# Common Ground's Urban Farm = A Laboratory for Learning High School Math

**Larry Dome, Evan Green, Shannon Raider Ginsberg, Sarah Tracy-Wanck, Joel Tolman**

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Eugenio Garcia, a freshman at Common Ground High School, stands in the cold with the 23 other members of his pre-algebra class, waiting to begin the hands-on work for which the class has been preparing over the last week. It is 8am on October 29th and uncharacteristically cold. So cold, in fact, that the ground into which the students are primed to plant garlic cloves for the spring crop is frozen. Off to the side, popped garlic bulbs are divided into 4 baskets -- one for each team of students.

This garlic planting day is the culmination of a week-long project, generated from the real crop planning questions of Common Ground's urban farm. Students have spent the last few days calculating the number of heads of garlic that they will need to plant, and the area of garden bed required, in order to ensure the yield needed for Common Ground's school lunch, mobile farm market, and on-site farmstand. Garlic bulbs from last year were weighed and averaged in an attempt to identify the number of pounds of garlic needed to plant two 100-foot long beds with three rows of garlic each, and six inches of space between cloves. That math took about two days, after which staff picked up that poundage of garlic from our local garlic and honey farmer and prepared for the days outside.

From the moment student teams begin to plant, Eugenio takes to the work with notable capability and vision, leading his team of students through the complicated procedure of preparing the garden bed (raking, shoveling the path, mixing in compost, smoothing it flat), staking out strings for the garlic rows at measured distances apart, and setting up the assembly line of tasks from measuring spacing for cloves, placing them in (pointy side up!), fertilizing, and covering with soil. This quiet student clearly has a capacity for problem-solving, taking initiative, and understanding how to apply his classroom math skills to the real world situation in front of him.

Two months later, Eugenio and his classmate Yasdira are speaking to nearly every one of Common Ground's 180 students from a video they recorded a few days prior. Neither has put together a presentation for an audience this big, nor has either one of them been expected to be an authority in math, a subject in which both have struggled. But Eugenio and Yasdira recognize that the work they have taken on in their pre-algebra class is significant and worthy of sharing, so they take the plunge. They share the results of the garlic project and discuss the math concepts involved, as well as the skills in communication and collaboration required to solve a problem with a team. A few days later, they make a similar presentation at a family awards banquet.

Fast-forward a year to a Saturday in late October. Eugenio, now a sophomore, is standing in the strong stance required to operate a double bevel sliding compound miter saw. He is poised to cut 2x10 boards for a hexagonal garden bed whose interior angles he calculated in order to determine the number of degrees at which to set the saw. Eugenio has quickly become the most competent, consistent, and attentive student to operate the saw, according to his fellow crew members.

Later in the fall of his sophomore year, Eugenio is standing at the whiteboard in Common Ground's farmhouse classroom. Once again, Eugenio is working alongside several of his peers, along with Sarah Tracy-Wanck (TW), Common Ground's Environmental Leadership Coordinator and the leader of our paid school garden resource center crew. There is a diagram of a raised garden bed on the board, along with some pretty complex math. TW has been texting back and forth with another Common Ground staff member, Camille Seaberry, to track down a formula that will help the team calculate the length of an arc of a circle that will complete part of a outdoor classroom the crew is helping to install at the new Elm City Montessori School. While Eugenio and the rest of the crew regularly use arithmetic and geometry when cutting hexagonal beds, and basic algebra when pricing out materials, in this case garden bed construction requires a little pre-calculus.

Eugenio continues to work on the School Garden Resource Crew through his entire sophomore year, applying math skills every single day of work. Math is just one of the domains in which Eugenio must call on to do this job; as a native Spanish speaker, he regularly steps up to communicate with Spanish-speaking home daycare providers for whom he and his crew are building garden beds. Because he demonstrates such capacity for the problem-solving required for this job, Eugenio finds himself standing before Common Ground's entire student body once again -- this time, winning an award for the sense of wonder he's displayed through this paid job.

Fast forward several more months. On a mid-July day the summer after his sophomore year, Eugenio and six other Common Ground students stand in the driveway off New Haven's West Park Avenue, talking with a homeowner, a Yale student intern, and staff from the New Haven Urban Resources Initiative. Eugenio explains the calculations that led him and his team members to determine that, in a half inch storm event, the homeowner can expect her new 55-gallon rain barrel -- which Eugenio's team helped to install -- to fill up 11 times. He talks quietly, and makes his points quickly -- but he seems sure of what he's sharing.

The work Eugenio and his fellow Common Ground students are doing to strengthen and feed their city is leaving its mark. Pictures of these students -- blown up ten feet tall and affixed to a highway underpass that was previously the site of consistent illegal dumping -- now look down on a neighborhood park, an "urban oasis" that they helped to create.

**Figure: Eugenio Garcia planting garlic in Common Ground's production garden, working with Sarah Tracy-Wanck to calculate the length of a circle's arc for a school garden project, standing next to hexagonal raised beds he helped to install, receiving a school-wide award for wonder, presenting calculations on stormwater runoff, and looking down from a photo on an overpass above a park he helped to restore.**

The line that connects these points is not a straight one. There are a lot of unexpected dips, as well as recoveries, in the curve that describes Eugenio's path as a math student and an emerging community leader. Eugenio explains that he couldn't always see the next step on his path -- "but it was always interesting, so I stuck with it."[1]

Still, the "best fit" line that connects these experiences may describe something significant. Eugenio is doing math that is rooted in a place and a physical experience; problems ask him and his peers to build bridges between abstract mathematical concepts and these places and lived experiences. Each of these experiences involves math with a purpose, as well. Eugenio and his peers are solving problems that don't just just resemble or simulate reality; they are solving actual problems that need answers. In some cases, this value is great enough that students are being paid to take on mathematical work. In every case, math is a social activity; young people and adults (math teachers, families, partner organizations, community members) are working together to explore problems and find answers. Math is also performative work -- there is a real audience for their answers, and both their struggles and their solutions are worth lifting up into public view.

At the same time, Eugenio and his peers are using math in contexts that are intentionally designed to practice extra-mathematical concepts and skills -- including communication, fine motor activity, planning, and problem-solving. As a result, the learning and leadership work that students are taking on is simultaneously more rigorous, more authentic, and more supportive than traditional mathematics instruction. The rigor and authenticity of Eugenio's work is likely clear on the surface; students are being challenged to solve complex problems and mobilize multiple skills and concepts from different domains simultaneously. Supportiveness is built in through several common features of these mathematical learning experiences. Students who may struggle in mathematics have the opportunity to apply skills and conceptual understanding from other areas in which they excel. They are invited into contexts different from the ones where they have previously struggled with mathematics, potentially giving them a fresh start. These contexts encourage students to use math to solve tangible problems, rather than remaining at an entirely abstract level. As they build these mathematical skills, students are surrounded by a broader range of teachers -- fellow students, farmers, community members, and others -- whose approaches can complement those of their math teachers. And, when students succeed in taking on challenging work that serves a public purpose, they are celebrated and lifted up as valuable, contributing members of their communities.

As an arc of experiences, Eugenio's math learning starts close to home -- in this case, on Common Ground's urban farm, directly outside the door of his math classroom. Over time, math experiences build from the farm and students' experiences out into the community -- tackling problems related to stormwater runoff and combined sewer overflows, for instance. At Common Ground, we continue to strive, as well, to create bridges between farm-based math experiences and the mathematical context of Eugenio's home and neighborhood -- for instance, by inviting students' families to see students' presentations of mathematical progress, and by asking students to identify how the mathematical concepts they're learning apply to their experiences as consumers and emerging entrepreneurs. At its best -- and we are certainly not always achieving this goal -- the boundary between the math classroom and the outside world is permeable, and students are climbing a ladder of connected, increasingly complex math and leadership experiences.

[1] The student voices shared through this chapter arise from individual interviews and focus groups facilitated by the authors.

**Figure: Ten Design Principles for Farm-Based Math Learning at Common Ground**

Mobilizing our urban farm as a learning lab, Common Ground strives for math learning that:

1. Is rooted in place, community & the lived experience of students
2. Answers compelling, complex questions through an inquiry-driven process
3. Focuses on actual, authentic problems where student work contributes real value
4. Involves work in collaborative teams -- emphasizing the social nature of mathematics
5. Engages teachers -- adults and peers -- beyond traditional classroom math teachers
6. Incorporates field experiences and research
7. Integrates mathematical skills and concepts with skills and concepts from other disciplines and domains
8. Starts close to home, and builds to engage larger issues, communities, and environments
9. Culminates in public products and performances
10. Is driven by cross-cutting standards of mathematical practice -- e.g., problem-solving, modeling -- as well as grade level specific math skills and concepts

## In Context: Common Ground High School, Urban Farm, and Environmental Education Center

Eugenio is a student at Common Ground High School, founded in 1997 as the nation's first environmentally themed charter high school. Common Ground is a small school, with just 190 students in the 2015-16 school year. These students, chosen by lottery, live primarily in the City of New Haven, though approximately 35% arrive from more than a dozen surrounding towns and school districts. About two thirds of our students are young people of color; Latinos are the largest subgroup, followed by African Americans. Approximately 55% of our students qualify for free or reduced price lunch. Common Ground aims to prepare students for college success and leadership; in each of the last 6 years, more than 93% of Common Ground graduates have been accepted to college, and every student must defend a portfolio showing their growth as an environmental and community leader. In 2014, Common Ground was one of four Connecticut high schools named to Newsweek's list of "beating the odds" schools -- the nation's high schools whose low-income graduates are statistically most likely to succeed in college.

Common Ground is an urban farm and community environmental education center, as well as a charter high school, located on 20 acres of city park land at the base of West Rock Ridge State Park in New Haven, Connecticut. This integration of urban farm and public high school -- on a single site, and within a single community-based non-profit organization -- has created rich opportunities for learning in math and across all subjects. These are opportunities that students, staff, and community partners continue to explore and develop; there is lots of unfinished business, and unmet potential, at this intersection of places and organizational identities.

Common Ground grew up in New Haven's West Rock neighborhood -- home to a large forested state park, a public university, the city's largest concentration of public housing, a landfill for the neighboring suburban community, and a mixed income residential community, among other development types. The school's first students and staff borrowed classroom space from Southern Connecticut State University during the day, and then walked over to their new site, where they removed dozens of truckloads of illegally dumped garbage and cleared several acres of invasive species to make room for their school.

Common Ground's school and farm grew together -- sometimes in concert, and sometimes in conflict. From the beginning, Common Ground's farm has been a source of shared cooking and eating experiences, applications for classroom learning, paid youth employment opportunities, leadership development, and personal exploration. At the same time, many students, families and community members assumed that, because Common Ground operated a farm, the school had a vocational agriculture focus -- even though this has never been a strong focus of the school. Some families pushed their children to attend Common Ground because they had struggled in other settings, and believed that being in a hands-on farm setting might allow them to experience more success. Students brought a variety of cultural associations to farming and farm work, as well -- making connections between their Common Ground experiences and slave labor, family farms in Puerto Rico and the Dominican Republic, summers spent with their grandparents in North Carolina. As these associations indicate, the relationship between school and farm is complex, challenging, and rich, and has changed over time.

Today, Common Ground's urban farm includes approximately ¾ of an acre in mixed vegetable production -- planted with an eye to maximizing diversity, modeling sustainable practices, and providing a harvest that meets the needs and appetites of the diverse community involved in both the high school and Common Ground's community educational programs. A separate learning garden -- featuring a variety of styles of raised beds and small learning zones -- is a classroom for field trips, after school programs, and summer camps that primarily engage children in grades K-8. Two high tunnels help extend farm production into the school year, and a heated propagation greenhouse supports seedlings for our gardens and an annual seedling sale. Our site is also home to chickens -- raised for both meat and eggs -- and to small numbers of goats, sheep, pigs, turkeys, and other livestock. Beehives, a small maple sugar operation, and small areas of edible landscaping model other aspects of small-scale agriculture for community members and students.

In 2013-14, Common Ground's farm generated roughly 8,250 pounds of produce, including vegetables, meat, and eggs. This harvest helped to fuel Common Ground's universal free school lunch program; more than 97% of students eat school lunch at least once per week, and more than 60% participate daily, according to survey data collected by the Yale School of Public Health.[2] In the fall and spring, high school students' families could also access weekly bags of produce for a Veggie Share program, paying on a sliding scale basis based on their free/reduced lunch status. In addition, more than half of produce grown on the farm was put to use beyond the high school -- through on-site farm stands, educational and fundraising programs, and a mobile market serving low-income and senior housing across the city.

Common Ground's urban farm -- along with the forests of West Rock and the City of New Haven -- acts as our high school students' laboratory for learning. We are fortunate to have this rich learning lab, because it allows us to have many opportunities to apply what is learned in the classroom to the real world. Since we are operating a farm inside a state park, we are tasked with being the caretakers of the property in a unique way. This being the case, we have many opportunities to analyze how we are impacting our site and how we can better manage the activities of our farm.

This work -- at the intersection of learning and leadership -- takes many forms. Students learn conversational Spanish and French as they work in small, student-led teams to grow and cook with food from our farm. They dive into team-taught, interdisciplinary block courses like Food & The Environment, where they examine the science and policy context in which conventional and organic agricultural ventures operate. They take on paid jobs growing and selling food from the farm, and operate small, student-managed business ventures centered around farm produce.

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[2] Donovan, C., Fernández, J., Foley, S., Kingsley, M., Pratte, M., Zhu, M., Tolman, J., Ali , S., Humphries, D. & Ickovics, J. (2015). *Evaluating the Impact of Common Ground High School, Urban Farm, and Environmental Education Center on Student Health Behaviors and Outcomes.* Published by the Yale School of Public Health and Common Ground High School. Retrieved from http://commongroundct.org/documents/FARhealthimpact.pdf.

## Integrating Mathematics with Authentic Tasks on the Farm

More than their peers in any other content area, Common Ground's math teachers mobilize the urban farm as a classroom and textbook for their courses, and engage farm staff as complementary teachers. Over the last several years, Common Ground's math teachers have explored a variety of opportunities to mobilize our urban farm to engage students and support their learning, from pre-algebra to calculus.

There is an incredible amount of math involved in running the farm. Mathematics is involved from everything to determining the size of garden beds and how many plants we can get into each bed, to determining if we can make a profit from any of our farm activities. As an environmental school, we are also concerned about the impact our activities on our site. Both farm planning and site stewardship provide opportunities for real student work. The tasks they complete and the results they generate are taken very seriously. The data they collect and findings they generate are often presented to key staff members and the results are factored into decisions made about the operations of the site and the farm.

This farm integration work happens in the context of our commitment to standards-based teaching and learning -- and, in particular, within the context of Common Core standards for mathematics. Common Ground's math department has been focused on the Common Core for a number of years, and the curriculum was officially migrated to the standards in the school year of 2014-2015. For us, these standards support and enable rich and meaningful farm-based learning, rather than forming an obstacle to this work.

In making the transition to Common Core, Common Ground's math department focuses on both grade level standards and the Standards for Mathematical Practice (SMPs) -- both essential components of these new standards. Each math class picks one or two SMPs to focus on during the year. The Standards of Mathematical Practice -- for instance, making sense of problems and persevering in solving them, or modeling with mathematics -- are learned through messy, authentic, tangible problems like those that exist on our urban farm. Through the SMPs, the standards focus on teaching students to become problem solvers and developing a deeper understanding of how mathematics is applied in the real world. There is time for skill based exercises, but a richer conceptual understanding comes from using the common core. In this context, there is no need to compromise between standards-based math instruction and authentic mathematical work; they are mutually reinforcing approaches.

Putting standards-based, active, authentic mathematics into action through our urban farm is a creative, ongoing effort. The following pages share two case studies from this work. After sharing these case studies, we then pan back to look at both the farm as a resource across the math curriculum and the enabling conditions that make this farm-based math work possible.

## Case Study: In An Accelerated Math Course, Students Calculate the True Cost of a Common Ground Egg

We have found the process of getting students involved in the larger fabric of Common Ground – most specifically in our site's agriculture cycles -- to be fruitful at all levels of mathematics. In a remedial math class called "LEAP" (Larry's and Evan's Acceleration Program), for instance, students work together to uncover the true cost of producing a single chicken egg on the farm. The lesson spans several days and culminates in an egg breakfast.

LEAP is an intensive block class -- meeting for 2 hours per day, every day of the week -- designed to prepare students for algebra 1. A sizeable percentage of Common Ground's student population comes to Common Ground with mathematical deficiencies that prevent them from diving directly into high school level math. In many cases, these struggles can be traced back to skills that were not mastered very early in their elementary education, creating a handicap that is prone to widen with each successive level of math. Student surveys at the start of LEAP indicate that a large number of these incoming students arrive with a built-up frustration, if not an antipathy, for math. Karissa Bowden, one of this year's students, describes her past experience: "I had questions in math, and my teachers would never slow down to answer them. I was told I should have learned the answer in previous years, and we don't have time to do it now."

The mission of LEAP is to target and strengthen students' core skills, conceptual understanding, and power of mathematical reasoning. Although LEAP is not a "life skills" course, its focus is on the mathematics that all students need in the world, regardless of their vocational paths. Implicitly, one of the major aims is to bolster students' confidence in their inherent ability to do math. As most math teachers have seen, inattention to an incipient fear of math can create a pernicious feedback loop between lack of confidence and lack of achievement. Getting out of the classroom can specifically allow students who are not traditionally successful in school to have an opportunity to be effective in a different environment. Emily Hausler, another student in the class, speaks to how hard it is to sit in a classroom with so many other students all dealing with their own learning challenges. "I felt like the walls were always closing in on me in the classroom… the clock drumming was always a ticking time-bomb in my brain… so when we got to go outside it would relieve some of the pressure."

The "Cost of an Egg" project grows out of a real and practical question for Common Ground's farming team, a team that is comprised of both students and professional staff: At what price should we sell our eggs? Since the application of decimal operations is consistently an area of weakness for students, the LEAP class devotes time to building these skills. This particular inquiry on the farm provided an opportunity for an authentic contextual investigation of the use of decimal operations to solve problems in a business.

Perhaps it shouldn't be surprising that a solid majority of hands go up when the class is asked, "How many of you would like to run your own business when you join the workforce?" Students recognize that understanding the basics of accurately calculating profit is essential for any business owner. The time spent contextualizing the real-world application beyond our project's specific focus is a significant piece of the puzzle to making authentic hands-on work feel meaningful, and is something students speak to when reflecting on the class. Karissa Bowden identifies that these questions help make the math feel real. "Being able to go outside and intervene in this work with everything around us helped see our futures… would we be able to do this in our jobs or careers we want to choose?"

From this starting point, the lesson examines some of the components of a cost-benefit analysis for running a business: capital/overhead costs, labor, retail price, income vs. profit, fixed cost vs. variable cost, etc. Students are asked if they think the current price at which we sell eggs, $5/dozen, is a lot. They argue their cases, based on relative costs of other foods, comparative nutritional analysis, average cost of eggs in the local grocery store, and, of course, taste. After investigating the nutritional inventory of some of their favorite snacks, they discuss and explain to their peers whether any of the information they have uncovered is likely to influence their future dietary decisions. In other words, how do they maximize taste and nutrition at minimal cost?

Now students shift from their own perspectives on the consumer side to the farmer's perspective on the market side, and at this point are ready to apply prior math and problem-solving skills to the task. Karissa Bowden explains that for these problems, "we have to remember everything you taught us, in order to work this one problem out." Students brainstorm a list of all costs associated with producing eggs, from overhead for the site to care of the animals to electricity and labor. They parse the fixed costs from the variable costs and calculate the farm's total cost per week. Finally, they take a sales inventory to deduce weekly income and calculate the farm's profit. This portion of the lesson elicits a thought-provoking discussion on the diverse costs associated with a business, and on the importance of a thorough business plan. Students make connections between paying rent to operate a business and the rent or mortgage payments their parents make every month. Elijah Voss identifies that it is these conversations in which students can picture themselves using these math skills in their future that inspire students to get involved in the math work. "The hands on activities could be challenging, but at the same time, it was something you could use in the future, depending on what you do."

The debrief portion of this project elicited some interesting conclusions, and as a result, some rich discussion. Last year's student team discovered that the egg business was operating "in the red"; the profit was negative, which, of course, meant that the farm was losing money. This discovery had a direct practical impact. Although Common Ground's farmer already knew that the egg business was operating at a loss, the students' figures indicated that the loss was greater than previously thought, and the farm raised its selling price as a direct consequence of their findings.

Perhaps even more importantly, students' research results led a richer understanding of the non-financial benefits of egg production at Common Ground. Students wondered why, if it was operating at a significant loss, would Common Ground continue to fund this piece of the farm. The discussion that ensued this year turned from one of ideal market price to one of personal and institutional values. Why might Common Ground continue to sell eggs at a loss? What extra-financial gains might there be, and to what extent should they be valued by our institution? Among these values, the class discussed our treatment of the animals (their feed, space, and general health and well-being); the differential between taste and/or nutritional value of these eggs and store-bought eggs, as well as the degree of subjectivity in devising a metric for these attributes; issues of food safety, including chemical, biotechnological, and hormonal treatment of animals and their feed; the advantages and disadvantages of buying local produce; the importance of knowing where one's food comes from and of the awareness of what processes are being supported when a consumer makes a purchase; and the educational opportunity inherent to the coexistence of this farm (and its concomitant values) and their high school.

Particularly engaging was how opinions ranged on that question, and how students, at this point in the project, could think of themselves as relative experts on the matter, with an important perspective. Still many identified the uncalculated educational value of the chicken yard as a reason to maintaining the business, one student piping up to say: "Check it out, we are even using it right now!"

The Cost of an Egg project is one of several inquiry-driven, site-based projects and performance tasks built into the LEAP course. Each unit of LEAP incorporates at least one such project. Eugenio's story, at the start of this chapter, shared another of these farm-based projects, focused on planning and planting our farm's garlic crop. Students also calculate how to harvest spinach most efficiently and effectively for a school lunch, and solidify their understanding of fractions through cooking projects. They use the math skills of each respective unit to make predictions, create plans of action, and implement them in the garden. Once students are on board with the investigation, the need for the mathematical tools required to probe for answers (i.e. to solve it) becomes self-evident.

**Figure: Cost of An Egg Student Worksheet**


**Uncovering Costs:** How much does it **really** cost to produce a dozen eggs? Brainstorm with your group what it takes to raise chickens for eggs. What are the costs associated in this business?

First calculate how much it costs to care for the chickens **each week.** **Calculate the total cost for *each* item for one week. Then add up all the weekly costs to determine the total cost for *all items combined.***

| ITEM | COST | NUMBER USED *PER* WEEK | TOTAL COST |
|---|---|---|---|
| **Feed** | 1 bag= $15.39 | 2.5 bag | |
| **Shavings** | 1 bag= $ 5.59 | 2 bags | |
| **Labor (collect/wash/sell)** | $8.75/hour | 6 labor hours | |
| **Labor (mucking)** | $8.75/hour | 3 labor hours | |
| **Labor (daily chores)** | $16.50/hour | 3.5 hours per week | |
| **Egg Cartons** | $.48 each | 13 | |
| | | | **=** |

What, if any, **profit** are we making?
To calculate profit: **Profit= Income – Costs.** We just calculated the **costs** per week, now we need to identify the **income** (amount of money you make before taking out costs).

| Average # of eggs produced per week: | Price per egg: | Total money made, or the **income**: |
|---|---|---|
| 160 | | |

Now that we know our **income** as well as our **costs** per week, we can plug these values into our equation **Profit= Income – Costs** in order to find our profit for weekly egg sales.

| **PROFIT =** | **INCOME -** | **COSTS** |
|---|---|---|
| | | |

Are we making a profit?

We did not include many of the **Overhead Costs** included in the requirements for maintaining the chicken yard. What do you think "overhead" costs mean? Try list at least three of these costs.

Karissa Bowden describes how these projects impact her investments as a student. “I think what helped us the most was that we were able to rely on problems that were like real life… and that we were able to work together as a team to solve problems.” As we build this culture we don’t need to say, “Remember this math… you’ll need it someday,” and we certainly don’t need to field the question, “When are we going to use this?”

Elijah Voss speaks to the lasting impact of this approach, as well. “I think probably the hands-on activities we did [were the most significant]… because it was unlike any other class… that’s the stuff that you remember from years on.”

**Case Study: In Algebra 2, Students Analyze pH Across Common Ground’s Urban Farm**

In Common Ground’s Algebra 2 class, the unit focused on logarithms -- a critical algebraic concept -- culminates in a capstone project focused on pH. Since pH is a logarithmic scale, this project affords students the opportunity to do some valuable research for the school while also deepening both their conceptual understanding of logarithms and their ability to manipulate them. Through the project, students gather data about pH levels in various locations around the campus and the farm, adding to a longitudinal data set developed by past Algebra 2 students. The goal is to track any potential impact farm or school activities may have on the pH levels; students’ research tells us whether there is a need to take immediate action, as well as tracking if there are changes to the pH levels on our site over time. Students collect both water and soil samples. Water samples are collected from a runoff stream that borders the edge of the school campus, a frog pond, and a recently built wetlands area. Soil samples are taken from locations in and around animal pens, from specific locations in the gardens and the area around the compost piles. Once students get the pH readings, they do research and analyze their results to present to members of the school and farm staff.

This project is designed to answer the following essential question: What effects do our agricultural and environmental practices have on the Common Ground environment? Essential questions like this one -- rooted in local environment, relevant to students’ lived experiences, requiring students to mobilize a range of skills and concepts -- are a critical starting point for all of Common Ground’s courses.

Nyasia Mercer, a junior in this year’s Algebra 2 class, is struck by how this question, and the project as a whole, asks students to work on multiple skills and concepts simultaneously. For Nyasia, “this was a really cool project, and it looked real easy at the beginning.” She even feels that the mathematical understanding of the pH scale was straightforward. But the physical collection and testing of the samples was only the start of the work. “When it came to doing the research, that was the really difficult part,” reflects Nyasia.

To make meaning of their mathematical results, Nyasia and her classmates discover that they needed to find out the appropriate pH levels for different environments, and if it the levels were not normal what they could do to modify these levels. This, in turn, requires students to deepen their understanding of ecological systems -- answering basic questions like “what is a wetland, and what kind of wetland is located on Common Ground’s campus” before drawing conclusions about their pH results. Students realize that these deeper questions had particular significance because pH is a logarithmic scale -- where a change of one unit represents a 10-fold increase in acidity or alkalinity. In combination, their mathematical knowledge and their commitment to Common Ground’s environment reinforce the relevance and value of their research.

The project stimulates more questions than could be answered in the scope of the project -- and that is what made it exciting and interesting for many of the students. Grace Knudsen, a senior in the course, describes how in so many math classes before she got to Common Ground, the work was mostly drill and some word problems, but very little applied work. For Grace, the math came alive during this project. “It was fun to go outside and work in my group collecting the samples and mapping the locations." Grace continues, "it was fun to connect the our class work to a real ecological project."

Students in the Algebra 2 class are expected to answer core questions about pH level of samples they collect and what that means chemically in terms of the hydrogen ion concentration. They are also expected to explain what a change of one unit on the pH scale means mathematically. The real learning takes place when students explore why pH would be important and especially trying to understand the consequences if pH levels is out of the normal range, and what could be done to change pH levels.

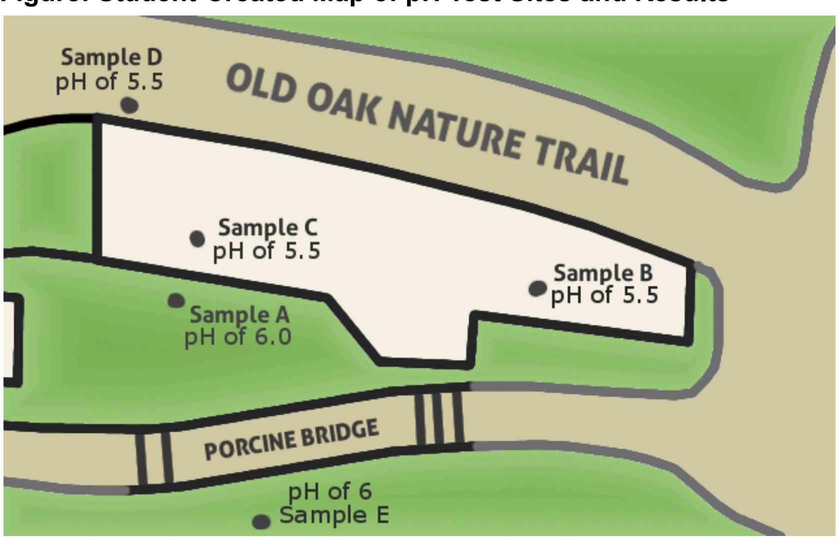
The pH project spans around four 60 minute class periods:

Day 1 - Students read the brief for the project, and form groups of approximately 3 students. These groups choose among locations around the campus and the farm at which to collect samples. Students also learn sampling techniques -- how to collect soil and water samples, prepare soil samples for testing by adding distilled water, perform the actual pH test in the class the next day.

With these sampling skills as the base, students and teachers discuss why the project matters. Students review the essential question, and take a few minutes to write down their ideas about why we are doing this project and what are we supposed to learn as a result. Students then share out the ideas they have about the project. In this preliminary discussion students point out the more immediate reasons for the project. They talk about understanding the environment impact of running the farm and having a school on state park lands. They discuss the benefit of collecting data over a period of years and theorize about what they expect to find at different locations around the farm and the campus.

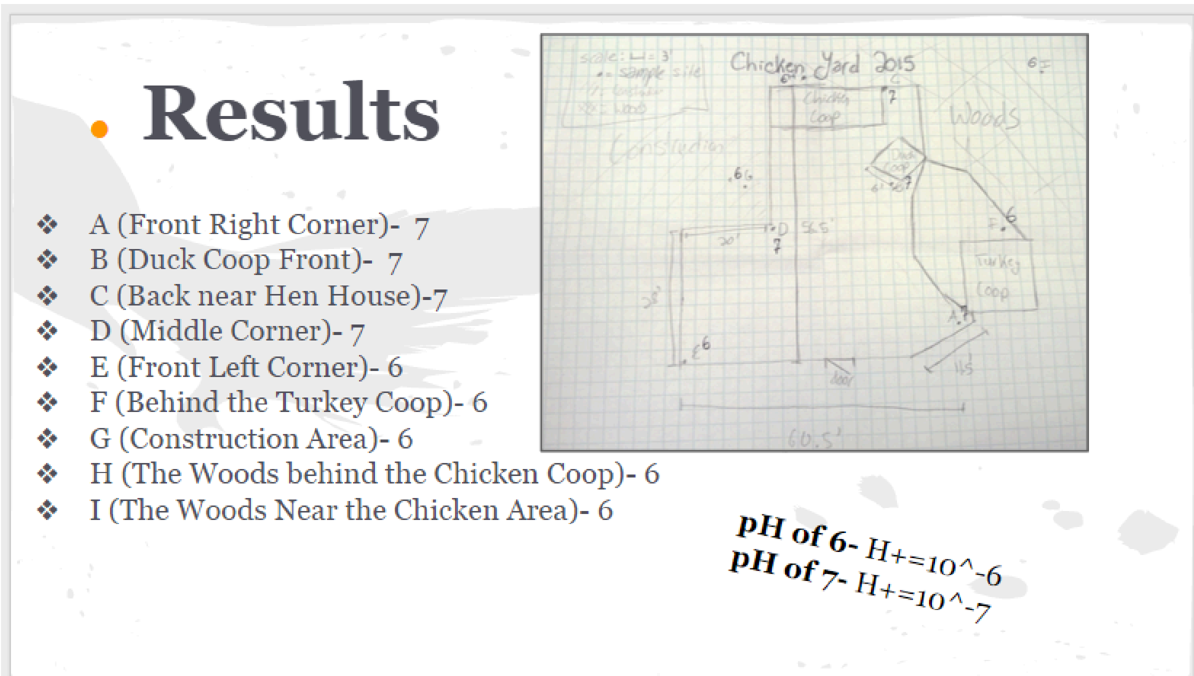
Day 2 – This is a very busy day for students; they collect about 8 to 10 samples from their assigned locations and get back to the classroom with enough time to prepare the soil samples. Students collect the samples, carefully label them and make a rough map of where the samples were taken. Figure X shows of how students used their map in the final presentation to share their test results. Students must work cooperatively as a team to complete sampling within a single class period.

**Figure: Student-Created Map of pH Test Sites and Results**




Day 3 – Students conduct the actual pH tests on their samples. Students are given two types of pH paper, the first type of pH test paper gives them results that are less refined, mostly to determine if the sample is more acidic or more alkaline.  Once the initial test is done, they use pH paper which gives results that include one decimal place so they can get more precise readings. Students are required to record all the results they will need for their final presentations and final report. When students have completed their testing they can begin to research their results.  Figure X shows an example of how a group of students presented their data along with the map they made during the collection process.

**Figure: Student-Created Map of pH Test Sites and Results**




Day 4 – Two or three days after testing is complete, students are ready to present their findings. In the intervening time, students are completing more research and putting together their presentations. On presentation day, students share their results with an authentic audience of farm and teaching staff.  Students' peers rate their presentations, determining part of their  grades for the project (see Figure X)

**Figure: pH Presentation Student Evaluation Worksheet**

**On a scale of 0 to 5 ( 5 being the best, 0 being the worst) rate presentations on the following areas. Provide evidence to support your ratings.**

1)  Was there a statement of purpose for the work and did the group identify where samples were taken?

2) Did the group present their pH test results in a way that was clear and understandable?

3) Did the group state whether the findings were within normal standards and if not did they recommend corrective action?

4) Did the group calculate the hydrogen ion concentration and if the pH was not in normal standards did they discuss the discrepancy level of hydrogen ion concentration?

5) Overall did the flow of the presentation make sense and the results were understandable?

Students wrap up the project by writing a report on their findings. The report is not a formal lab report, but it is supposed to summarize their findings and answer the essential question posed at the beginning of the project.

Students need to create this report individually and they are given an individual grade for this work which is combined with their group presentation grade.

Testing results to date show that the activities of farming and running the school have led to significant year-to-year change in pH levels, and that pH is at or near ideal levels across our site. Ironically, some students are disappointed in the results, as they had predicted a potentially significant or negative impact.  Students reflect on how Common Ground's agricultural and land use practices might lead to these relatively stable and neutral pH levels, leading into a discussion of other ways we may be impacting Common Ground's site beyond pH.

This project is designed to get students to help students understand that mathematics has a purpose, and explore how math is used to model and explain what is happening in the real world.  As the student quotes at the start of this case study indicate, most students find that mathematical work for this project leads them to more questions and research.  Even the surprise at the results generates yet more questions and inquiry.  The students also realize that this data is being archived and that they have made a contribution to the health of their community by performing this project. The project helps students realize the importance of the math they used and deepen their understanding of that math -- while also helping them recognize that real problems can only be solved when math is used in concert with other disciplines.

**Authentic Urban Ag Work Across the Math Curriculum**

Over their four years at Common Ground, students move through a typical sequence of math courses -- starting with LEAP if they need to make rapid progress before taking on high school level math, and then continuing into Algebra 1, Geometry, Algebra 2, Pre-Calculus, and AP Calculus. In each of these courses, they tackle projects and performance tasks like those described in the case studies above -- pushing students to explore their local environment, work in teams, solve real problems and conduct original research, integrate mathematical understanding with skills and concepts from other disciplines, and present their work to public audiences. Many of these projects are rooted in Common Ground's urban farm

In **algebra 1**, students mobilize Common Ground's annual seedling sale as an opportunity mathematical learning. Student teams are challenged to design a fundraising strategy -- raising funds for a Common Ground program or project of their choice -- and put this strategy into action at the seedling sale.  For instance … Teams are given a $50 budget to work with however they decide is most strategic (buying a raffle prize, buying advertising, etc.). Mathematical analysis is a critical component of the projects; students are charged with writing, solving, and graphing systems of equations to calculate potential profit; explaining the meaning of x- and y-intercepts and break-even point. When students reflect on their strategies, they use both mathematical and extra-mathematical techniques to evaluate their success. The goal is a pragmatic one, not just a hypothetical one; Common Ground's fundraising team can gain insight from student approaches, and the project actually raises funds for the school.

In **pre-calculus,** students take on a modeling project focused on Common Ground's meat chickens.  Common Ground raises two batches of meat birds during each school year; these chickens are sold to staff, members of the community and to local restaurants.  The project is a simple one; the students, over several weeks, weigh the meat chickens several times a week and get an average weight for the chickens.  Students then need to make a mathematical model for the growth of the chickens. This project involves two Standards of Mathematical Practice: making a model and forming a logical argument.  There is truly no correct model, so the students must be able to defend the model that they come up with.  The project also evokes questions such as, How do we maximize our feed to weight ratio?  How long does it take for the average weight to plateau?  What is the optimal time to process the chickens? What is the average growth rate for the chickens? Is the a way to vary improve the growth rate?

Three years ago, Common Ground's farm manager challenged our **advanced placement calculus** class to determine the volume of the school's compost pile -- an irregular, complex ellipsoid solid. Working in the weeks after they finished their AP exam, students tested two different calculus-driven approaches to the challenges. One group of students developed a formula that approximated the half ellipse shape of the compost pile's profile, and then integrated this equation to determine the volume of the entire pile. Another group used a Riemann sum -- treating the compost pile as a series of elliptical slices, and finding the volume of each of those. The two groups then compared their approaches -- determining that one represents an overestimate of the volume, and one an underestimate. Together, they produced a video documenting their process and results (online at https://www.youtube.com/watch?v=s5a_Fran-ts).

In most cases, these farm-based math learning opportunities take the form of culminating projects or performance tasks within a unit of study -- or, as in the calculus example, an end-of-course opportunity to integrate skills and conceptual understanding to tackle a particularly complex problem. Because our urban farm is just one Common Ground's three laboratories for learning, these urban agriculture-focused learning opportunities are complemented by others that use the forests of West Rock Ridge State Park, and the city of New Haven, as their context. For instance, students in Algebra 1 also use inequalities to model the payback period on appliances with different levels of energy efficiency, and use equations and graphs to find the optimal fundraising plans for the Rock to Rock Earth Day Ride, an annual environmental fundraising bike ride organized by Common Ground. In a team taught math and science course called Biodiversity, students analyze data on insect biodiversity from habitat restoration sites across New Haven, and write articles for publications of the Long Island Sound Study.

**Enabling conditions: Creating the context for math & urban agriculture**

Common Ground was founded with the goal of supporting experiences like those described above: active, authentic learning and leadership opportunities, driven by challenging academic standards, and rooted in our farm, forest, and city. Our founders chose and developed our site and organizational structure to enable this kind of work -- and we have built on this foundation over the last 18 years.

As a result of this ongoing work, our site provides many opportunities for engaging students in real-world problems. Covered outdoor spaces adjacent to and looking down on our production gardens provide a physical space for classes to gather. Walking trails and interpretive exhibits, developed by students, staff, and community partners, provide students the opportunity to connect with the cycles of the farm on a daily basis. Classrooms with direct outdoor access, tool sheds proximate to growing spaces, and outdoor storage bins with clipboards and other materials are all designed to facilitate teaching and learning. Most importantly, the diversity of our agricultural operation, on the same site as our high school, opens up possibilities for learning across all subjects, including math. Our farm is planned with production in mind -- but aims to privilege education above production whenever the two are in conflict. Each aspect of this diverse agricultural operation -- maple sugaring, beekeeping, raising animals for food and fiber, mixed vegetable production, farmstand sales, etc. -- opens up space for learning in math and other subjects.

Human capacity is, like access to a diverse urban agricultural venture, a critical enabling condition for the math learning experiences described in this chapter. Common Ground has hired staff who are explicitly tasked with managing our urban farm, as well as individuals focused on working with teachers to develop authentic, farm-based learning opportunities for students. A full-time, year round farm manager -- with a background that includes leading commercial and non-profit farms, and leading farm-based educational programs -- manages our urban agriculture venture, now with the support of an assistant farm manager. A farm internship program provides additional farm labor, while also providing college students and young professionals with the opportunity to explore urban agriculture.

Just as important as this growing capacity are staff who form connective tissue between the high school and the farm. A full-time Environmental Leadership Coordinator supports farm-school collaborations through whole-faculty planning and professional development workshops, one-on-one planning sessions, and in-classroom and farm-based support to teachers and students. A teacher is released from part of his teaching load to facilitate curriculum planning, including farm-based curricular work. Teaching assistants, present in many of our classrooms, provide individual supports to students, facilitate small groups in site-based projects, and help build cultural relevance and community connections.

Over time, we have built, re-built, and strengthened structures and systems that will support active, authentic learning. A two week-long faculty summer institute launching planning and professional development for each the year, which continues through weekly faculty meetings, made possible through early school dismissal each Wednesday. Summer institute always involves a substantial focus on site-based learning -- through farm tours, planning sessions, etc. -- and this school year, one faculty meeting a month is dedicated to engaging all school staff in experiences that build their capacity to use our site and community as extensions of their classrooms. Small investments -- such as a shared Google spreadsheet, used to track farm-based classroom projects -- also make an enormous difference in supporting teachers' planning work.

Common Ground's diverse urban agricultural operation, staff capacity, and structures all help to lift up and support math learning that uses our farm as a learning lab. With that said, it is the mindset of seeking real-life laboratories for learning that is the real foundation for this work. Real problems are those that have not already been answered. They are questions that the learners and the adults have a stake in answering. Real questions prioritize students as assets in problem-solving and in generating creative solutions. Ideally, they are grounded in situations that relate to the lives of the young people in the classroom. They are questions that develop transferable skills.

The idea that every Common Ground student can mobilize what they are learning in and outside their classes to create sustainable change in the world around them is what enables us to find these connections. This factor is particularly critical in creating opportunities for engaged, applied math learning, since math often feels to students like it is divorced from anything relating to real life.

We are convinced that this sort of learning can happen anywhere. Every school is situated in a specific physical, social, cultural, temporal context. All of these dimensions, in combination with a mindset of engaged problem-solving, provide opportunities for active, authentic, standards-rich learning.

Working from this mindset, the staff at Common Ground explicitly seeks opportunities for student-driven problem-solving. These class-based opportunities are supported by a backbone of explicit student leadership programs that encourage continued questioning and involvement in the solutions. These are often site and community-based experiences that tie directly with Common Ground's environmental focus.

For instance, Common Ground's Green Jobs Corps -- a year-round program -- annually connects more than 50 of our students with opportunities for paid work, ongoing career and leadership development, and wraparound supports. Eugenio's experiences creating raised garden beds and measuring stormwater runoff from city roofs -- shared at the start of this chapter -- are possible because of Green Jobs Corps. Year-round, a crew of Corps members helps to operate Common Ground's urban farm, taking part in all aspects of growing, harvesting, and sharing produce. Corps members also take on paid work placements at city farmer's markets, operating New Haven's mobile farmer's market, and leading educational programs at New Haven Farms, another urban agricultural venture.

Students looking to continue to push STEM learning can apply their skills in a student-led business program called Environmental Ventures, as well. Students in the Environmental Ventures programs collectively run farm-related business, such as raising chickens for meat, raising the laying flock of chickens and maintaining the egg selling business, and sifting and selling finished compost.  In this program, students develop a variety of applied concrete skills (math, economic theory, marketing, using technology, writing), physical skills involved in the daily care for farm systems, as well as soft skills, such as communication and collaboration. They navigate challenging intellectual, physical, and emotional situations that mirror real-world situations. The Environmental Ventures program is co-managed by the Farm Manager, Shannon Raider-Ginsburg, and the Environmental Leadership Coordinator, Sarah Tracy-Wanck.

Another essential component to encouraging applied math learning is that students are aware that the skills they are building in site-based projects in their classes can transfer forward and upward in their lives.  These class projects lead young people directly into the next level of experience at Common Ground, when then ideally lay the groundwork for continued engagement in college and/or the workforce.

This knowledge is transferred indirectly through the culture of Common Ground, which acknowledges and celebrates real-world work that contributes to sustainable change.  School-wide POWER assemblies recognize students who demonstrate environmental leadership inside and outside of academic classes every other month. Each semester culminates in a day-long Presentation of Learning, in which students share significant academic and extracurricular learning and leadership work with their peers. Perhaps most significantly, students develop electronic leadership portfolios over their four years at Common Ground. In these portfolios, students reflect on significant experiences they have had through their classes, jobs, volunteer or community work, or after school opportunities and programs.  They make connections to Common Ground's set of Environmental Leadership Standards and the national 21st Century Skills (which are specifically designed around real-world application of learning).  Through the process of reflecting on their experiences, and then formally defending their portfolio during their senior year, students take the time to understand how their class-based work connects to their larger contribution to the world.  They are able to see the path they took from science experiment to job shadow to summer program and the importance of the applied learning throughout.  The portfolio work is a significant aspect of Common Ground's culture, with the senior defences taking on a special significance for students as their time to really prove how they have grown and how they hope to use what they have learned.

Common Ground invests heavily in creating the enabling conditions for active, authentic mathematics learning rooted in our urban farm. Yet, as we said earlier, we are convinced that this sort of learning can happen in any school -- even in those that do not have a farm on school grounds, or full-time staff dedicated to facilitating this work, or substantial youth employment programs. The enabling conditions described above are essential, but they are also scalable. For instance, a school garden or a partnership between a school and another urban agriculture venture can facilitate many of the same opportunities that an on-site urban farm can generate. The figure below shares some forms these enabling conditions can take at different levels of resource intensity.

**Figure: Enabling conditions that support urban agriculture as a context for math learning**

| Enabling Condition | In Action At Different Scales, from low to high intensity |
|---|---|
| Access to an urban agriculture venture | ● School garden<br>● Community garden or urban farm accessible by foot or public transit with staff open to public school collaboration<br>● Urban farm on school site |
| Staff capacity experience in agriculture, teaching & learning, connection-building | ● Team of teachers, non-teaching staff, and students tasks with leading effort<br>● Teacher released from one or more periods of teaching responsibility or stipended to play coordinator role<br>● Paid student crew responsible for garden construction, stewardship<br>● Paid part-time garden coordinator, responsible for maintaining garden for educational use<br>● Americorps/VISTA volunteer working across one or several schools<br>● Full-time farm manager<br>● Teacher coach/resource teacher responsible for modeling and supporting teachers in integrating urban agriculture<br>● Full-time coordinator, manager, or director responsible for managing school-farm integration |
| Opportunities for students to extend mathematical work beyond math classes | ● Volunteer clubs and after-school programs that combine agricultural work and learning<br>● Farm-based business ventures operated and managed by students<br>● Paid after-school and summer urban agriculture programs |
| Collaborative infrastructure -- planning time and tools | ● Curriculum planning templates that provide space for teachers to name active, authentic projects.<br>● A shared document -- e.g., on google sheets -- that allows teachers to identify plans for farm-based projects, including course names, essential questions, the length of the experience, the standards addressed, supports needed, and next steps in planning.<br>● A series of three planning sessions over the course of the school year -- to map out farm-based projects, check in mid-year on challenges and resources needed, and share successes at the end of the school year.<br>● Monthly workshops and networking events for teachers from across schools within a city, facilitated by a community-based non-profit with an educational/urban ag mission.<br>● An informal book group or support group among teachers working to integrate urban agriculture into their courses. |
| A culture and structures that value and evaluate students' active, authentic work | ● Reflective writing opportunities within individual classes, allowing students to make meaning of their experiences.<br>● School-wide and family award ceremonies that lift up students engaged in farm-based mathematics learning.<br>● A student portfolio system that provides opportunities for students to reflect on their progress. |

## Conclusions

What do we, at Common Ground, really accomplish by bringing the farm and our site into our mathematics curriculum? As you have seen going through this chapter, there are accomplishments at several levels. At a most basic level, authentic tasks help students to understand that mathematics has a practical purpose. Many tasks cannot be completed successfully without the use of mathematics. An authentic task also helps to deepen a student's understanding of the skills and concepts that were applied to complete the task. Nyasia Mercer from the algebra 2 class said, "that the pH project helped create a lasting understanding of the concepts in the unit compared to just working on worksheets." Grace echoed this sentiment saying that for her, "I am more confident about logs and pH. I remember much more of this math."

Data on students' achievement in math seem to support Nyasia and Grace's conclusions. Between 2007 and 2013 -- the same period in which Common Ground consciously integrated active, authentic learning opportunities with standards-based teaching and learning -- the percentage of students demonstrating proficiency on math increased from 31.8% to 76.7%.[3]

While learning mathematics at a deeper level is a very important goal on its own, using authentic tasks in the curriculum also provides students with extra-mathematical opportunities for learning, as well. There is a heavy focus on 21st century skills at Common Ground and providing students with many authentic projects in the curriculum, mathematics or any content area, gives students the opportunity to practice and hone 21st century skills. Working in collaborative teams is one such skill and all the projects described in this chapter had a significant component of group work.

Finally, what may be one of the most important results of this type of student engagement is that it is an entry point to much richer and deeper discussions. In both case studies, students exercise a basic set of mathematical skills and concepts -- but the math ultimately provided the the understanding necessary to start to ask deeper questions around the project. The LEAP cost of an egg project expanded into areas such as the cost of nutritional value and what it means to run a business. The pH project for algebra 2 caused students to more richly describe and define the micro-environments they were testing and engaged them in a discussion about what else might we be doing to environment even though the pH looks okay.

This type of authentic work is clearly most valued by the students because it causes them to think about the project in a much more rigorous way. Students almost cannot help themselves from taking the initial task and questions and generating and even larger list of questions and interests that they are determining and therefore they are interested in answering.

There is, of course, plenty of work to be done as we build the strength and reach of this program. Most significantly, we are seeking to move beyond our immediate campus and learn to see the larger New Haven community, and specifically the neighborhoods in which our students live, as a laboratory for learning at least as rich as our farm. We have a long way to go towards this goal, but are making our intentions explicit and addressing that first important step: shifting our mindset to include this part of our world.
For all these reasons, our experience indicates that urban agriculture provides a powerful context for high school math learning -- and, in fact, we see emergent characteristics of urban agriculture that lend themselves to high school math. For instance:

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[3] Over this period of time, the percentage of students earning proficient scores doubled or more than doubled in every subject area. Since 2013, the State of Connecticut has been making the transition to new Common Core-aligned assessments, so standardized tests results are not available for math or other subjects.

- Agricultural systems are inherently growing systems -- and thus provide a context in which to model linear, exponential, logistic, and chaotic growth can be modeled and explored.
- More generally, small urban farms also provide a variety of manipulatives and concrete manifestations of mathematical concepts -- for instance, the angles in Eugenio's raised garden beds and the irregular volumes of Common Ground's compost piles -- that provide opportunities for student learning.
- Urban agriculture is by its nature a business venture -- and small-scale urban agriculture provides a manageable context in which to explore costs and benefits, pricing models, and other business concepts that build and apply mathematical understanding.
- For city students, urban agriculture provides a mix of the relevant and close to home-- connections to food justice issues and cultural foodways, for instance -- and an experience of the new and wondrous in the form of first experiences with particular sensory experiences.
- Urban agriculture provide direct feedback loops to students -- crops and animals thriving or not -- that create opportunities for authentic assessment and lend heightened significance to students work.

At the same time, we are not convinced that urban agriculture provides a singularly powerful setting for high school students to learn math. Other aspects of urban environments -- from disproportionate incarceration rates, to major downtown development projects, to start-up fashion or tech ventures, to urban habitat restoration, to cultural diversity -- can provide opportunities for learning aligned with the design principles shared early in this chapter. Eugenio and his peers could thrive in a school co-located with a youth media organization or or a juvenile justice reform group, just as they do at Common Ground. For us, the existence of other rich environments for math learning doesn't undercut the value of urban agriculture. It just reminds us that there is no good reasons that cities should not be the incubator for a new, diverse generation of STEM learners and leaders, given the many opportunities that exist in our urban centers.

In the end, we want to know more -- and in particular, to learn more from our students' own experiences. Writing this chapter allowed us to learn directly from students about how experiences with urban agriculture support their growth as mathematicians and leaders. This was an incredibly rich opportunity for teachers and staff who support this work, and is a necessary step in supporting productive and authentically-engaged work. We learned that these students really value the hands-on work -- that it challenges them in a way that makes their learning feel more important, and that it is a very welcome break from the confines of a classroom. We also learned where students see the challenges for this work, such as the potential for distraction when outside. Karissa Bowden discusses her personal experience, saying, ""I can get distracted really easily, but being able to be distracted with the [outside, hands-on] work that has to be done... I think that's what helped a lot for me."

This, for us, is the work ahead: lifting up our students' voices and experiences, so that they can teach us how to help them learn and lead, on and beyond our urban farm.

**About the Authors**: ***This practice toolkit was originally written as part of a potential book project on urban farming and STEM learning, but never published. In 2024, it was brought back to life and published at [teachcity.org](teachcity.org) with support from a USDA NIFA grant.*** At the time this practice toolkit was written, Larry Dome and Evan Green were math teachers at Common Ground. They co-taught Common Ground's LEAP course, and also teach Algebra 1 and Algebra 2 courses that integrate farm-based problems and projects. Shannon Raider Ginsberg was Common Ground's Farm Manager at the time, and had worked for more than 4 years to grow the production and educational impact of Common Ground's farm. Sarah Tracy-Wanck was Environmental Leadership Coordinator, and is responsible for facilitating farm-school connections, both during school and through after-school opportunities. Joel Tolman, Director of Impact & Engagement, is responsible for efforts to evaluate and grow Common Ground's impact, including efforts to share and partner with other schools.