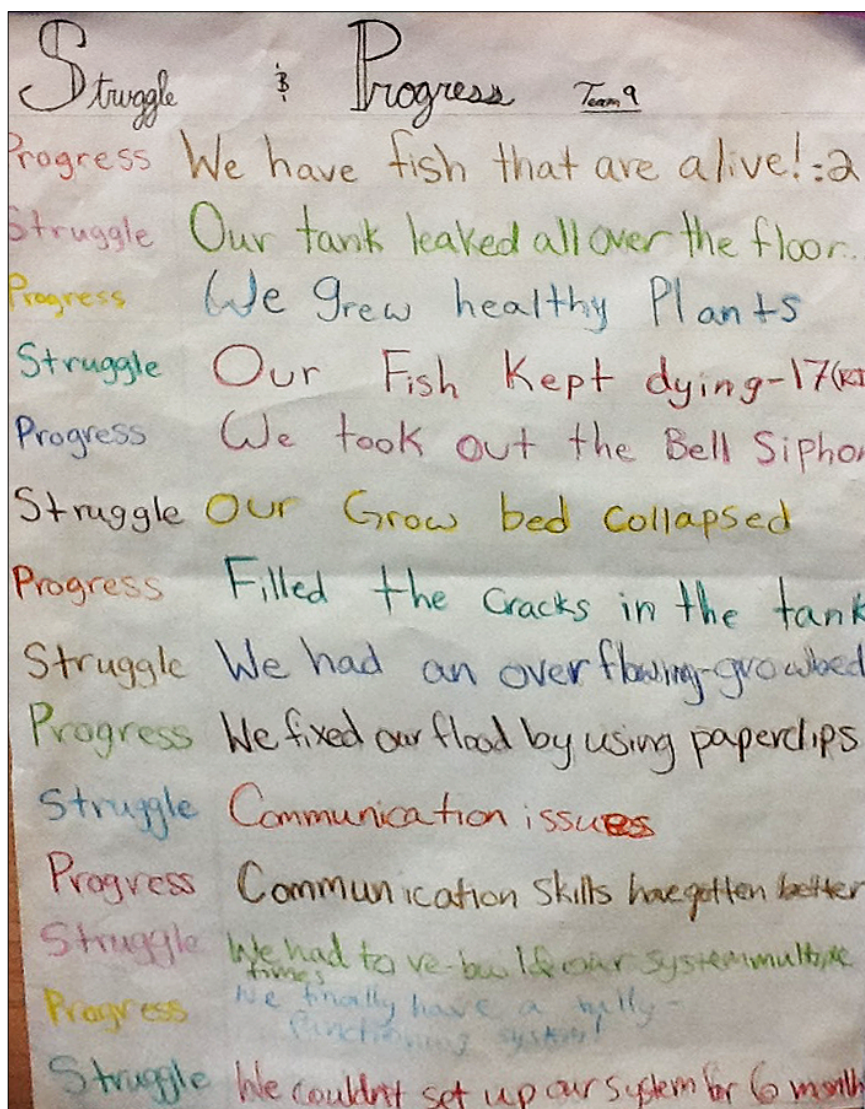


FIGURE 7. Team 9 documented struggles and progress.

this project from a cooperative learning lens worked well for them.

For example, here is what some of our students had to say in regards to the importance of group work:

*"Group of work is absolutely necessary to project based learning. Students are able to collaborate, locate their strengths and weaknesses, and develop skills for later in life when group work is almost definitely going to be a large thing in their life."*

*"Whether it be long, or short term groups, having a group of people to give you constructive criticism or beneficial feedback is very important when working on a project. P3 is about group work and team problem solving."*

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### **Students Believed That Successful Projects are Authentic in Nature, Integrated and Interdisciplinary, and Connected to Real World Issues.**

Students were clear and articulate in expressing that the project needs to be authentic in nature, connected to real problems and integrated across subject areas. Our work with the book *The Omnivore's Dilemma* as well as work connected to César Chávez and issues related to farm labor in the industrial food chain made the aquaponics portion of the project real for them. These connections created relevance, and it was important for them that others around the world were also exploring aquaponics to see if it was a viable solution to food and food systems issues. This idea of authenticity and integration cannot be overstated; it was a critical element of what worked for our students. The frequent reflections and students' involvement in decisions about curriculum integration and efforts to create relevance made huge impacts on our students, some even life changing. Many students told us that they had begun to change their own behaviors as a result of what they were learning--both in what they chose to eat and in potential future career choices.

The quotes below are a good example of how our students felt about authenticity and integration during this project:

*"If we were just doing aquaponics it would just be a bunch of kids growing things and learning about fish, which is all well and good, but we were able to learn so much more about the issues, and politics, and how to write well and improve reading skills."*

*"P3 connects multiple subjects with an interactive, real-world topic. These all need to connect in some way, and most of the times it has to do with world issues, or economics. I recommend for project based learning is to*

*choose a topic that's relevant to the community, or even the world. I think that if students know that the work they are doing is actually meant for something, a world problem or something similar, they can better focus on the task. The students know that they are solving a problem, and this gives them a goal."*

*"We actually did something real, and I think that that was really important to a lot of people in our class. P3 teaches us that we can make a difference. Not just become someone with a fulfilling career, but we have the power to change the world, and be activists. I think that these kind of high stakes are exactly what a school needs, and project based learning is ideal for this."*

### **Students Wanted Structure, but Also Wanted Their Teachers to Trust They Can Solve Problems and Make Decisions**

Generally speaking, students think teachers need to provide students enough space to fail and succeed on their own. Throughout the project, one challenge that kept coming up was trying to assess when to step in with teams and when to let them manage their own problems and struggles on their own. While the teacher teams felt uneasy about when we chose to intervene and when we did not, in our summative assessments, students reflected that one of the strengths of this project and project based learning, in general, is having structured guidelines and letting students figure out their own problems as they come up. Students were very clear and articulate in saying they did not want adults hovering over them and solving all their problems.

For example, during an early stage of the automation project, one student was having difficulty powering and lighting her LED lamp. She turned to a peer from another team to see if she was doing the right thing, and asked *"have you guys changed the pin number?"* and her peer guided her to make the Arduino board working. In the interview, she indicated that what she would have liked more of was whole-class reflections, noting that problems were common across groups and stating, *"I think if we had more time to get together as a whole classroom and reflect on our problems and everything... If [] had time to go around and see what everyone else is doing."*

### **OUR TEAM'S REFLECTIONS: DESIGN AND IMPLEMENTATION TENSIONS**

As our team reflected on the implementation and the students' perspectives, we noted some common tensions that persisted.

#### **What Constitutes the Right Amount of Guidance?**

As we have alluded to previously, we were never quite sure of what constituted the right amount of guidance. Student reflections after the project indicated that they wanted low

teacher intervention, but this was not necessarily confirmed in our experience. Throughout the team automation project, students struggled with tasks that involved considerable troubleshooting due to the trial-and-error approaches. For example, one student stated, *"one of the things I did not like was...just how many mistakes we made. I sort of wish in the beginning I understood a lot of concepts better...Basically what we would do is we would keep slightly tweaking until we either figured out it's working now or we decided it's too much trouble than it's worth, let's just do the easier way."*

In complex open-ended projects that involve many decision points, students can learn a tremendous amount from trial-and-error, but they can also struggle and form misconceptions. For example, during the automation project, it is a long conceptual journey from the starting point, which essentially involved the initial approach of "do as I do," to the knowledge of why things are set up the way that they are. This was exemplified by one student stating post-project, *"I still don't understand the data ports... If there is data connected to a sensor, the data is how it sends the information back to the computer, but I don't really understand how it does that."*

The tension of how much guidance is enough needs to be contextualized within the parameters of the overall instructional goals. As we approached it, we considered what we wanted students to accomplish-- that is, automating tasks that would provide temperature information, water level status, and a feeding schedule. Making more explicit the underlying architecture for the students, such as how the data is fed from the sensor to the output through the board, would help students understand the flow of information. But this has to be explicitly identified and prioritized as a goal within the environment for it to happen.

### **How do we Make Local Connections More Meaningful?**

Despite being located close to many small and large farming operations that sell locally in a vibrant farmers' market, we never systematically connected with the local farming community. While we made attempts to work with local farms and aquaponic organizations, we were not successful in getting our students out into the community more than once during this project. Field trips typically involve multiple phone calls and scheduling efforts to try to arrange, and with all the other classroom and school priorities, we were not successful in making a meaningful connection. What we feel we missed out on was the opportunity to make more concrete the ideas surrounding food production and food systems. We believe that a community connection is a critical element for our P3 model as we move forward.

### **What are the Right Assessments?**

From one perspective, the programmed and installed working automation system suggests successful student achievement. More specifically, all teams were able to experience success, though some teams performed a significant amount of troubleshooting at various stages: programming each sensor, getting the sensors and the feeder to work together, and installing the full system. While the teachers targeted specific standards, two intentional structures impeded use of a test or a similar formal assessment: (a) because each team member had a role, students became experts in different aspects of the project; and (b) the primary deliverables, including reports, were collaboratively documented and submitted by the team. While the teachers made decisions for students to engage in individual essay and reflective writing, alignment with standards for these deliverables was not specifically prioritized. As such, we acknowledge that this did not give our team a complete and specific understanding of individual student achievements, and it was a tradeoff we were willing to accept given that the teachers were able to use other class time to target specific standards (and ones that they knew would be tested on state assessments). Furthermore, in this context, the unique full-day, multiage middle school classroom enabled this to happen.

### **WHAT NOW?**

Following the 2015-2016 success, failures, and experiences, our collaboration continues to thrive, though we will not have students engage the aquaponics project again for several reasons. First of all, because it is a combined grade 7 and 8 classroom, about half of last year's students have returned as 8th-grade students this year; it would not make sense for them to repeat this project. Second, our partnership has evolved, and we are all willing to take more risk. We are open to seeing what students can do given an even more open-ended and less concrete challenge, which is where we will go next. Though the funding that initially supported aquaponics has run out, we will continue to seek additional financing and community resources to support these efforts.

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