A MATH GREENHO

An old, unused greenhouse in the middle of the campus inspired me to think of all the ways that this building could become a laboratory for inventing, building, and using mathematical models to teach core algebra concepts and skills. As a result, I developed the Cibola Greenhouse and Composting Company. My students, all of whom have disabilities, engaged in project-based learning and transferred habits of hard work and perseverance to the math classroom. This article shows how project-based learning and skilled manual labor developed dispositional habits in learners; sets forth the connections between greenhouse work and the Common Core State Standards in Mathematics (CCSSI 2010); and presents suggestions for practice in your mathematics classroom. Throughout, reflective feedback from the students describes their experience in this program.

PROJECT-BASED LEARNING FOR STUDENTS WITH DISABILITIES

My students were freshmen at a large, urban, southwestern high school. Many had a history of low attendance, gave up on problems quickly, refused to work, and were suspended often, resulting in failing grades in middle school. Many of them talked about dropping out yet were not ready for a job, nor were they able to pass the GED. What can a teacher do? I asked myself these driving questions: How can I

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EMATICS USE

Students create authentic models in community-based projects while learning about composting and mathematics.

Anthony M. Rodriguez

connect mathematics to my students' daily lives? How can I breathe life into the mathematical models they use in Algebra 1? How can I engage them enough so that they wanted to show up to class? How can I develop a positive disposition toward work in my mathematics students?

Twenty incoming freshman signed on to take two mathematics classes: a math strategies course with project-based learning at the core paired with an Algebra 1 course. Project-based learning (PBL) is a powerful way of engaging students, increasing motivation, and developing ownership of the learning of mathematics while connecting students to the school community (Blumenfeld et al. 1991; Larmer, Ross, and Mergendoller 2009). The topic begins with a driving question, to be answered through the work on the project.

The initial project that we designed was called Selling Plants and Helping a Brother Out. (A faculty member's wife had cancer, and we raised $600 to buy plane tickets for him to see her in a specialized hospital in Houston.) This seed grew into a year-round, integrated greenhouse, gardening, construction, and composting company.

Access to "Real" Algebra

Many people with disabilities struggle with problem solving, thus lowering their overall mathematics achievement (Krawec et al. 2013). A correlation shows between levels of service (the hours of special education service) on the Individualized Education Program (IEP), mandated by the Individuals with Disabilities Education Act (2004), and access to "real" algebra. Often, as the level of service within the IEP increases, authentic problem solving decreases and "canned," programmatic, and remedial basic skills work increases. This decrease in access to authentic problems removes the most compelling reasons that students need to work on skills—to solve everyday problems in the community. Many teachers wonder why their students in these programs hate mathematics, refuse work, and stop attending classes when in fact this refusal is often the only power they are granted in these classrooms (Daniels and Arapostathis 2005). Repetition is useful only when it has purpose for the individual, but solving real-world problems within PBL methods breathes life back into learning core skills (Blumenfeld et al. 1991).

It is of paramount importance that students with disabilities be taught at high levels and expected to become expert problem solvers. Problem solving requires individuals to become reflective learners (Hiebert and Carpenter 1992; Kolb and Kolb 2005; Zull 2002). Through the real-world problem solving of PBL, students connect to their community; create their own mathematics problems, which they then solve and use as reference; and thus increase their potential for learning the content at a deep level through autonomy and competence (Deci and Ryan 2000).

Celina, a senior, commented that PBL "really show[s] me what I am working with, it makes sense to me, and gives me a good picture of the problem in my head. I really liked my projects. I could be very creative." After taking class with me for three years, Daniel, a junior, summed up his experience, "I still remember in ninth grade I really didn't like coming to school, but with the greenhouse, I am actually doing a lot better. I am passing all my classes with mostly As and Bs."

To help their struggling learners, teachers must be prepared to connect their lessons to a real-life context (Gutstein 2003; Allen 2012) so their students can engage deeply and enjoy the work intrinsically (Csikszentmihalyi 1990; Shernoff et al. 2003). The PBL incorporating the greenhouse work with the freshman algebra class was that initial connection for many of my students.

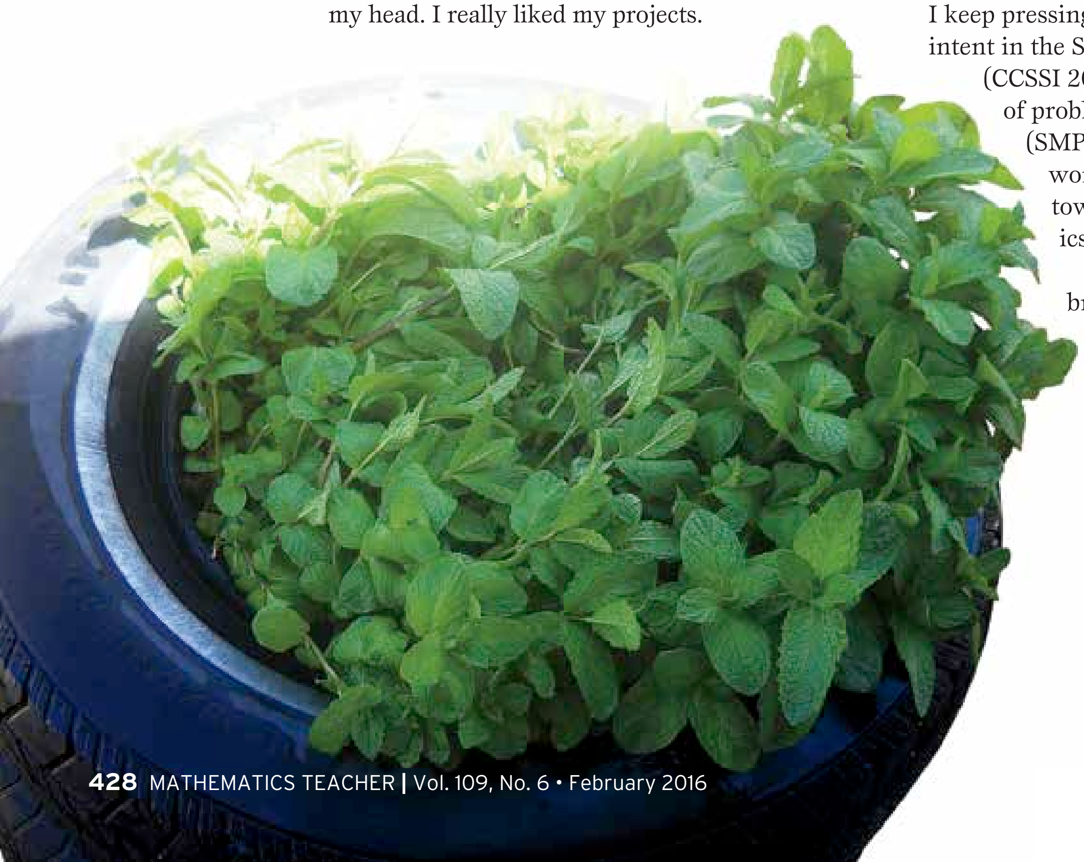
Work Habits and Challenge

During the economic downturn of 2008, many of the parents of my students took jobs that traditionally went to high school students. One objective of the greenhouse project, therefore, was to replicate the experience of a paid job in which students learned good work habits. Sustained work in one activity transfers to all endeavors and develops a habit of agency and self-determination (Deci and Ryan 2000; Csikszentmihalyi 1990). Project-based learning in the greenhouse activity transferred into the ability to work through challenging mathematics problems.

Each project produced by the class led to the next, and students became aware of the connections between standards and the projects they completed. Melissa, a senior, discussed her path of sustained work: "When I am frustrated with math, I do stress, but because I do not want to give up, I keep pressing and tell myself I can do it." The intent in the Standards for Mathematical Practice (CCSSI 2010), that students must "make sense of problems and persevere in solving them" (SMP 1, p. 6), reflects her disposition of working through times of uncertainty toward any new challenge in mathematics and beyond.

Similarly, as Stephanie, a senior, bravely admitted,

> I learned a lot I didn't think I would have been able to learn. . . . I took an extra math class in my senior year because, in my opinion, I know I would need it later on in life. So I took the class to show I was a hard worker, because I wanted to prove that I'm strong and well educated and don't give up on anything so easy, even though I didn't need the credit.



THE TRANSFORMATIVE POWER OF MANUAL LABOR

Other programs that emphasize connection to the community and engagement in skilled manual labor have proved effective.

The ideas that John Dewey (1938) developed for his Lab School almost a hundred years ago are relevant to today's increased demands for more prescribed teaching and teaching to the test (Anderson 2007). Dewey worried about mass-produced curricula, which he believed weakened teachers' abilities and skills. By developing our own lessons and curriculum, we become stronger in the classroom. Everyone benefits.

Frank Lloyd Wright invited the best architectural minds to Taliesin, in Spring Green, Wisconsin, to master architectural design—and to do chores: milking cows, chopping wood, quarrying stone, sawing planks from trees, sifting sand for mortar, and tending to the vast gardens. Wright wanted to build old-fashioned work habits in his apprentices through manual labor. Only after many hours toiling at this repetitive, physically demanding work would they earn a seat at the drafting table to be taught by the master and to "learn by doing" (Taliesin Fellows 2012).

When Malcolm Beck looked out at the vast, inexpensive land in San Antonio, Texas, and unlimited quantities of local recyclable farm waste, he saw an opportunity. He created Garden-Ville—a multimillion-dollar composting business supplying the soil amendments for a Texan's passion for growing championship-caliber roses (Beck 1997).

Inspired by the work of these individuals, I saw that this empty one-seventh-acre, weed-infested space in the middle of campus had this same potential—to be transformed into my own version of Taliesin, Lab School, and Garden-ville to shape the habits and dispositions of my freshman algebra students.

Get to Work!

Fashion-conscious high school students might object to sifting compost, pruning, weeding, carrying water 100 yards to 1500 growing plants, and loading a yard of soil on the back of a truck. Alex and Matt, both juniors, captured the essence of many students' resistance to the work: "You get dirty and stink . . . at first I hated greenhouse because of the manual labor, but you grow up and get over it."

Over time, the physical, tough, and often dirty work centered these students; it allowed them to burn fuel and work out tensions that previously would have ended up in office referrals, avoidance of work, and other unproductive habits. The greenhouse harnessed their abilities in ways that traditional mathematics programs do not.

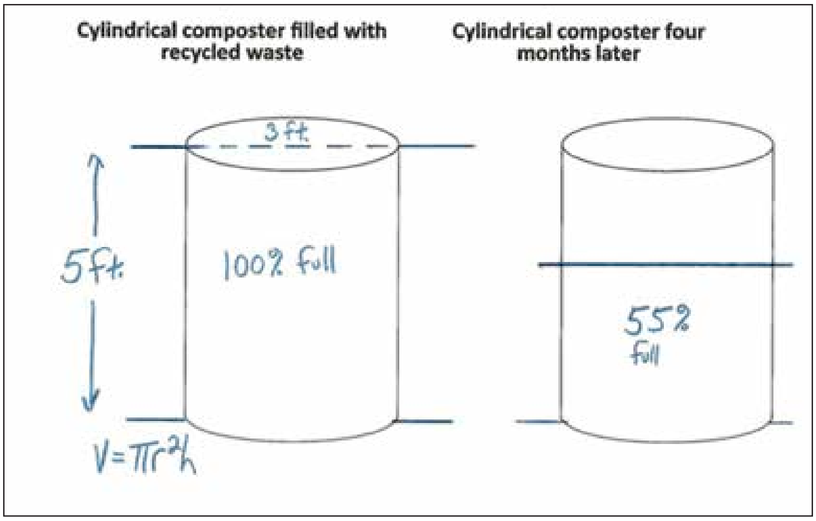


Fig. 1 Volume calculations were needed for finding the reduction of compost.

Daniel exemplifies the confidence that comes from deep learning and strenuous work. "You want to come over and learn tips? Come on over. . . . We know everything!" a typically modest Daniel says. It sounds bold—the type of bold confidence that emanates from working with shovels, hoes, and pitchforks many hours each day, through extreme heat, sunshine, and foul-smelling compost wafting in the distance from "Mount Corona," a hill of recycled material estimated at 30 cubic yards. A seemingly impenetrable attitude earned through hard work transferred to everything these students did—growing plants, building raised beds, and even persevering through frustration on a mathematics problem. After working with their hands in the hot Southwest sunshine, these students knew that they could solve mathematics problems in the comfort of an air-conditioned portable classroom.

THE MATHEMATICS OF A GREENHOUSE PROGRAM

After debating the need for both basic skills and appropriate, grade-level challenges, I built the combined class that fused project-based learning and a rigorous algebra curriculum focused on mathematical modeling. Creating mathematical models, such as the composter (see **fig. 1**), which demonstrates the way our natural world composes and decomposes waste (mass) over time, helps transfer real-world mathematics to the classroom practices (Boaler 1993).

We graphed and explained how different plant-based recyclable waste in different content ratios heats and cools at different rates. The class used cylindrical drawings similar to those shown in **figure 1** to solve related problems.

We understood that compost reduces in mass over time (depending on the type of materials

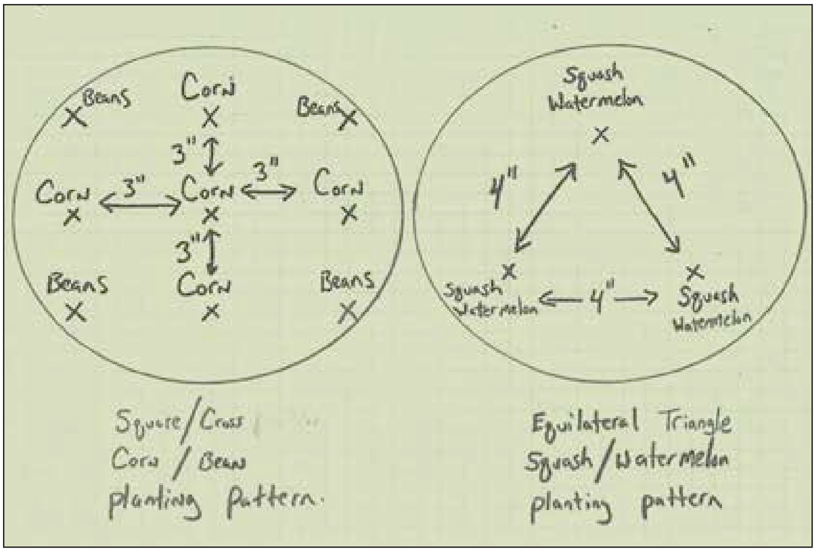


Fig. 2 Planting patterns showed measurements for each hill.

being composted and rate of decomposition), and we could calculate the percentage reduction over time to understand how much finished compost we would have to sell. Turning and mixing the pile added another variable to work with. Problems of capacity and profit were posed to the class:

> How tall would the compost measure within this cylinder at 55%, 70%, and 87% capacity? How much compost would we have to sell to our customers at these heights? And what would our profit be if we sold 2 cubic foot bags at $3.00, $3.50, 4.00, or $5.00?

My goal was to have students represent and analyze mathematical situations and structures using algebraic symbols as well as patterns, relations, and functions. I found that a great mathematics problem has many access points and connections to other mathematics standards. Primarily, we addressed the following Common Core State Standards for Mathematics: using mathematical models to represent and understand quantitative relationships (throughout algebra and geometry, denoted by * in the standards); applying geometric concepts in modeling situations (HSG.MG.A.1-3, CCSSI 2010); creating equations that describe numbers or relationships (HSA.CED.A.1-4); using coordinates to prove simple geometric theorems algebraically (HSA.GPE.B.4); and distinguishing between situations that can be modeled with linear functions and with exponential functions (HSF.LE.A.1).

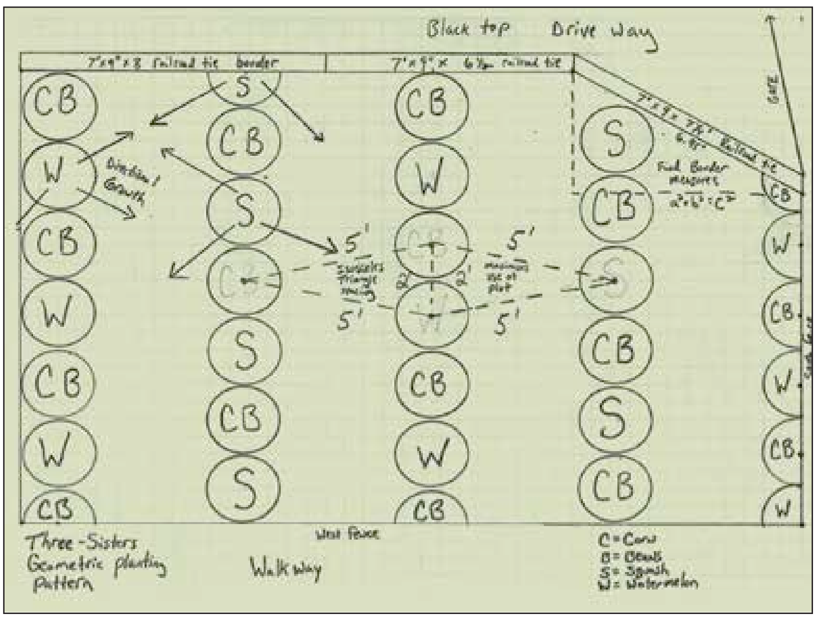


Fig. 3 Geometry patterns were used to design available space in the corner of a lot.

Concepts and Blueprints

Many researchers conclude that deep conceptual understanding grounded in rigorous procedural practice improves overall learning in mathematics (Fuson et al. 1997; Hiebert and Carpenter 1992; Hiebert et al. 1996; Lampert 1986). Understanding mathematics concepts also gives meaning to the procedures and work involved in learning mathematics. Conceptual understanding is rich in relationships and connections, which are helpful in generalizing to new problems.

Using the underlying components of conceptual understanding and problem solving is critical to developing well-rounded mathematicians. An example of this occurred when Matt and his team developed the "best design" for garden blueprints. The class voted on three components: efficient use of space, potential to maximize yield, and use of geometry skills to solve the problem. The winning team used planting patterns shown in **figure 2**, with equilateral triangles (for squash and watermelon) and in a matrix cross pattern (that encouraged the beans to grow vertically on the corn), thus increasing yield. They then staggered isosceles triangles to space the hills optimally, saving 1/3 foot per row. They also applied the Pythagorean theorem to measure accurately the corner by the gate and install a railroad tie border (see **fig. 3**). Matt wrote, "I was proud that my design was chosen, because I, with the rest of the class, really put a lot of work into the greenhouse. . . . We had to measure the whole garden to figure out how far and how many plants would fit and use the theorem for the corner with $a^2 + b^2 = c^2$."

I wish I could say that there was a touchstone moment where it all came together and I knew that PBL through mathematics modeling was working for my students. What I can say is that I began, very slowly, to notice that my students talked more about mathematics, described the mathematics in the greenhouse algebraically, and wrote more in their mathematics notebooks about both understanding and procedure. The mathematics equations that I graded often had detailed drawings of what they had learned, drawings mainly of the models that they built in the greenhouse.

SUGGESTIONS FOR CLASSROOM PRACTICE

When planning for PBL in mathematics, I look at how I can integrate local happenings in the community with the Common Core Standards and the Individualized Education Program goals and supports. (See the sidebar **Developing Project-Based Learning for Students at Risk**.) This can be done by interviewing students to find out what they care about, what interests them in the community, and what they would like to change through PBL. Moreover, we have used algebra to investigate scams through Pawnshops and Payday loans. We have built suspension bridges with parabolic wire supports to learn Algebra 2 content. The mathematics goals found within Individualized Education Program goals can be used to create instructional targets for these students with disabilities. Finally, I am mindful to plan for supports and accommodations and to eliminate the barrier of "Well, this kid can't do that."

Taking Risks and Influencing Performance

All students need to freely experience the environment, take risks, and learn from mistakes. As Dewey noted, "We can be aware of consequences only because of previous experiences." (1938, p. 68). Many students with disabilities are sheltered and protected from ever having to take risks (Perske 1972), are unable to work outside their comfort zone, and are never given the chance to engage in grade-level tasks. Matt would offer this advice to another student: "I wanted a challenge, but don't take it if you can't handle the work, because it is hard but worth it. Everything you learn here will help you in the long run." When educators reduce demands on students, they are grossly underestimating students' capacity to recover from failure, reconstruct a new strategy to work with, and ultimately succeed in school. PBL is the perfect vehicle for sustained struggle and collaborative risk taking.

Esprit de Corps

With my own disposition toward work and mathematics—that everyone who keeps working will succeed—anything less is unacceptable. I see my job as continuing to cajole, prod, and motivate at all times. I worked side by side with my students, doing anything in the greenhouse that needed to get done.

My students knew that they were a part of a team and counted on one another to finish each task. Chris, a junior, recalls that it was not easy: "First, being new to the greenhouse, I did not really enjoy working outside at all, but helping each other as a class, I began to value this a lot . . . it became something I kinda looked forward to."

Things got better, then regressed, and then for months my students exemplified esprit de corps. A coworker, a retired member of the U.S. Armed Forces, observed that my students looked like they were "locked in to a common goal, worked as a seamless, cohesive unit and showed high morale and pride in their work."

TANGIBLE GAINS

Over the course of the four years, the harder my students worked in the greenhouse, the more purposeful they became in the mathematics classroom. These habits of determination and toughness generalized to sense making and perseverance in their mathematics work within my Algebra class. In addition, when it came time for the eleventh-grade standardized test (New Mexico Standards Based

Developing Project-Based Learning for Students at Risk

1. Think of five things that you and your students care about or love to do.
2. Pick one idea and write driving questions for this idea with your class.
3. Categorize the questions under the Common Core State Standards for Mathematics.
4. Align Individualized Education Program (IEP)/Response to Intervention (RtI) goals and learning targets.
5. Think of accommodations and supports needed in accomplishing tasks.
6. Write an outline, fill in day-to-day plans, and set start and end dates.
7. Begin work.


Hooped tents housed seedlings.

ANTHONY M. RODRIGUEZ

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Assessment [NMSBA]), my students scored higher than expected. They had the highest improvements in our district, resulting in commendations of our special education students and an A rating of our school by the state, the only area high school with such a rating with our demographics. From the success that our students had on the NMSBA test, we also secured a $30,000 Intel innovation grant for the rehabilitation of our greenhouse, which needed significant repairs. Many students, who three years earlier were ready to drop out of school, scored proficient on the test. In addition, these students took an elective precalculus class their senior year.

Engaging students in mathematical modeling has also helped me improve my craft. Working out my mathematics practices has made me a better mathematics teacher in ways that teaching solely from the textbook or prescribed curriculum would not have supported.

My students were just like all other high school students in their initial reluctance. However, their experiences proved malleable over time. I saw in these students what my first employers must have seen in me—a work in progress, for sure; however, when placed in a position of responsibility, I grew into the job, and my students did too. I am very proud of them. Edward, a junior, captured this sense of achievement: "It was a wonderful experience, I met a lot of great people, and it felt great doing some good and productive things for the community."

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