STEM Smart: Lessons Learned From Successful Schools

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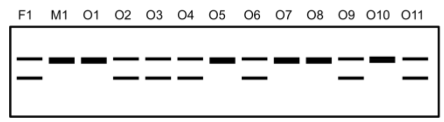
Biology Levers Out of Mathematics (BLOOM)

Background

The *Next Generation Science Standards* highlight understanding and application as well as the integration of mathematics and computational tools into science. The gap between these goals and classroom reality is particularly salient in high school biology, where memorization is king and mathematics/computational tools are largely absent, even though they are critical for understanding many big ideas and even more critical for later instruction in biology (including AP Biology exams and all biology-related majors in college). As biology is typically a first exposure to high school-level science, it is particularly unfortunate that students experience such an uninteresting, memorization-driven approach.

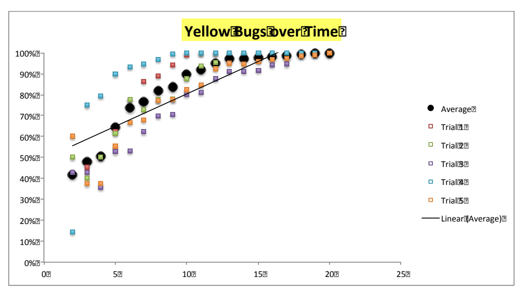


We present a new approach to teaching core biology concepts (inheritance and evolution) involving engaging engineering design challenges that students solve using a combination of inexpensive hands-on materials, basic mathematics, and simple simulations.

These materials are made available to teachers through an online tool called iPlan, which gives just-in-time guidance on the how and why of the curriculum steps, an opportunity for teachers to customize the materials to their own classroom needs, an opportunity to see how other teachers have customized each lesson, and an opportunity to engage in discussions with other teachers about these materials.

Documented Results

Through engineering design challenges (breeding rare animals for a zoo or breeding rare insects to help children in developing nations), students see purposes and applications of science not normally presented in a science classroom. As a result, we find increases in student engagement during our lessons, and increases in science and engineering career interest.



Because students are asked to reason through how to apply mathematics and computational tools to solve the problem, they build deeper understandings of inheritance and evolution concepts. This allows them to solve science problems beyond the memorized examples, and sets a foundation for stronger learning of later science topics. Further, their mathematical skills improve as well, which will be important in the broader high-stakes testing environment (in science and in mathematics).

Through use of these materials, teachers also develop a deeper understanding of the concepts they are teaching (e.g., a better understanding of inheritance and evolution). Teachers also learn about engineering design practices (e.g., constraints, optimization, tradeoffs), something that most biology teachers have little knowledge of but will be asked to teach their students about under the *Next Generation Science Standards*.

Potential Applications

Variations of the materials have been used successfully implemented across multiple states in a range of urban, suburban, and rural schools districts in the following high school science courses: Biology 1, Honors Biology, Ecology, and AP Biology.

For More Information

Contact Christian Schunn at schunn@pitt.edu.
http://www.lrdc.pitt.edu/schunn/research/design.html

The FabLab Classroom: Learning Middle School Science Through Engineering Design and Manufacturing

Background

The undergraduate engineering curriculum is being transformed by advanced manufacturing technologies. Within the past year, desktop manufacturing systems have become affordable at the K-12 level. The Commonwealth Engineering Design (CED) Academies are being established with two goals:

(1) To help create the skilled workforce needed for the future by preparing K-12 students for the jobs expected in the future and related skills required for those jobs

(2) To respond to draft Next Generation Science Standards that call for integration of engineering design into science education (National Research Council [NRC], 2011)

The draft standards respond to a crucial need for our nation to have both scientifically and engineering literate students. The CED Academies are being developed to address this need by teaching middle school science in the context of engineering design through use of advanced manufacturing technologies.

Documented Results

The FabLab Classroom (NSF DRL-1030865) is exploring use of digital fabrication to allow students to create digital designs that are realized as physical objects, such as model satellites (in collaboration with NASA), wind turbines, and speaker systems. This work provides a context for addressing the goals described above.

For example, in one project, undergraduate engineers collaborated with science teachers on a series of hands-on lessons involving periodic motion. An initial activity illustrated the nature of periodic motion through paint flowing from a swinging bucket. A 3D-printed valve that could be easily opened and closed by a child produced an even flow of paint. Once the concept was illustrated through a physical demonstration, it was extended with a physical pendulum that recorded its motion on an electronic strip chart on the screen of a tablet computer.

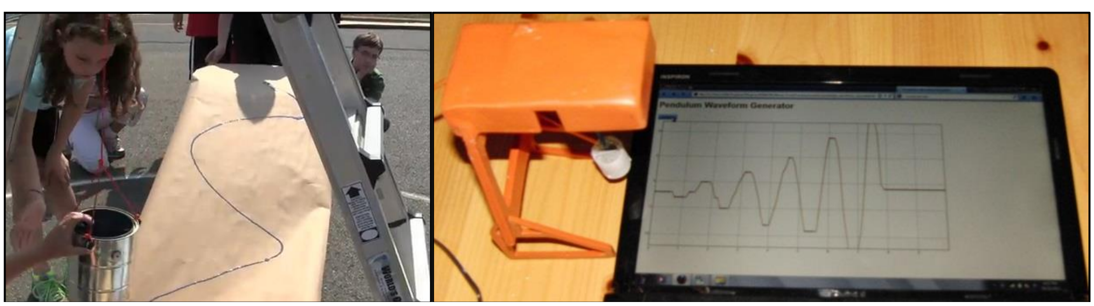


Figure 1. Paint flowing from a swinging bucket on the playground generates a sine wave, and a mixed-reality pendulum with a simulated paint bucket records its motion on a computer screen.

The understanding gained through these concepts and relationships was then used as the basis for designing a digitally fabricated speaker. This provided a real-world context for applying the knowledge gained through experimentation.

Figure 2. Ariana, a middle-school student, inspects the speaker that she manufactured.

The students then compared the acoustic characteristics of the speakers that they designed and manufactured to commercial speakers. They used their analyses of the frequency response curves to revise their designs for woofers and tweeters. This provided a real-world context for applying the concepts they learned.

This project illustrates the range of activities possible through advanced manufacturing. A 3D printer was used to manufacture the mixed-reality pendulum and other science equipment. This allowed the science teacher to design and create science demonstrations through advanced manufacturing technologies. The pupils employed the same technologies in the design of working speakers, supported by the teacher.

Potential Applications

We are creating an infrastructure for teaching science through advanced manufacturing technologies. The project has demonstrated that participating teachers can use CAD software and fabrication hardware and are enthusiastic about doing this. In the process, they gain experience in incorporating fabrication in science instruction. A systematic approach to learning related engineering concepts is needed to allow teachers to achieve the full potential of these technologies. To achieve this, the Curry School of Education and the School of Engineering and Applied Sciences are jointly developing a course, “Engineering for Science Teachers.” Once the course has been piloted, it will be made available to science teachers nationally in an online format.

For More Information

The activities and designs for the pilot activities described are housed on WISEngineering, a learning management system for K–12 engineering education, and are available at http://wisengineering.org/soundwaves/. Other resources that support digital fabrication in the classrooms are available at http://maketolearn.org/.

The GLOBE California Academy Program: Strengthening College and Career Readiness in STEM by Leveraging School Structure and Student Aspirations

Background

In October 2011, WestEd and UC Berkeley's Career Academy Support Network (CASN) received a three-year collaborative ITEST Strategies grant to improve learning and workforce development in science, technology, engineering, and math (STEM) and in information and communication technology (ICT)—especially for underserved students. The proposed strategy integrates the hands-on science pedagogy of the Global Learning and Observations to Benefit the Environment (GLOBE) program into the multi-year curriculum of the California green high school academies. The GLOBE California Academy Program (CAP) engages students in research related to climate change together with career development activities. Teachers are supported by professional development and other forms of support in career academies that focus on the growing renewable energy and clean technology workforce sector.

Hands-on laboratory experiences, inquiry, and project-based learning have long been standard features of science education. GLOBE is an example. Project-based learning also can be part of a multi-disciplinary strategy to engage students and prepare them more effectively for college and careers. In career academies, students implement projects that both strengthen their science practices and connect the content and practices to students' career aspirations. Further, integral to career academies are opportunities for students to engage in "work-based learning"—an extension of project-based learning beyond the classroom, linked to professional standards and transferable 21st century skills, and using employer or community interaction to engage students and intentionally promote learning and access to future educational and career opportunities (Darche, Bracco & Nayar 2009). The opportunity that the GLOBE initiative offers—for students to contribute to real science by using high-quality scientist-developed protocols and entering their data into an international database for scientific analysis—is consistent with this definition of work-based learning. Students not only learn, but they also produce outcomes of value to others beyond school. These kinds of experiences also activate adolescents' developing sense of agency (Bandura 2006), which may produce further positive outcomes. Finally, the structure of academies, based on cohort scheduling over three years, offers coherence and continuity for students over time, supporting academic skill-building and both career and socio-emotional development from one grade to the next. This structure also allows for the embedding of multi-year initiatives. GLOBE CAP will build students' knowledge and skill over a span of three years as follows:

- **9th and 10th grade:** Students focus on collecting data using GLOBE protocols and learning activities, understand science from scientists, and gain exposure to the career path of a scientist through direct interaction.
- **11th grade:** Students continue to collect data but, in addition, develop their analytical skills through data visualization and interpretation; begin collaboration with sister schools in other countries to build global awareness; and continue career exploration in STEM fields.
- **12th grade:** Students continue to collect, interpret, and create visualizations of data but also explore the links to public policy and apply their knowledge and skill in a service-learning project or social enterprise in their local community.

Documented Results

In its first year, GLOBE CAP enrolled teachers and students; conducted needs assessments in order to customize teacher support; provided GLOBE training to teachers; built partnerships with key organizations, including the Chabot Space and Science Center, the UC Berkeley Departments of Chemistry and Earth and Planetary Science, and the GLOBE Program Office; placed college mentors in classrooms; created a three-year framework for student projects that embeds GLOBE data collection and activities; developed assessment tools; facilitated scientist visits to GLOBE classrooms; built internal and an external websites; and laid a foundation for future replicability. Six northern California high schools are participating in GLOBE CAP, including 19 teachers and over 300 students. GLOBE instrument shelters have been sited and student data collection is underway.

GLOBE CAP is currently undergoing a rigorous evaluation process that will track students' course-taking patterns and grades in science, GLOBE-related science content knowledge, students' science-related attitudes, and the development of an array of science practices and 21st century skills. It will also examine teacher facility with GLOBE protocols and science practices as well as programmatic outcomes.

Potential Applications

A growing number of schools are implementing career academies as a high school reform model; there are currently over 7,000 academies nationwide. In addition, the demand for professional and technical workers in the renewable energy sector is likely to grow. Occupations in this sector, from installing and maintaining new energy technologies to conducting basic research, require knowledge and skills across several STEM disciplines. Implementation of GLOBE within California's green academies will provide a proof of concept for more widespread implementation in California and across the country. Partnership with the GLOBE network, detailed documentation, and communication with national groups involved with STEM and career academies will help pave the way to broader replication.

For More Information

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http://www.globalstudentsolutions.org
http://www.globe.gov

Improving STEM Education Through the Redesign of the Advanced Placement Science Courses

Background

To stay strongly aligned with college credit policies and to prepare AP students for college and subsequent STEM careers, the AP Program recently redesigned several science courses. The purpose of such a redesign is to help students increase depth of understanding of essential concepts and develop capacity to use critical skills by limiting breadth of content covered. Additionally, the purpose of the AP Science redesign included the goal of preparing students for success in college-level courses within disciplines and stimulating them to consider careers in those disciplines.

The AP Science redesign draws upon current research and theory on learning, instruction, and assessment and infuses such redesigned courses with topics drawn from cutting-edge research and emerging issues. Such research recommended the redesign of the AP Science courses focus on establishing coherence within and across the disciplines by organizing curriculum, instruction, and assessment using unifying themes and creating learning programs accessible to students from a broad range of backgrounds.

As a result of the AP Science redesign process, teachers now have access to learning objectives embedded in a well-articulated set of curriculum frameworks for AP Biology, AP Chemistry, and AP Physics 1 and 2. As the redesigned AP Science courses launch, teachers will have access to additional support resources such as practice exams, course planning and pacing guides, sample syllabi, and associated professional development.

Documented Results

As a result of engaging subject matter experts, pedagogical experts, and both higher education faculty and secondary education AP Science teachers in the redesign process, the redesigned courses articulate the appropriate amount of content; emphasize the essential knowledge, key concepts, and thinking skills valued by colleges and universities; and provide learning objectives that describe the knowledge and skills students should develop through the courses. A review of the research in the NRC 2011 report *Successful K-12 STEM Education* report reveals a more focused set of standards and skills that provide transparency to teachers and students about what students should know and do to be successful in such courses. Furthermore, each of the redesigned AP Science courses requires teachers to engage students in inquiry-based labs to apply science practices for the purpose of personally discovering and strengthening their understanding of scientific concepts. Such practices include:

- Generating representations and models
- Developing strategies for collecting data
- Making connections across scales, concepts, and domains

A substantial body of research reveals that requiring an inquiry component in the instruction of such courses strengthens students' retention of foundational and required content as well as increases students' development of the skills that practicing scientists use to advance knowledge within the various fields of science. Accordingly, the AP Science course redesign addresses the recommendation of *Successful K-12 STEM Education* to improve STEM curriculum and instruction by engaging students and raising standards.

Potential Applications
In collaboration with the National Science Foundation and eminent educators nationwide, the AP Program has spent several years reviewing and redesigning several AP Science courses. This collaboration has led to a set of robust courses, with an emphasis on reasoning, analytic, and inquiry skills. Higher education faculties have endorsed these courses as designed to offer students a solid foundation for further college coursework in science. The redesigned AP Biology course launched in fall 2012, with the redesigned exam to be administered in May 2013. AP Chemistry will launch fall 2013, with the redesigned exam to be offered in May of 2014. AP Physics 1 and AP Physics 2 will launch fall 2014, with the redesigned exam to be administered May 2015.

For AP Science teachers and students, the redesigned courses have associated curriculum frameworks and support documents that promote differentiation and provide teachers with a well-defined set of learning objectives. These objectives support teaching for deeper understanding in a variety of instructional settings and address a variety of student differences.

Additionally, the AP Exams will be congruent with the learning objectives of the provided curriculum frameworks. Such transparency pertaining to the exam design will help teachers and students (of varying levels of content knowledge and skills) achieve appropriate learning goals to help students become successful in the course and the exam. Such success can lead to continued student interest in the sciences and to student motivation to continue coursework in the sciences in college. Accordingly, the redesigned courses will increase interest and success within a new population of students who can then contribute to both science education and the practice of science.

For More Information
For more information on the redesigned AP Science course curriculum frameworks and additional teacher support documents, visit the Advances in AP website: http://advancesinap.collegeboard.org/

Loudoun County Public Schools Academy of Science

Background

In 2002, Loudoun County identified a need to provide a program for county residents that would specialize in science and math. In January 2005, upon hiring a director, the planning for the Academy of Science (AOS) began. In delineating a mission statement, the core of planning revolved around creating an environment where students would be challenged to leave high school with the skills needed in an increasingly "global" society where STEM skills will be important, regardless of career choices.

The mission of the AOS is to provide an academic environment where students are encouraged to develop creative scientific endeavors of their own design, while having the opportunity to pursue a rich, well-rounded high school experience. It was proposed that a student leaving the AOS will possess the following skills:

- Ask sophisticated scientific questions and conduct research and experimentation
- Read, write, and communicate at a level that is required of university students
- Integrate personal scientific and academic background into a broad (holistic) view of the world

To implement this vision, instruction in both math and science was designed around three basic principles: Integration, Inquiry, and Research.

The Loudoun County Public Schools (LCPS) AOS opened in September 2005 for grade-9 and grade 12 students. In 2006, the academy expanded to include a program of studies for grade-10 and grade-11 students. Students attend the LCPS AOS on alternating days, with the opposite day being spent at their home school. Instead of a typical four-block day, they attend for three 90-minute blocks, because one block is used for transportation to and from home schools. Students take science and math courses at the Academy and all other subjects at their home school.

Academic Program

Students have a double block of science and a single block of math in all four years. The cornerstone of instruction in 9th and 10th grade is an integrated science course (students complete Earth science, chemistry, and physics in grades 9 and 10) and focus on research and experimental design.

Starting in the ninth grade, physical-science-program students are challenged to design all of their own lab experiments as teachers work as inquiry guides. No lab book is used. During the three semesters (over two years) of this course, students work with colleagues to answer, experimentally, questions relating to content. Within these three semesters, content is equivalent to, at a minimum, the content found in typical honors-level curricula in physics, chemistry, and Earth science. The key difference is the way material is presented. Intertwined in the second year of this course is "Introduction to Research", a one credit course where students are taught basic research skills by participating in projects across science and math disciplines.

By the end of sophomore year, students design (with faculty mentoring) independent, two-year research projects to be carried out in-house. Juniors and seniors enroll in Independent Science Research in addition to AP Science and Math offerings. The research course is geared toward developing scientific habits of mind as well as integrating statistics, writing, and communication skills into scientific experimentation. In grade 11, students take a project-based biology course and their first year of Independent Research. In grade 12, students choose from one of four AP sciences and continue their research project.

In mathematics, students take a course in "AOS Analytic Geometry, Functions, and Trigonometry with Transformations" in grade 9, followed by math analysis in grade 10. In grade 11, students may choose to go directly into BC Calculus and continue to multivariable calculus or take the typical AB to BC Calculus route. Statistics and modeling are stressed at all math levels.

Documented Results
The AOS does not, at this time, have longitudinal students to document undergraduate and career success. We have had four graduating classes totaling approximately 225 students. However, there are multiple anecdotal evidences of success:

- Community acceptance: AOS applications have risen from 185 in 2005 to 744 in 2012.
- College acceptance: AOS students have been accepted to all Ivy League schools including MIT and Stanford, as well as most competitive universities in the country.
- Research Internships: AOS students have excellent success securing summer internships while still in high school. Many have easily stepped into research labs at the university setting, including some labs that do not normally hire undergrads.
- Science Competitions: AOS student projects are very well received in national and international competitions. We currently have a student research collaboration with Hwa Chong Institution in Singapore and are creating a collaboration with Daegu Science High School in South Korea. AOS students have been Siemens semifinalists, Intel finalists, Virginia State Science Fair first place winners (five in 2012), ISEF Best of Category winners, and an ISEF young scientist awardee.

Potential Applications
This model is adaptable on many levels:

- At the district level, schools can be set aside much like the Loudoun model, or where block scheduling is not available, this can be done on a half-day basis rather than alternating days.
- At the school level, curricula can be modified to allow students to build the skills needed to perform independent research.
- At the classroom level, the inquiry and integration can be accomplished by a long-term staff development program which incorporates aspects of the AOS curriculum into existing programs.

For More Information
Contact George Wolfe, AOS Director, at George.Wolfe@lcps.org; Odette Scovel, LCPS Science Supervisor, at Odette.Scovel@lcps.org; or Duke Writer, Math Instructor, at Duke.writer@lcps.org.

Urban Advantage: Formal-Informal Collaborations to Improve Science Learning and Teaching

Background

Informal science education institutions can play a significant role in helping develop students' science literacies in schools serving high-poverty communities, and may have a particular role in engaging children from high poverty and cultural and linguistic minority communities who find science to be "alienating, boring, and difficult" (Center for the Advancement of Informal Science Education, 2010). Collaborations between schools and informal science education institutions build on the partners' particular resources and strengths to meet shared goals of making science learning more accessible and compelling to students. Drawing on the educational resources found in New York City's (NYC) informal science community and its long-term commitment to science education, the Urban Advantage (UA) program was launched as a museum-led middle school science initiative to provide professional development for teachers and hands-on experiences for students to learn how to conduct scientific investigations. The goal of UA is to improve students' understanding of scientific knowledge and inquiry through collaborations between public school systems and informal science education institutions, such as museums, gardens, zoos, and science centers. UA designs and shapes learning experiences to align with the science standards and assessments in school systems. In addition, both students and teachers are provided opportunities to engage in authentic science—conducting investigations in which they pose scientifically oriented questions, prioritize evidence, and develop logical explanations—a prerequisite to understanding science (National Research Council [NRC], 2005; 2007).

The UA program was initiated in 2004 by the American Museum of Natural History (AMNH) working in collaboration with several informal science education institutions in NYC that include the Brooklyn Botanic Garden, New York Botanical Garden, New York Hall of Science, Queens Botanical Garden, Staten Island Zoological Society, the Wildlife Conservation Society's Bronx Zoo and New York Aquarium, and the New York City Department of Education. Support for the program is provided by the New York City Council and the New York Department of Education. The UA program combines the expertise and resources of these eight partnering informal science education institutions to enhance teachers' skills and students' performance on long-term science investigations that are part of the NYC K-8 science curriculum scope and sequence.

The UA framework has six key components that are designed to provide comprehensive support for schools, principals, teachers, and students to facilitate the completion of high-quality science investigations: (1) high-quality professional development for teachers and school administrators; (2) classroom materials and equipment for schools, teachers, and students that promote scientific inquiry and authentic investigations; (3) access to UA partner institutions through free school and family field trips; (4) outreach through family events, celebrations of student achievement, and parent coordinator workshops; (5) capacity building and sustainability structures, including a network of demonstration schools and support for the development of lead teachers; and (6) assessment of program goals, student learning, systems of delivery, and outcomes.

In 2010, the Denver Museum of Nature & Science received a five-year grant from the National Science Foundation (DRL #1020386) to implement and study a UA program in Metro Denver. UA Metro Denver is a partnership between three public school districts and three informal science education institutions in Denver designed to improve science literacy among middle school students in urban environments. The partners in UA Metro Denver are the Denver Museum of Nature & Science, the Denver Zoo, the Denver Botanic Gardens, Denver Public Schools, Aurora Public Schools, and Adams County School District 14. Currently in its third year of implementation, UA Metro Denver is working with 16 schools and 28 science teachers, reaching almost 2,600 students and their families.

The study aims to answer the following questions: How does participation in the program affect students' science knowledge, skills, and attitudes toward science; teachers' science knowledge, skills, and abilities; and families' engagement in and support for their children's science learning and aspirations?

Documented Results

Educational researchers and policy analysts at New York University have examined the impact of the UA-NYC program on student achievement. Researchers at NYU's Institute for Education and Social Policy have found that beginning in the third year of the program, differences in student performance between students in UA schools versus students in non-UA schools began to emerge. Specifically, in the third year of the program, 44.2% of eighth-grade students in UA schools passed the state science exam, versus 40.5% in non-UA schools. This difference has continued to widen in subsequent years of implementing the program. No significant differences were found for either ELA or math, suggesting that these findings are not due to coincident overall improvement at UA schools. In addition, their analysis showed that participating in UA also contributed to post-eighth-grade outcomes, including the probability of attending a STEM high school and taking and passing high school state science exams. Specifically, attending a UA school had the greatest impact on whether a student took the Living Environment Regents (state biology exam) in eighth or ninth grade. Students at UA schools are 25.5% more likely to take the high school state biology exam than those at non-UA schools. This could have implications in STEM for a students' high school career since research has shown that students who take the state science exams early are more likely to take additional science courses and exams in chemistry or physics compared with those who wait to take the required state exam in science to graduate.

For More Information

http://www.urbanadvantagenyc.org/
http://www.urbanadvantagedenver.org/

Broadening Advanced Technological Education Connections (BATEC)

Broadening Advanced Technological Education Connections (BATEC) is the National Science Foundation's Advanced Technological Education National Center for Computing and Information Technologies. BATEC's efforts in curriculum, outreach, and research reflect the demands of the 21st century workplace.

BATEC is working in the urban areas of Boston, Chicago, San Francisco, and Las Vegas to:

- define, extend, and strengthen computing and information technology pathways and career opportunities;
- facilitate and leverage strategic partnerships with education, business, government, and community to build awareness, generate interest, and support learning opportunities;
- conduct actionable research to inform policymakers, IT educators, and workforce development agencies; and
- participate in and lead the national discussion on the subject of integrated curriculum and applied IT.

BATEC is changing it education by encouraging Educators & Industry to support each other.

Curriculum development is authentic and centered on a team-based approach, with educators and industry partners working together to explore emerging technologies. Advanced rigorous content is collaboratively created in response to current and emerging industry needs. Academic faculty engage with students in a **performance-based learning model** that makes use of case- and/or problem-based methodologies. Students develop strong technical knowledge combined with authentic **critical-thinking and higher-order analytical skills** that will empower and advance them in today's workplace. BATEC is also working to integrate applied IT skills for the career professional working in broader fields of study such as business, energy management, education, law enforcement, health, and the life sciences.

BATEC is connecting industry, educators, & students in open dialog about the future of IT education.

The BATEC community convenes and participates in strategic initiatives designed to build lasting relationships and meaningful dialogue. **Industry Forums** introduce educators and students to relevant information technologies and services that are driving our local economy. **Summer Institutes** support academic faculty in their efforts to learn and develop curricula that integrate skills standards and problem-based methodologies. **Workforce Education Summits** convene a forum for thought leaders from business, education, government, and community to explore critical research-based trends and opportunities for identifying the right balance of education, experience, and skills for success in the 21st century workforce.

BATEC is inspiring students to discover the opportunities that exist for them in IT and IT-dependent fields.

College and Career Fairs connect students with higher education opportunities, admissions counseling, and career information. Student Leadership Programs such as the **Tech Know How Lab** and **BATEC Ambassadors** are developing the employability skills needed for future career pursuits. **Dual Enrollment Courses** are an opportunity for high school students to experience college classes and receive course credit. The **Tech Apprentice Program** connects talented high school students with paid technology-focused internships in local companies, while college students gain experience and provide real value for **small businesses** and **high-tech start-ups**. The **Bridge to Community College Initiative** transitions underserved adults to the Community College system.

BATEC is leading the way by sharing the knowledge and success of our partners with others.

BATEC enjoys a history of success contributing to the continuous improvement of computing and IT programs. Our partner institutions rely on us to shape their programs so that their students benefit from the right balance of education, experience, and skills development. Conference presentations and "How-To" manuals allow others to learn from our models. Our **Synergy Conferences** convene educators in a forum designed to share learning models and experiences focusing on new tools and approaches for implementing 21st century teaching and learning practices.

For More Information
http://www.batec.org

Cultivating Mathematical Habits of Mind in All Students

Background

EDC's ***Transition to Algebra:*** *A Habits-of-Mind Approach* (TTA) project is developing, piloting, and field testing an intervention course to be taken concurrently with Algebra 1 in support of success in algebra for at-risk students. TTA focuses on a small number of underlying ideas and builds essential algebraic habits of mind that, in alignment with the *Common Core* Mathematical Practice Standards, include abstracting regularity from repeated reasoning, using general purpose tools strategically to organize mathematical thinking, seeking and using structure, communicating with precision, and puzzling and persevering through mathematical problems. The approach is designed for a diverse population of students at risk of losing access to STEM coursework and careers. TTA assumes that most students were mathematically capable when they were young and are still clever and that their major impediment in school mathematics is that they believe they're no good at *school*. Therefore, TTA sees its major goal as getting these students back to being as smart and intrepid as they were when they were young. As a consequent strategy, it makes heavy use of logic puzzles with mathematical content. It also builds strong mental mathematics skills and offers student dialogues, discussion prompts, and non-routine "explorations" of rich mathematical tasks to help students learn to think and communicate mathematically.

Our ***iPuzzle****: Transforming Mathematics Learning Through Social Puzzling* project is developing and researching elements of an interactive puzzle-based environment for use in formal and informal settings. Apps are being designed for both tablet and browser use, and puzzle content is selected from our TTA project. One type of puzzle helps students build the logic of balancing equations, the foundation for algebraic "moves" involved in solving equations and systems of equations. The design aims to explore the affordances of interactive information technology and the possibilities for socially interactive and informal learning. Social solving—students engaging socially over puzzles—reduces pressure on each partner and, through the development of the social "stock" of a puzzle, also raises the incentive to keep going.

Why Puzzles?

Central to a number of our projects is the use of mathematical puzzles and logic. One beauty of puzzles as an educational tool is that their difficulty can vary independently along two dimensions—prerequisite mathematical knowledge or skill, and the cognitive demand of the puzzle or mathematical "infrastructure" required for solving it. A second advantage is their ability to bridge the gap between formal and informal settings: puzzles are applicable in class but approachable *and appealing* outside of class as well. Also, puzzles are *fun* because they engage the intellect, give permission not to know the solution method before starting, and allow for social collaboration in solving them.

Our project ***Implementing the Mathematical Practice Standards:*** *Enhancing Teachers' Ability to Support the Common Core State Standards* is developing Illustrations of the Mathematical Practices, along with a professional development curriculum for teachers of grades 5–10, to support teachers in better understanding and identifying the Mathematical Practices in order to help their students develop these practices. Each Illustration contains a mathematical problem, a student dialogue that exhibits one or more of the Mathematical Practice Standards, an analysis of the mathematical content and practices, and related resources for teachers and students.

Documented Results

The TTA project team is investigating students' achievement in algebra and changes in their attitudes toward mathematics, as well as teachers' and students' experiences using the TTA materials. We have collected and are currently analyzing both qualitative and quantitative data, classroom observations and student and teacher survey and interview data, and mathematics assessment data.

The TTA project also conducted a District Algebra Supports Study to understand and document the range of district practices and supports offered for students identified as struggling, and the challenges district leaders face in serving these students. Preliminary findings indicate that most districts require algebra for graduation and provide supports in the form of an intervention class covering Algebra 1 content with materials developed by the teachers or within the district.

Potential Applications

The TTA materials were designed for at-risk ninth-grade algebra students and are also being successfully used in other contexts including middle school courses, summer school programs, and at the university level with struggling math students and preservice teachers. The primary use of the Implementing the Mathematical Practice *Standards* Illustrations is for teacher learning, yet several components (including the dialogues, student discussion questions, and related mathematical tasks) can be used with students in grades 5–10. The iPuzzle apps are designed for players of all ages in both formal and informal settings and are being tested with middle school students.

For More Information

Contact Paul Goldenberg at pgoldenberg@edc.org or Mary Fries at mfries@edc.org.

Transition to Algebra: ttalgebra.edc.org
Implementing the Mathematical Practice Standards: mathpractices.edc.org
iPuzzle: ipuzzle.edc.org

The Impact of Different Early-College/Dual-Enrollment Programs on Minority Student Persistence in Science Disciplines

Background

There is considerable evidence that minority students benefit from early exposure to college-credit courses while in high school. Researchers have also studied minority students' predisposition to pursue higher education. However, the question of whether the benefits of dual enrollment for minority students include increased persistence *specifically in science fields* has been largely unexplored. This study aims to explore this question in a specific context: two dual-enrollment interventions implemented in a large majority-minority school district. To this end, the study was designed as a mixed-method, longitudinal case study involving the two different dual-enrollment programs.

The context of this ongoing study is a large-scale Math Science Partnership project (funded by the NSF) that aims to expand the minority-student pipeline into science fields in higher education. The project includes two different early-college/dual-enrollment programs for high school students, following different instructional models, which have been running for the past four years:

1. *A concurrent-enrollment program*: Science faculty from Prince George's Community College (PGCC) come to area high schools and teach credit-bearing science courses during the regular school year. To date, 225 students have participated.
2. *A summer residential program*: On the campus of Bowie State University (BSU), area high school students enroll for three consecutive summers during their high school careers. Students get supplemental courses and tutoring in mathematics and college skills along with credit-bearing science courses. To date, 70 students have participated.

The unique structure of this intervention allows for comparisons to be made between the two types of dual-enrollment programs employed to help determine what factors are most important for increasing post-secondary matriculation and choice of science major among underrepresented minorities. In particular, we are guided by the following research questions:

1. Does exposure to college-credit courses in high school result in higher college attendance rates by underrepresented minorities?
2. Do opportunities to take college-level science courses in high school increase the likelihood that minority students will consider majoring in science?
3. What differences can be found on these questions between the two programmatic models, and what factors may account for them?

Our primary quantitative data sources include a longitudinal unit-record database, which will enable us to track the course-taking behavior and retention of student participants (and appropriate comparison groups) through their high school careers and (in many cases) into college. In addition, written surveys are administered to each student at the beginning and end of each early-college course, focusing on interest in science and in attending college. Focus-9group interviews on the same topics were conducted with a subset of 25 students.

Documented Results

There were no statistical differences between pre-program and post-program surveys, and none between the participants in each kind of dual-enrollment program (summer residential vs. in-school). Participant students are already highly motivated to attend college and pursue science. The focus groups revealed various trends in students' thinking, including these key findings:

- Students are generally positive about the prospect of attending college. However, they are somewhat anxious about choosing the college that best suits their needs. Students do not think that high schools have an atmosphere that supports discussions about college and life after high school with teachers or other students.
- Students see family and media/marketing as important factors in the college choice process.
- Students' top reasons for going to college are directly related to enhancing their opportunities for career and earning power.

Potential Applications

With this study, we hope to learn a great deal about how to help minority students persist in college science. For example, if we find differences in some measures between students of the summer early-college program and those of the in-school courses and can attribute them to the programs' different structures, it would have implications for how best to design future dual-enrollment programs. Ultimately, we would like institutions to incorporate those practices that positively impact underrepresented groups' persistence to science degrees and careers.

For More Information

General information about the $(MSP)^2$ project may be found online at http://mspsquared.mspnet.org. This specific research study has not yet been published, but you can contact us for more information at dmay@usmd.edu.

Separating Facts from Fads: How K–12 Educators' Choices Impact Students' College Performance and Persistence in STEM

Background

Pre-college teachers and administrators hold many theories about how best to interest and prepare students for success as STEM majors in college. Effective or not, based in fact or in faith, these beliefs play out in our nation's classrooms. While many research studies have shown large and statistically significant effects of particular interventions or innovations, most often they examine small, homogeneous populations such as single schools or classrooms. They are commonly carried out as "hot house" studies with generous support and attention under the auspices of the original development team. In spite of the wide variation in teaching methods and materials used in U.S. schools, there is little in the way of large-scale, rigorous study of educational practices and technologies that compares the effectiveness of these approaches on a national scale.

While pre-college teachers make much of their choice of methods and materials, college professors are less sanguine about the preparation that high school provides in math and science. Many are dismayed by the difficulty that students have in their introductory college courses despite their preparation. Dropout and failure rates are high in introductory college science and math "gatekeeping" courses. Many students find themselves shunted off to remedial courses. While success in introductory college science courses opens the door to opportunities in engineering, health, scientific research, and other technical careers, poor performance in these courses closes those career options and channels students toward non-science fields, negating years of preparation and aspiration.

Our research team has utilized epidemiological methods to mine the backgrounds of more than 20,000 college students taking introductory science and mathematics courses for predictors of performance and persistence while controlling for demographic differences. Some of the findings include:

- Female students lose interest in STEM during high school. Presenting STEM careers with an emphasis on people (i.e., of working on teams and helping society) is more effective than focusing on extrinsic rewards (e.g., money, status, fame of discovery).
- STEM AP courses rarely substitute for college coursework and often are ineffectual in preparing many students for future success.
- AP courses offer no advantage in increasing student interest in STEM careers over other advanced level (i.e., home-grown or dual-credit) non-AP courses.
- High school courses that cover fewer topics in greater depth prepare students better for introductory college courses in science and math than courses with greater coverage.
- Students who are best prepared for college calculus have high school math courses that emphasize the specialized language of mathematics; memorization of key procedures, terms, and facts; mathematical reasoning; and the use of hands-on activities.
- The use of technology (e.g., graphing calculators, MBL computers) for labs, simulations, and graphing in high school STEM courses has no impact on later college success.
- Reduced class size and block scheduling does not alter the choice of pedagogies used by STEM teachers.

- Changing the order of high school science courses (i.e., Physics First) has no impact on student learning in other sciences, while increasing math content does.
- Teacher awareness of common student misconceptions has a profound impact on student learning.

For More Information

Contact Phil Sadler at psadler@cfa.harvard.edu

Other Resources

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Studio STEM: Engaging Middle School Students in Networked Science and Engineering Projects

Background
Studio STEM is a three-year afterschool and summer program aimed at educational and workforce needs. The project uses a design-based science approach to scaffold youth to learn about energy conservation. An interdisciplinary curriculum is infused with digital tools and social media to enhance and extend the experience.

A primary goal of Studio STEM is to engage middle school students in interesting projects related to environmental issues that allow them to acquire critical knowledge, skills, and dispositions. These experiences, in turn, are designed to lead to increased likelihood of youth electing and succeeding in STEM and information and communication technology (ICT) courses and careers. Our team proposes that the synergy of curricula, activities, technology, and mentoring in an informal setting will engage and motivate students from rural, low socio-economic communities. Using a social constructivist approach of action, preservice and inservice teachers (referred to as site leaders) and engineering and science undergraduates (referred to as facilitators) work with Studio STEM participants using a curriculum with real-life problems in energy sustainability. As one example, the *Save the Penguins* curriculum takes the plight of penguins and climate change as a way to motivate students to explore science topics such as convection, conduction, and radiation to apply engineering practices to construct a protective dwelling. The project places emphasis on (a) a content-rich curriculum that links students to their environment, (b) support and scaffolded discussions with mentors, and (c) an online network that supports the creation and maintenance of relationships among program participants. The informal character of this program allows students the freedom to explore and self-identify with topics.

The project has trained site leaders, facilitators, and other informal STEM educators through a series of professional development workshops and onsite training. The training is aimed at helping Studio STEM leaders become knowledgeable about engineering, engineering design, and ICT use to a level at which they can effectively work with youth on projects. As a result of increased STEM and ICT knowledge and skills, teachers, as indicated in preliminary analyses and informal debriefing interviews, likely have higher efficacy in using newer design projects and ICTs and will be more likely to integrate STEM and ICT projects and ideas into their formal teaching practices.

Studio STEM is also partnering with NanoSonic, Inc., a biotechnology company located in Giles County, VA. NanoSonic employees volunteer as facilitators to youth during the afterschool programs. Moreover, NanoSonic sponsors site visits to introduce youth to the technologies being developed in the area of nanotechnology. Studio STEM has also worked to offer experiences to youth to demonstrate that STEM-related careers are available in the New River Valley. Site leaders, facilitators, and youth have taken field trips to the New River Valley Regional Jail, home to the largest solar powered hot water system in Virginia. Opportunities and partnerships like these help students recognize that STEM-related careers in markets that involve sustainable (or green) technologies exist in their own communities.

Potential Applications

Studio STEM is serving as a model for partnerships between institutes of higher education and rural schools, science museums and centers, and related businesses. The model could be adopted to address local educational, professional development, and workforce needs in similar rural areas around the Mid-Atlantic Region. As a result of Studio STEM, students, teachers, site leaders, facilitators, and community partners have increased access to a range of online tools, materials, strategies, and activities. During the first 18 months of the project, Studio STEM has served over 100 students in grades 5–8 from rural Appalachia in low socio-economic communities. We also trained close to 30 middle school teachers and undergraduate students in how to implement the Studio STEM ETK and use the online network.

For More Information

http://www.studiostem.org

The National Survey of Science and Mathematics Education

Background

Horizon Research, Inc. (HRI), with funding from the National Science Foundation, conducted the 2012 National Survey of Science and Mathematics Education (NSSME). The 2012 NSSME, the fifth in a series of surveys dating back to 1977, was designed to provide up-to-date information and to identify trends in the areas of teacher background and experience, curriculum and instruction, and the availability and use of instructional resources. Data were collected from a nationally representative sample of over 1,500 schools and 7,700 teachers to answer several key questions, including:

1. What instructional/assessment practices do science and mathematics teachers use, and how well do these align with current understanding of learning?
2. What influences teachers' decisions about content and pedagogy?
3. What are the characteristics of the science/mathematics teaching force in terms of race, gender, age, content background, beliefs about teaching and learning, and perceptions of preparedness?
4. What are the most commonly used textbooks/programs, and how are they used?
5. What formal and informal opportunities do science/mathematics teachers have for ongoing development of their knowledge and skills?
6. How are resources for science/mathematics education, including well-prepared teachers and course offerings, distributed among schools in different types of communities and different socioeconomic levels?

Data from the 2012 National Survey are reported for each subject and by grade range (elementary, middle, and high school). Key indicators are also reported by a number of equity factors, including prior achievement level of the class, percentage of underrepresented minorities in the class, percentage of students eligible for free/reduced-price lunch in the school, school size, community type, and region of the country.

Some of the key findings from the 2012 NSSME follow:

- At the elementary level, 81 percent of teachers feel very well prepared to teach reading/language arts and 77 percent feel very well prepared to teach mathematics; only 39 percent feel very well prepared to teach science.
- Classes composed of mostly low-achieving students are less likely than classes composed of mostly high-achieving students to be taught by teachers who feel well prepared to teach science/mathematics.
- About one-quarter of high schools offer some form of engineering course. AP science and mathematics courses are each offered in about half of high schools.
- Female students are more likely than male students to be enrolled in advanced high school science courses. Students from racial/ethnic groups historically underrepresented in STEM continue to be underrepresented in advanced high school science and mathematics courses.
- Mathematics teachers are more likely than science teachers to feel they have sufficient resources for instruction.

- About half of all schools offer a professional learning community (PLC). Roughly three-quarters of secondary science and mathematics teachers participate in a PLC; two-thirds of elementary teachers participate in a mathematics-focused PLC, while just over half participate in a science-focused PLC.

In additional to the main results report, a compendium table with complete survey results is available. Subject-specific reports are also being created, including one each for the status of high school biology, chemistry, physics, and mathematics teaching.

Results from the 2012 National Survey of Science and Mathematics Education can inform the work of stakeholders at multiple levels of the education system, including national and state policymakers, district and school leaders, curriculum developers, and professional development providers.

For More Information
Additional information about the 2012 National Survey can be found on the study's website, http://www.horizon-research.com/2012nssme/. The website includes copies of the survey instruments and links to reports and presentations. We can also be contacted at nssme@horizon-research.com or by calling 919-489-1725.

Next Generation Science Standards and Building Capacity for State Science Education

Background

The *Next Generation Science Standards* (NGSS) are being developed based on a vision for science education established by *A Framework for K-12 Science Education: Practices, Crosscutting Concepts, and Core Ideas,* published by the National Research Council in 2012. Publication of the *Framework* was the first of a two-step process to produce a set of *Next Generation Science Standards* for voluntary adoption by the states. The NGSS are being developed by a team of writers including researchers, education policy specialists, scientists, and classroom teachers with feedback provided by diverse review teams from 26 lead states and other critical stakeholders, coordinated by Achieve. The second public draft of the NGSS was available for review in January 2013 and the final standards are expected in 2013. These standards describe student performances at the intersection of the three dimensions of science described in the *Framework*, and are designed to provide assessable performance expectations for all students. Understanding the *Framework* and NGSS is essential to implement meaningful changes in science teaching and learning. The potential for the *Framework's* vision to be fully realized hinges largely on the quality of the NGSS and practitioners' understanding of the intersection of the three dimensions of science described in the *Framework*. The *Framework's* vision takes into account two major goals for K–12 science education: (1) educating all students in science and engineering and (2) providing the foundational knowledge for those who will become the scientists, engineers, technologists, and technicians of the future. The *Framework* principally concerns itself with the first task: what all students should know in preparation for their individual lives and for their roles as citizens in this technology-rich and scientifically complex world (NRC, 2012).

Reducing the ideas down to a few core ideas that have utility across all of science helps teachers improve instruction. When students develop a deeper understanding of a few core ideas, they are able to make sense of novel phenomena. Focusing on core ideas requires eliminating ideas that are not central to the development of science understanding. Core ideas should be both foundational in terms of connections to many related scientific concepts and have the potential for sustained exploration at increasingly sophisticated levels across grades. Students are able to make sense of scientific phenomena when they are able to develop causal relationships, supported by evidence, of observed phenomena in defined systems. The crosscutting concepts organize a set of familiar touchstones for students to use in their sense making and evidence gathering. Students utilize these crosscutting concepts in the process of gathering and using evidence for the science and engineering practices. The practices engage students in gathering and using information from investigations and other sources, developing and using models, constructing explanations, and communicating arguments that support these explanations (NRC, 2007).

Possible Implications

Kansas is one of 26 lead states that have been actively involved with the development of the NGSS and one of 45 states involved with the Building Capacity for State Science Education project of the Council of State Science Supervisors. Now that these standards are nearly complete, it is time to think deliberately about implications for adoption and implementation—

ways to leverage partnerships to increase capacity for science education not only within, but also between, states. Instruction that focuses student learning on the three dimensions may be accomplished in a number of ways, but what should be clear is that separating the doing of science from the knowing of science, as many current state standards imply, is not consistent with the *Framework*'s vision.

Furthermore, classroom instruction focused on state standards that distills out practices from content are also swirled with assessments and an accountability model that puts the focus on a single summative event as the only important measure of student learning. Successful implementation of the NGSS not only requires coherence of all the components of the education system (P-20) working in logical ways to support the renewed vision, but also requires active collaboration with informal science educators, business and industry, and local communities.

For More Information

- The *Framework* is available to download at http://www.nap.edu/catalog.php?record_id=13165
- Information about the NGSS is available at http://www.nextgenscience.org/
- Taking Science to School is available at http://www.nap.edu/catalog.php?record_id=11625

Pathways to Calculus: A Research-Based Model for Transforming Precalculus-Level Mathematics Teaching and Learning

Background

Over the past 20 years, mathematicians and mathematics educators have engaged in numerous projects to re-conceptualize the teaching of precalculus-level mathematics so that students are more prepared to learn and succeed in calculus (e.g., Carlson, 1998; Carlson, Jacobs, Coe, Larsen & Hsu, 2002; Harel & Dubinsky, 1992; Monk, 1992; Thompson, 1995). Many of these projects have generated knowledge of the mathematical thinking that is needed to help students understand concepts such as function, rate of change, and exponential growth. Other projects have identified the mathematical habits of mind and problem-solving abilities that students need to acquire for success in STEM fields. This knowledge has not had a widespread impact on the teaching of undergraduate mathematics courses in the U.S., the result of which is (1) the teaching of precalculus courses are currently not effective in terms of student retention or in supporting student learning of key course ideas (e.g., Carlson & Oehrtman, 2012); and (2) typical approaches to teaching precalculus do not incorporate research-based knowledge on student learning to support improvements in the teaching and learning of undergraduate mathematics.

If one considers the processes of scientific inquiry that have led to new products and practices in engineering, medicine, business, etc., we observe very different processes at play in the practice of improving mathematics teaching and curriculum development. As a response, we have leveraged our and others' prior work on understanding and teaching key ideas of precalculus, and have engaged in multiple iterations of design and research to develop the Pathways Professional Development Model for Precalculus Level Mathematics (P^3DM) (*Project Pathways*: NSF Grants: DUE 0412537 & 1050721).

The Pathways resources include student curricula (e.g., in-class student activities, an online interactive textbook, online videos), teacher materials (e.g., teacher notes, exemplary lecture videos, and dynamic computer applets for use in instruction), and workshops designed to support teachers in engaging their students in genuine inquiry and mathematically substantive conversations. The Pathways Project instructor resources have been documented to be useful for helping teachers shift their instruction so that their students acquire both the understandings and mathematical practices articulated in the *Common Core Standards for Mathematics*. The student resources are organized around key ideas of precalculus mathematics and are packaged in 12 modules that can be accessed online. The summer workshops engage precalculus instructors in completing the in-class activities and discussing the lesson's rationale and implementation. The detailed teacher notes for the in-class activities and homework provide model solutions and explanations, and description of common student misconceptions. A sample introductory trigonometry lesson with teacher notes can be viewed at https://www.rationalreasoning.net/products.php

A Lesson for Introducing the Concept of Function

In an introductory lesson on functions, students are supported in conceptualizing the quantities in a problem context and developing a meaningful formula that describes how two quantities change together. Studies of student thinking on a collection of tasks have revealed that students who effectively conceptualize the varying and fixed quantities in an applied problem are able to build meaningful formulas, graphs, and tables, and then use these representations to describe how the quantities are changing together. This finding has influenced the design of Pathways tasks intended to support students in acquiring the reasoning abilities, approaches, and confidence to succeed in using precalculus concepts to solve novel "word problems."

Documented Results

The *Pathways Precalculus Professional Development Model* was designed, researched, and refined over an eight-year period, and is now consistently realizing significant pre-post gains in precalculus students' scores on the Precalculus Concept Assessment (PCA)[1], with student mean scores improving from ~9.5 to ~17, out of 25. Further analysis of PCA data revealed that schools with large percentages of students receiving free and reduced lunches are achieving the same or greater PCA gains as the most affluent schools in three districts. This finding is consistent with research (Treisman, 1992) that found that engaging minority students in thought-provoking, collaborative work on problems centering on fundamental concepts in mathematics and science levels the playing field for underrepresented populations.

Our research on teachers and teaching has revealed that high gains in teachers' mathematical understandings, reasoning abilities, and beliefs about teaching and learning, although necessary, are often not sufficient for transforming a teacher's instructional practices. We engaged teachers in graduate courses and workshops over a four-year period prior to developing the *Pathways Precalculus* student curriculum and instructor resources and measured only small gains in student learning and teachers' questioning and the conceptual focus of their lectures. This is because the school curriculum they were using did not support student understanding of key concepts or construction of mathematical practices, and teachers were unable to engage students in meaningful mathematical activity in the context of the school tasks and assignments. However, with conceptually coherent materials that embody research knowledge on student learning, we have consistently documented teachers making sense of student thinking and their making profound shifts in their ability to pose questions that support students in developing reasoning patterns that lead to their understanding key concepts.

Potential Opportunities

The P^3DM model has been successfully scaled to over 30 high schools and 4 colleges and universities, including over 300 teachers and 20,000 students. The P^3DM resources are ready to be disseminated to other schools and districts across the nation.

For More Information

Contact Marilyn Carlson at carlson@math.la.asu.edu.

[1] The PCA is a 25-item instrument that has been validated to assess student readiness for Calculus. The highest PCA mean score for precalculus students at the end of the course was 10.4.

Successful STEM Education and *Education for Life and Work*: Some Critical Connections and Implications

Background

Business, political, and educational leaders are increasingly asking schools to teach students skills such as problem solving, critical thinking, and collaboration. Such skills are often referred to as "21st century skills" or "deeper learning." As argued in the 2012 NRC Report, *Education for Life and Work: Developing Transferable Knowledge and Skills in the 21st Century,* these skills are best developed within the teaching and learning of academic subjects—and, in fact, are key to helping students master academic subject matter and being college and career ready. By engaging in deeper learning, students go beyond rote learning of facts and procedures to understand underlying principles. They know when and how to transfer their knowledge and skills to solve new problems and navigate new situations. This type of learning will be needed to meet the goals set by the new state standards for English language arts, mathematics, and science. And as technology reduces workplace needs for routine skills, success in coming years will demand people who can apply their knowledge and skills effectively to changing situations rather than rely solely on well-worn procedures. But, creating school environments that support deeper learning and the transferable knowledge and skills that result—known as "21st century competencies"—will require changes in teaching methods, curricula, and assessments.

Deeper learning, as defined in the report, is the process through which a person becomes capable of taking what was learned in one situation and applying it to new situations—in other words, learning for "transfer." Through deeper learning, students develop expertise in a particular discipline or subject area. They don't simply learn isolated procedures or pieces of knowledge; they also learn when and why to use their knowledge and skills. They recognize when new problems or situations are related to what they have previously learned, and they can apply their knowledge and skills to solve them. Through the process of deeper learning, students develop 21st century competencies. Instead of "skills," the report uses the broader term "competencies" to include both knowledge *and* skills. Many foundations and organizations have developed lists of competencies that they believe to be important. The competencies vary widely—ranging from critical thinking and argumentation to flexibility and "grit"—but the report argues that they can be organized into three overarching domains:

- **the cognitive domain,** which includes thinking, reasoning, problem-solving, and related skills
- **the intrapersonal domain,** which involves self-management, including the ability to regulate one's behavior and emotions to reach goals
- **the interpersonal domain,** which involves expressing information to others, as well as interpreting others' messages and responding appropriately, and collaborating with others

The report argues that goals for deeper learning and 21st century competencies converge with goals in the new *Common Core State Standards* in English language arts and mathematics and the NRC *Framework for K–12 Science Education*. All three documents highlight the importance of helping students understand the general principles underlying specific content, a hallmark of deeper learning. And all three documents support cognitive competencies such as critical thinking, problem solving, and evidence-based argumentation. Coverage of other competencies—especially those in the interpersonal and intrapersonal domains—is uneven.

Developing the full range of 21st century competencies within the disciplines will require systematic instruction and sustained practice, a change in approach that will require additional instructional time and resources.

The report also discusses features of instruction that aid deeper learning and the development of transferable knowledge and skills. For example, instruction should help learners understand the general principles underlying the specific examples they are taught. In addition, teaching should emphasize not only content knowledge, but also how, when, and why to apply this knowledge. As students gain understanding of how to use their content knowledge to solve problems and address challenges—both inside and outside the classroom—they will become more motivated to engage seriously in deeper learning. As argued in the report, instruction should follow a set of research-based teaching methods that can be readily identified in successful STEM education instructional programs.

The report also discusses specific areas that need the attention of policymakers and funding agencies:

- **Curriculum.** Curriculum and instructional programs are needed that include research-based teaching methods to help students develop transferable knowledge and skills. Policymakers should support the development and use of curricula that foster instructional techniques that focus on the process of thinking rather than only the products.
- **Assessments.** The extent to which teachers will focus on helping students develop 21st century competencies will be strongly influenced by the degree to which these competencies are included in district, state, and national assessments. Currently, educational policies and accountability systems rely on assessments that emphasize recall of facts and procedures, posing a challenge to wider teaching and learning of 21st century competencies. However, recent policy developments offer an opportunity to address this challenge. With the support of the U.S. Department of Education, two large consortia of states are developing new assessments aligned with the *Common Core State Standards*. Through these consortia, states should work to ensure that these assessments—as well as those eventually developed based on new science standards—include tasks that call upon facets of 21st century competencies as applied in each major content area.
- **Teacher education.** New approaches to teacher preparation and professional development will be needed to help current and prospective teachers understand how to teach for deeper learning, as well as the role of deeper learning and 21st century competencies in helping students master core academic content. Currently, the instructional practices described in the report and that characterize successful STEM education are rarely reflected in the knowledge and practices of teachers and school administrators.
- **Research.** Foundations and federal research agencies should support studies to fill research gaps on teaching and learning for transfer.

For More Information
Download the *Education for Life and Work* report at
http://www.nap.edu/catalog.php?record_id=13398.

Using Research Findings on Interest Generation to Help Us Provide Equal Access to Quality STEM Experiences

Background

We have three active projects where we are trying to gain a deeper understanding on the experiences that generate and maintain interest in STEM across the K–20 spectrum and in both formal and informal settings. First, our ***Spark to Flame*** project is an effort to understand student learning preferences (e.g., learning in a group vs. alone) and how they are related to the evolution of interest in science and STEM careers across grades 3–12. Second, the ***Assessment of Multinational Interest in STEM*** project is building off of collaboration with *Scientific American* magazine to survey university students and faculty regarding the key experiences that played a role in their STEM persistence. We are actively working on efforts to revise the survey and to collect data from students in the U.S., China, and Australia. Finally, in the ***Undergraduate Scientists:*** *Measuring the Outcomes of Research Experiences* project, we are focusing specifically on undergraduate research experiences and their effect on participating students, graduate mentors, and faculty. Specifically, we are focusing on how the experiences influence student plans for further STEM study and careers.

Documented Results

While we generally hear anecdotal reports that programs incorporate our results into their design, there are no large-scale efforts based strictly on our work. The most germane example of our results influencing program design was through our evaluation of a summer program in Chicago Public Schools meant to increase student interest and achievement in math and science, particularly among girls. Based on our prior work and surveying of those students, we could guide program administrators in their selection of program curricula related to health and medicine as a strong choice based on results that said the large proportion of eighth-grade girls indicated career choices in medicine and veterinary studies.

Potential Applications

Given that the responses we collect are directly from those who are currently making the decision whether or not to pursue STEM (or those who did so previously), we think the results of our work are directly applicable to a variety of contexts. In particular, we have tried to delineate those experiences that were important at different stages of interest generation.

For More Information

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http://tinyurl.com/MalteseIU