



Students at the Center for Advanced Research and Technology in Fresno take extracts from herbs to test for antibacterial properties.

Making STEM Real

By infusing core academics with rigorous real-world work, Linked Learning pathways prepare students for both college and career.

Gary Hoachlander and Dave Yanofsky

As the test began, the concerned expressions on the students' faces betrayed their anxiety. But the students weren't filling in multiple-choice bubbles. They were standing in front of the stress analyzer machine in Jose Valazquez's engineering classroom at Harmony Magnet Academy. The three 10th graders were watching as their truss bridge was put to the test. "Ten pounds, 20, 40, 80, 120!" Valazquez

called out. As the balsa-wood bridge started to crack and then snapped, Valazquez exclaimed, "One hundred and sixty pounds of pressure! That's a new record!" The students' faces turned triumphant as they gave one another high fives, an appropriate reward after weeks of hard work.

Harmony Magnet Academy, situated in the heart of California's Central Valley and with farmland stretching for miles around, is growing engineers.

Reconnecting STEM

There are few more crucial initiatives on the school improvement agenda than increasing student proficiency in science, technology, engineering, and mathematics (STEM). Yet in too many schools, STEM is still mostly science and mathematics, taught separately with little or no attention to technology and engineering. Where connections do get made to technology and engineering, too often they happen through a hodge-podge of disconnected projects that lack coherence or strong grounding in content standards and student performance objectives.

Also, STEM tends to function in isolation from other core subjects. As some observers have wryly commented, STEM might have more STEAM if it also paid attention to the arts, acknowledging the importance of creativity and design in STEM-related fields.

Core academic courses in Linked Learning meet the admissions requirements of postsecondary institutions.

There is no one right way to address this need. However, in California, Linked Learning: Pathways to College and Career Success offers a promising comprehensive strategy for focusing on STEM in high school. Linked Learning connects core academics to challenging professional and technical education in such fields as engineering, biomedical and health sciences, energy, information technology, manufacturing, media and digital design, transportation, and agriculture and natural resources.

Integrated Engineering

In a small but growing number of high schools in California, students have the

opportunity to enroll in an engineering pathway, organizing their four-year program of study around engineering and related fields, such as architecture and construction. A Linked Learning pathway is much more than a sequence of three or four engineering courses. When designed well, the pathway also includes the full complement of core academics (mathematics, English, science, social studies, and world language); work-based learning; and support services.

Students learn, for example, the role of algebra and geometry in designing structures that will withstand gale force winds or bridges that can survive strong

Students measure eye movement and fixation during reading, testing the effects of font size on eye stress.



earthquakes (see sidebar Learning by Doing). Team teaching by both academic and technical teachers helps strengthen these connections. The pathway also engages students in a series of increasingly challenging work-based learning opportunities designed to connect classroom instruction to real problems and professionals in the engineering world. Schools can also develop supplemental instruction in reading, writing, and mathematics around the industry theme.

ConnectEd has created such a curriculum for algebra and pre-algebra; it emphasizes engineering-related project-based learning and application of mathematical concepts and skills (see sidebar Resources for STEM, pg. 5). For example, students design and build a wind turbine, seeking to maximize the transformation of wind energy into electricity. They begin with a review of basic fractional operations, applying these skills to building the turbine tower within specified area and height constraints. Subsequently, they practice using protractors to measure angles, paying special attention to how the “angle of attack” affects the aerodynamics of the wind turbine rotor. They experiment with different blade shapes and angles of attack, evaluating how these characteristics affect voltage output.

Creating Strong Pathways

Whatever the industry focus, the process of designing and implementing high-quality pathways that advance STEM learning depends on four crucial elements.

Element 1: An Integrated Curriculum

Linked Learning pathways can

help focus and scaffold a curriculum that connects abstract academic concepts to concrete applications. For example, consider a lesson designed to help students understand the role of electricity in regulating the human heart as part of a larger examination of the cardiovascular system. Although it’s helpful to point out connections to electrocardiograms as a practical application in detecting heart disease,

merely emphasizing an application is not likely to deepen or reinforce student understanding.

In contrast, the lesson takes on more significance when it’s part of a coherent curriculum in a biomedical and health science pathway. Students could perform actual electrocardiograms in a hospital or office setting, working under the supervision of professionals who also help them interpret the results. The students could then explore the science and technology behind pacemakers, perhaps engaging in a group project to improve an aspect of pacemaker design or to consider less invasive strategies for achieving cardiovascular health. In English classes, students might work on a research assignment that delves into cross-cultural differences in rates of heart disease and the relationships among culture, diet, and human health. In Spanish class, lessons might focus on the vocabulary needed to help caregivers diagnose common ailments reported by their Spanish-speaking patients.

Creating such a coherent curriculum depends on three supports: (1) a cluster or sequence of technical courses that enable in-depth exploration and cross-disciplinary applications, (2) integrated units for academic teachers to help them connect their disciplines to authentic uses in an industry, and (3) supplemental materials in mathematics and English language arts that incorporate the theme as well as project-based learning. Project Lead the Way (www.pltw.org), for example, provides a menu of challenging courses for both engineering and biomedical sciences pathways; and the Education Development Center

Learning by Doing

Harmony Magnet Academy in Strathmore, California, opened three years ago with engineering as one of its two pathways for freshmen (the other is performing arts). According to Mike Henson, former principal of Harmony, industry themes were chosen with considerable input from the community and an eye toward the local economy. “Our potential for occupations is not obvious to students,” said Henson. “Students see orange groves and think about picking oranges. They don’t realize the engineering options that are connected to soil and water management or that deal with the insecticides and pesticides that go along with the agriculture industry.”

When Henson recruited teachers, he made it clear that Harmony would be adopting a new approach to teaching and learning in which students would demonstrate proficiency by *doing*. Project-based learning and integrated curriculum would define the student experience. Students in the engineering pathway conducted experiments on corrosion in their chemistry class; focused on tension and load-bearing formulas in geometry; and capped off the project in Principles of Engineering by importing those math formulas into MDSolids, a computer program that helped them create virtual models of a bridge.

Math and engineering teacher Jose Valazquez says this approach makes learning real, relevant, and seamless. “Most kids will do math only to get a grade. But if you have them build something with the math, they forget about the grade—it’s more about ‘let’s see if it actually works!’”

Three years later, this approach is showing compelling results. In 2009–10, every 10th grade student in the engineering pathway passed the California High School Exit Exam in math, and 98 percent passed in English language arts.

(www.edc.org) is producing a curriculum that will support green technology and digital media and design.

A primary strategy for linking technical and core academic courses is a menu of integrated units that academic teachers can use to relate their disciplines to projects and applications in a given industry. For example, in partnership with Project Lead the Way and the National Academy Foundation (NAF), ConnectEd has developed integrated units for use in NAF's Academies of Engineering, as well as in other engineering pathways offered in California high schools.

Integrated units for biomedical and health sciences are available as well (see www.connectedcalifornia.org/curriculum/units.php). One of the Health Sciences units, *Catch the Fever*, focuses on communicable diseases. Students investigate the role of microorganisms in causing disease and study the effect of a public health infrastructure, along with medical and pharmaceutical advances, on the evolution of microorganisms.

Core academic courses in Linked Learning meet the admissions requirements of postsecondary institutions. Consequently, to ensure student success, supplemental instruction (both enrichment and remedial) in mathematics and English language arts is essential. ConnectEd has designed an engaging curriculum that aims to increase students' motivation to learn and retain mathematical concepts by including such project-based activities as designing a wind turbine or building a combination lock.

Element 2: Project-Based Learning

Daily instructional practice in high schools is still dominated by lectures, individual silent work, and recall-based assessments. The primary focus thus remains on content coverage and delivery, not on deep learning.

Well-designed project-based instruction and integrated curriculums



Students at Life Academy in Oakland learn about biotechnology in class and in the field.

Teachers can use a menu of integrated units to relate their disciplines to projects and applications in a given industry.

bring new rigor and relevance to learning. Teachers assess students through authentic performances that tap into individual creativity and motivation, help students make connections across subjects, and bring greater real-world relevance to classroom learning.

For instance, in one unit, students design and build a model funicular railway that ascends a prespecified incline. They learn that railed transport systems are one practical application of such concepts as velocity, graphing, and integer operations. They explore the shape of graphs depicting constant speeds, acceleration, and deceleration. They gain practical experience with altering speed by experimenting with gears and performing gear ratio calculations; to test the accuracy of their calculations, they attach their model funicular bases to a geared motor.

To help teams of academic and technical teachers improve student engagement and learning, ConnectEd and its partners have developed tools to design and implement quality curriculums and instruction for STEM-related Linked Learning pathways. Chief among these is a new online curriculum and performance mapping tool¹ that helps teachers align curriculum and student projects to state content standards in both academic and technical areas, unpack those standards to reflect desired student performances, build effective cross-disciplinary projects, and manage the project-related work of both teachers and students.

For example, teachers can use the curriculum mapping tool to design a forensics project involving English, science, math, and world history. The selected English standards might focus

on building understanding with technical text or analyzing related fiction and nonfiction. In science, the project might highlight the structure and purpose of DNA. Math standards might focus on logarithmic equations to apply Newton's law of cooling. World history might look at war crimes and the role that forensics played in such events as the Nuremberg trials. The tool helps ensure that the project is explicit about the learning objectives it is designed to support, and not simply a fun exercise.

Because industry partners are involved in project design, students experience real-world applications and meet working adults. Industry partners can often serve as clients for projects, not only helping to structure the work but also providing feedback to students on what performing to industry standards and expectations actually entails.

Element 3: Work-Based Learning

By experiencing the workplace and working alongside professionals, students deepen their understanding of STEM's relevance to their career aspirations and postsecondary plans. This kind of work-based learning can take many forms. Mentoring and job shadowing introduce students to offices, laboratories, manufacturing facilities, and a wide range of working professionals. Even many of our most advantaged students have little or no contact with working adults or much awareness of the range of career opportunities in STEM fields. And for disadvantaged students who have rarely ventured out of their immediate communities, a downtown high-rise office of an engineer or architect might just as well be located on another planet.

But work-based learning is about much more than career awareness. As it evolves into more sophisticated experiences for students, it begins to involve them in real work under the guidance of industry professionals. Internships, paid and unpaid, are the best-known examples of this kind of opportunity.

However, internship opportunities are difficult to provide for large numbers of students. Geography often poses major challenges, as do the logistics of finding and managing large numbers of internship opportunities.

Creating new forms of virtual work-based learning offers one promising strategy for making these opportunities available to many more students, regardless of the locations of schools and industry partners. For example, Acme Animation, an early pioneer in "virtual apprenticeship," uses the web and videoconferencing to connect stu-

dents in animation classes with professional animators at Warner Brothers, DreamWorks, and other motion picture studios. Students work on a carefully structured design challenge (for example, animating a bouncing ball), which professionals then critique to industry standards.

Building on Acme Animation's approach, ConnectEd is collaborating with Chevron to develop a series of engineering- and energy-related design challenges for students in academies of engineering and for the growing number of green technology partnership academies in California. These design challenges may involve different kinds of pipeline valves, for example, or LED displays monitoring fuel flow through land-based pipeline systems. Through ConnectEd Studios, students will be able to post their work in online portfolios for review by both their teachers and industry professionals at Chevron, and teachers will receive support in online project planning.

Another promising work-based learning strategy is school-based enterprise, student-led business or community service initiatives in which students design, produce, and deliver real products and services. For example, in collaboration with a local utility, students engage in energy audits for local homeowners and small businesses. Alternatively, schools may team with a local economic development agency to undertake environmental impact analyses. School-based enterprise can be especially useful in schools with limited access to industry partners and other work-based learning opportunities.

With any kind of work-based learning initiative, the biggest challenge is ensuring that the activity promotes structured, challenging learning that relates to the classroom and reinforces explicit content standards and learning objectives. Otherwise, work-based learning can quickly devolve into little more than a series of low-level work experiences that are not good uses of

Resources for STEM

Creating an Integrated Curriculum

- Engineering and biomedical science curriculum: Project Lead the Way (www.pltw.org)
- Pre-algebra and algebra support curriculum in engineering: www.connectedcalifornia.org/curriculum/support.php
- Biomedical and health science curriculum: www.connectedcalifornia.org/curriculum/units.php
- Business, economic, and technology skills curriculum from the Ford Partnership for Advanced Studies (PAS) Curriculum: <http://fordpas.org>
- Digital media arts curriculum from the Education Development Center: <http://dma.edc.org>

STEM/Linked Learning Resources

- Alliance for Regional Collaboration to Heighten Educational Success: www.arches-cal.org
- ACME Animation: www.acmeanimation.org
- California STEM Learning Network: <http://californiastem.org>
- Career Academy Support Network: <http://casn.berkeley.edu>

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students' or teachers' time. As with other forms of project-based learning, sound work-based learning depends on being explicit about the academic and technical learning objectives the experience is intended to support. The curriculum mapping tool can help teachers clarify learning objectives and specify the assessment strategies they will use to determine whether students have met these objectives.

Element 4: Continuous Improvement

Strong pathways depend on well-thought-out, comprehensive programs of study; standards-based curriculum and curriculum integration; new forms of collaboration among teachers; and innovative and scalable school and industry partnerships. To promote better planning and development as well as continuous improvement, a growing number of schools in California are pursuing formal Linked Learning certification.

In collaboration with the Career Academy Support Network, the National Academy Foundation, and the National Career Academy Coalition, and in consultation with the California Department of Education, ConnectEd has developed certification criteria and rubrics for schools in four major areas—pathway design, student engagement, system support, and evaluation and accountability.² The certification process relies on self-assessment as well as on a site visit by a trained certification expert.

In June 2010, the Academy for Digital Media and Design at Kearny High School in San Diego and the Academy for Architecture, Construction, and Engineering at Jordan High School in Long Beach became the first two Linked Learning certified pathways in California. Approximately 30 more pathways will be seeking certification during the 2010–11 school year.

Both Career- and College-Ready

One of the great promises of STEM is breaking down the isolation of science and mathematics—from each other and from the fabric of technology and design in the world outside school. That is also the goal of Linked Learning, which seeks to increase student engagement, deepen understanding, raise achievement, and increase rates of high school completion and successful transition to both college and career. 

¹For more information about the curriculum mapping tool, visit www.ConnectEdCalifornia.org/services/studios.php.

²Certification criteria and rubrics are available at www.ConnectEdCalifornia.org/about/publications.php.

Gary Hoachlander (ghoachlander@ConnectEdCalifornia.org) is president and **Dave Yanofsky** (dyanofsky@ConnectEdCalifornia.org) is director of media and youth development at ConnectEd: The California Center for College and Career.



2150 Shattuck Avenue, Suite 1200
Berkeley, CA 94704
T: 510-849-4945 F: 510-841-1076
www.ConnectEdCalifornia.org