Theories of Action for STEM Education

The Role of the National Science Foundation Investments in STEM Learning and Higher Education

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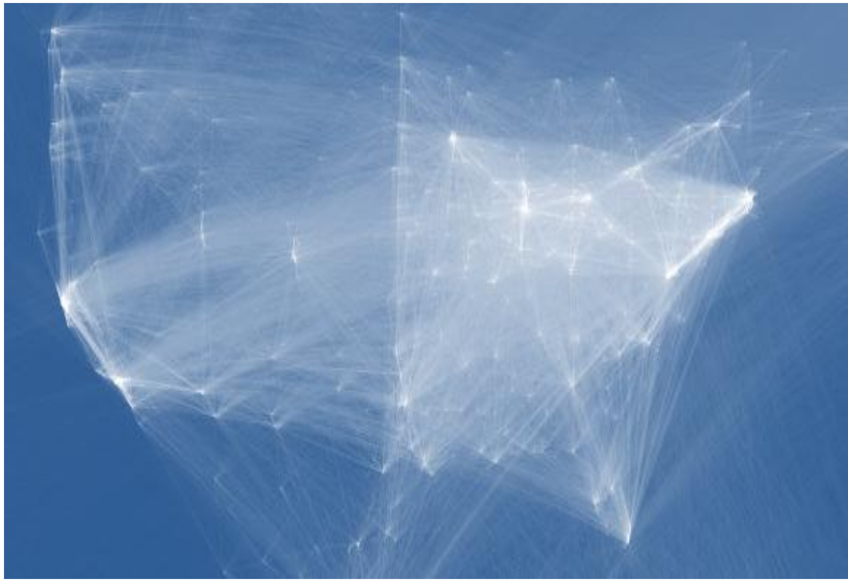
OVERVIEW OF ARGUMENT

1. The US needs a higher proportion of, and more diversity in, STEM graduates.
2. The nation's STEM graduates must be well prepared.
3. There are multiple "theories of action" for how to accomplish 1 and 2.
4. You, the NSF, and many other stakeholders together are positioned to make a difference.



1. The US needs a higher proportion of, and more diversity in, STEM graduates.

For Most Students, College Is More Dream than Reality.

- While the U.S. faces a shortage of 3 million college-educated workers by 2018, relatively low percentages of students attend and graduate from college:
- Nationwide, only 10 percent of the class of 2010 took an AP test in math, and 10 percent took an AP test in science. Students who take and pass an AP test are significantly more likely to graduate from college than academically similar students who do not take a test.
- Although 94 percent of high school students say they plan to attend a two- or four-year college, only 36 percent of all 18- to 24-year-olds are actually enrolled in a post-secondary institution.

Change the Equation. (2011). National *STEM Vital Signs*. www.changetheequation.org.

4

- Students who begin college programs often do not finish. Nationally, only 28 percent of students who begin an associate's degree program receive a certificate or associate's degree within three years. Only 56 percent of students who enroll in bachelor's degree programs receive a degree within six years.
- College graduation rates vary widely from one state to the next. For example, the six-year graduation rate for bachelor's candidates ranges from 22 percent to 69 percent.

Change the Equation. (2011). National *STEM Vital Signs*. www.changetheequation.org.

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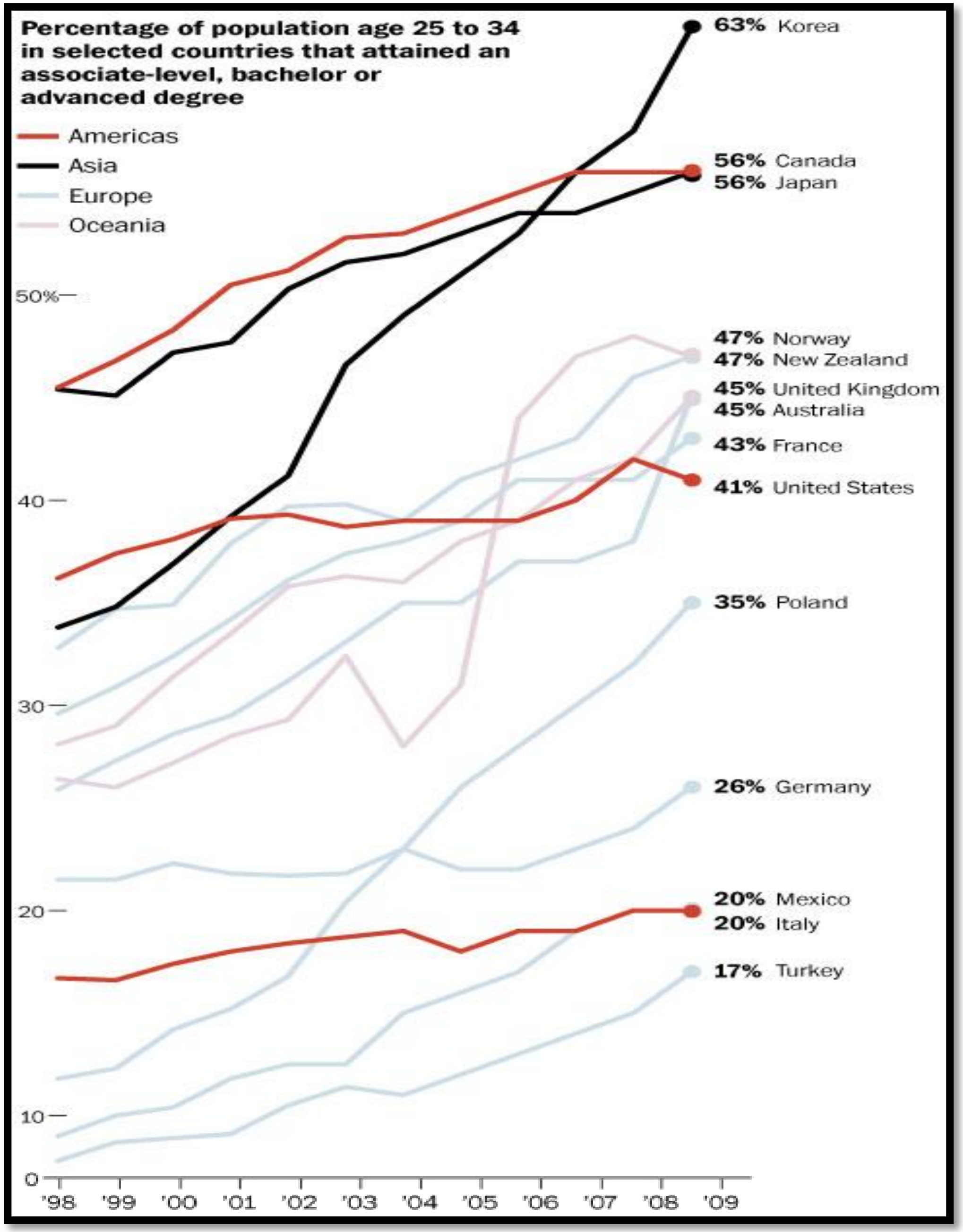
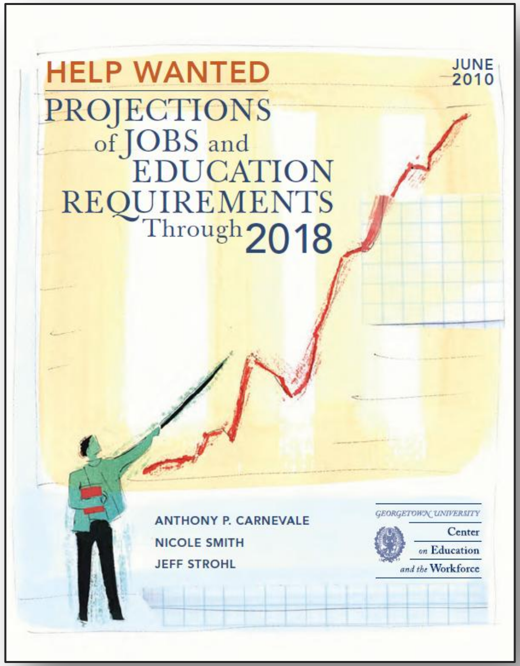
The US trails much of the developed world in college attainment among young adults, a key measure of global competitiveness.

Source: OECD. Washington Post, September 12, 2011: http://www.washingtonpost.com/local/education/playing-catch-up-in-college-completion/2011/09/12/gIQAegt6NK_graphic.html



EDUCATION AND JOBS



Prominent economists agree that no other investment generates a greater longer-term return to the economy than scientific R&D – and that starts with our educational systems.

During the next decade, overall U.S. demand for scientists and engineers is expected to increase at four times the rate for all other occupations.

Georgetown Center on Education and the Workforce. (June 2010). Help Wanted: Projections of Jobs and Education Requirements through 2018,

MEETING FUTURE WORKFORCE DEMANDS

Table 2.3 Industries with the fastest growing and most rapidly declining wage and salary employment, 2008 and projected 2018

Industry description	Sector	2007 NAICS	Thousands of jobs		Change	Average annual rate of change
			2008	2018	2008-18	2008-18
Fastest growing						
Management, scientific, and technical consulting services	Professional and business services	5416	1,008.9	1,844.1	835.2	6.2
Other educational services	Educational services	6114-7	578.9	894.9	316.0	4.5
Individual and family services	Health care and social asistance	6241	1,108.6	1,638.8	530.2	4.0
Home health care services	Health care and social asistance	6216	958.0	1,399.4	441.4	3.9
Specialized design services	Professional and business services	5414	143.1	208.7	65.6	3.8
Data processing, hosting, related services, and other information services	Information	518, 519	395.2	574.1	178.9	3.8
Computer systems design and related services	Professional and business services	5415	1,450.3	2,106.7	656.4	3.8
Lessors of nonfinancial intangible assets (except copyrighted works)	Financial activities	533	28.2	37.9	9.7	3.0
Offices of health practitioners	Health care and social asistance	6211, 6212, 6213	3,713.3	4,978.6	1,265.3	3.0
Personal care services	Other services	8121	621.6	819.1	197.5	2.8
Outpatient, laboratory, and other ambulatory care services	Health care and social asistance	6214, 6215, 6219	989.5	1,297.9	308.4	2.8
Facilities support services	Professional and business services	5612	132.7	173.6	40.9	2.7
Software publishers	Information	5112	263.7	342.8	79.1	2.7
Independent artists, writers, and performers	Leisure and hospitality	7115	50.4	64.8	14.4	2.5
Local government passenger transit	State and local government	NA	268.6	342.6	74.0	2.5
Elementary and secondary schools	Educational services	6111	854.9	1,089.7	234.8	2.5
Scientific research and development services	Professional and business services	5417	621.7	778.9	157.2	2.3
Waste management and remediation services	Professional and business services	562	360.2	451.0	90.8	2.3
Other miscellaneous manufacturing	Manufacturing	3399	321.0	399.4	78.4	2.2
Community and vocational rehabilitation services	Health care and social asistance	6242, 6243	540.9	672.0	131.1	2.2

Bureau of Labor Statistics

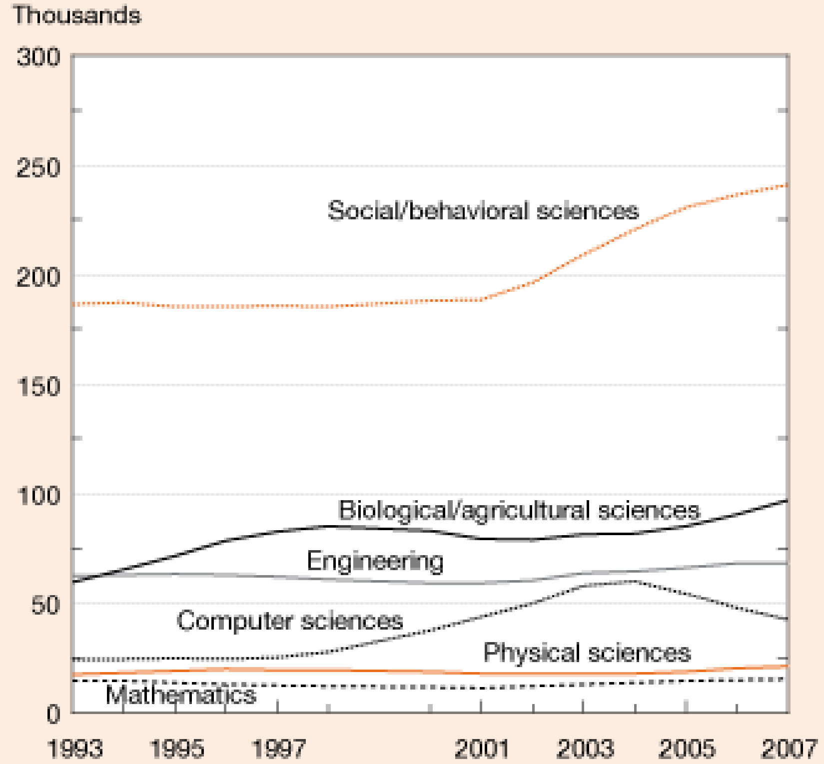
MATHEMATICS AND THE WORKFORCE

"Computer and mathematical science occupations are projected to add almost 785,700 new jobs from 2008 to 2018. As a group, these occupations are expected to grow more than twice as fast as the average for all occupations in the economy. Demand for workers in computer and mathematical occupations will be driven by the continuing need for businesses, government agencies, and other organizations to adopt and utilize the latest technologies.

Occupational Outlook Handbook, 2010-11 Edition, Bureau of Labor Statistics. http://www.bls.gov/home.htm

S&E bachelor's degrees have consistently accounted for roughly one-third of all bachelor's degrees for the past 15 years.

Figure 2-5
S&E bachelor's degrees, by field: 1993–2007

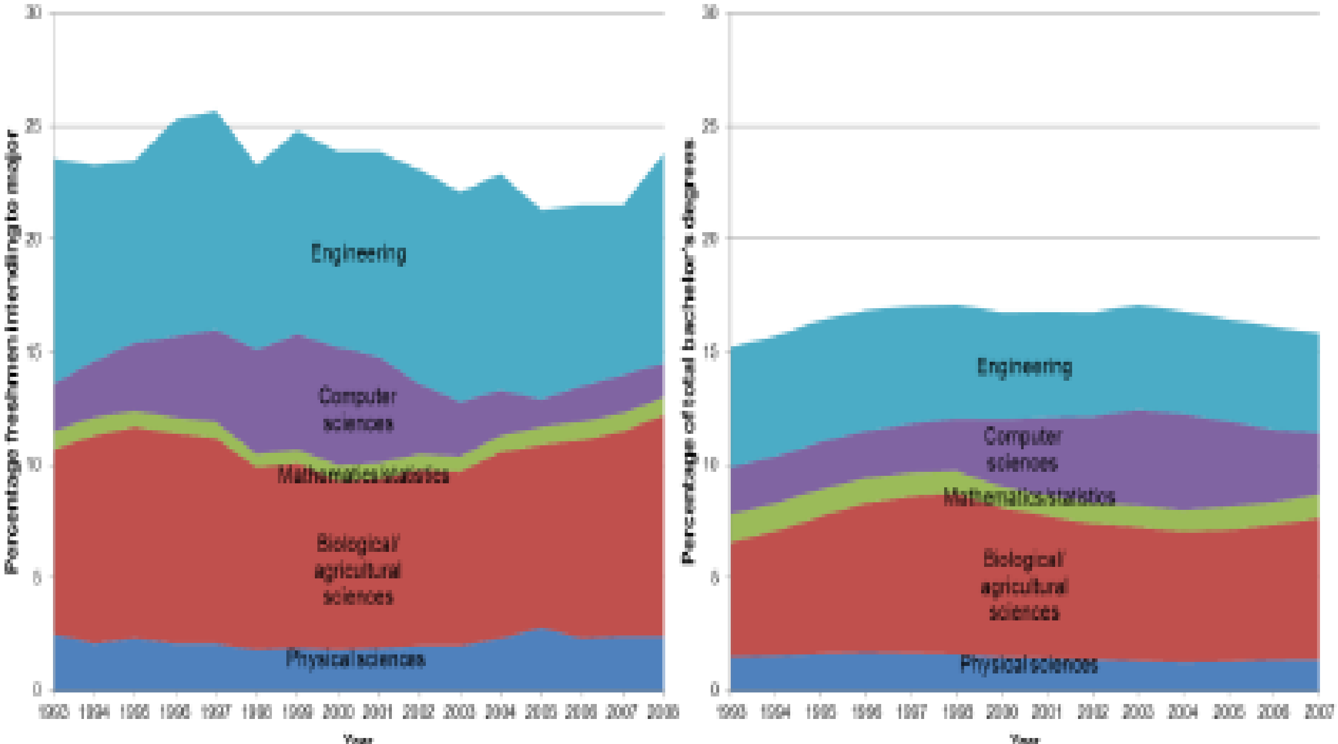


NOTES: Physical sciences include earth, atmospheric, and ocean sciences. Data not available for 1999.

SOURCES: National Center for Education Statistics, Integrated Postsecondary Education Data System, Completions Survey; and National Science Foundation, Division of Science Resources Statistics, WebCASPAR database, http://webcaspar.nsf.gov. See appendix table 2-12.

Science and Engineering Indicators 2010

NSB. 2010 S&E Indicators



Source: NSF S&E Indicators 2010, Appendix Tables 2-6 and 2-12

Figure 3

half of all students who begin in the physical or biological sciences and 60 percent of those in mathematics will drop out of these fields by their senior year

American Association of Universities. (September 15, 2011). 5-Year Initiative for Improving Undergraduate STEM Education: Discussion Draft.

Table 8. Among 1995–96 beginning postsecondary students who entered STEM fields between 1995–96 and 2001, percentage who earned STEM degrees, persisted in STEM fields, or left STEM fields as of 2001, by selected student characteristics

	Degree attainment and persistence in STEM field as of 2001				
	STEM completers		STEM persisters	STEM leavers	
Selected student characteristic	Attained a degree or certificate in a STEM field	Attained a bachelor's degree in a STEM field	No STEM degree or certificate but were still enrolled in a STEM field	No STEM degree or certificate and changed to a non-STEM field[1]	Left post-secondary education without a degree or certificate
Total	40.7	26.5	12.0	20.6	26.7
Gender					
Male	40.8	25.5	12.3	20.3	26.6
Female	40.6	28.4	11.4	21.2	26.8
Race/ethnicity[2]					
White	43.9	29.5	12.1	19.4	24.6
Black	31.7	15.5	9.4	23.8	35.2
Hispanic	33.1	16.3	15.7	19.7	31.6
Asian/Pacific Islander	39.9	31.2	9.4 !	27.0	23.8

NCES. (2009). Students Who Study STEM in Postsecondary Education. (P. 15)

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Of white students entering STEM degree programs, 25% left higher ed; of Black students, 35% left

NCES. (2009). Students Who Study STEM in Postsecondary Education. (P. 15)

Retention in STEM after First 2 Years

Most students who leave STEM do so between the first and second year, rather than later in their college career . . . , and because most students who leave STEM do so during the first two years of college, those years are especially critical in terms of teaching.

Information Technology and Innovation Foundation (2011). Refueling the U.S. Innovation Economy. (p. X)

THE NATION'S STEM GRADUATES MUST BE WELL PREPARED.

STEM GRADUATES AND SOCIETAL INNOVATION

"STEM college graduation exhibits what economists call an externality: STEM graduates produce innovations that are responsible for the lion's share of increases in U.S. standard of living."

Information Technology and Innovation Foundation (ITIF). (2011). Refueling the U.S. Innovation Economy. (p. 126)

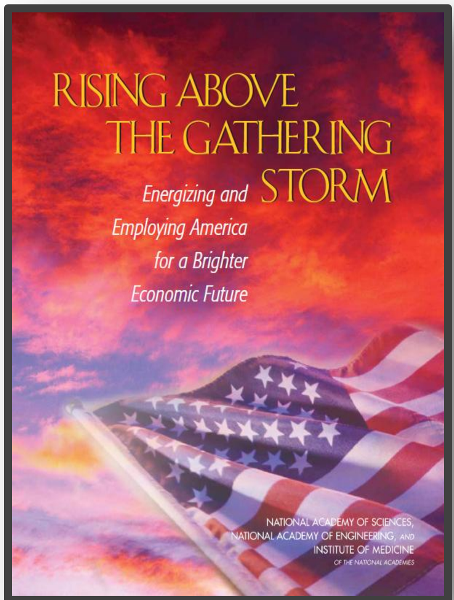
MEETING FUTURE WORKFORCE DEMANDS

"The strength and versatility of [our] labor force, [and] its capacity to nourish research and innovation are increasingly dependent on an education system capable of producing a steady supply of young people well-prepared in science and math"

~Education Commission of the States

Rick Stephens and Michael Richey. (July 2011). "Accelerating STEM Capacity: A Complex Adaptive Systems Perspective," *Journal of Engineering Education*. Vol.100 (3).

NATIONAL ACADEMY OF SCIENCES
RISING ABOVE THE GATHERING STORM



"We owe our current prosperity, security, and good health to the investments of past generations, and we are obliged to renew those commitments in education, research, and innovation policies to ensure that the American people continue to benefit from the remarkable opportunities provided by the rapid development of the global economy and its not inconsiderable underpinning in science and technology."

National Research Council (NRC). (2007). *Rising Above the Gathering Storm*.

What Would a 21st Century Higher Education System Look Like?

- Enrollees and graduates who meet the challenges of today's world because they have a broader set of skills linked to proficiency in STEM such as skills in communication, critical thinking, and analysis
- Enrollees and graduates who are cross-trained in STEM content for STEM and non-STEM employment
- Enrollees and graduates who make informed decisions based on scientific knowledge
- Enrollees and graduates aware of issues related to policy, ethics and sustainability

Adapted from NRC. (2011). *Promising Practices in Undergraduate Science, Technology, Engineering and mathematics Education* (p. 1-59)

INNOVATION AND IMAGINATION

"Innovation begins with the talent, knowledge and creative thinking of a workforce. High-quality STEM education and learning environments that prize **innovation and imagination** produce graduates who will germinate new inventions, develop new products, and create new solutions to many of our world's most pressing problems."

Photo from http://www.harrisburgu.net

— Dr. Mel Schiavelli, "Commentary: STEM Education Benefits All," September 10, 2008

NSF-funded undergraduate microbiology research, Clark-Fork River, Chief Dull Knife College, Montana

3. There are multiple "theories of action" for how to accomplish 1 and 2.

OUTCOMES

✓Retention and STEM degree completion
✓Student learning and preparation

- Adequate entry-level preparation
- Evidence-based instructional practice
- Opportunities to learn authentic science
- Role models, mentors, cohorts of peers
- Financial support and student services
- Scale-up of best practices

✓Retention and STEM degree completion

✓Student learning and preparation

- Faculty preparation
- High school experience and teaching
- Integration of research and education
- Innovative instruction, relevant curricula
- Research on teaching and learning
- Policy incentives

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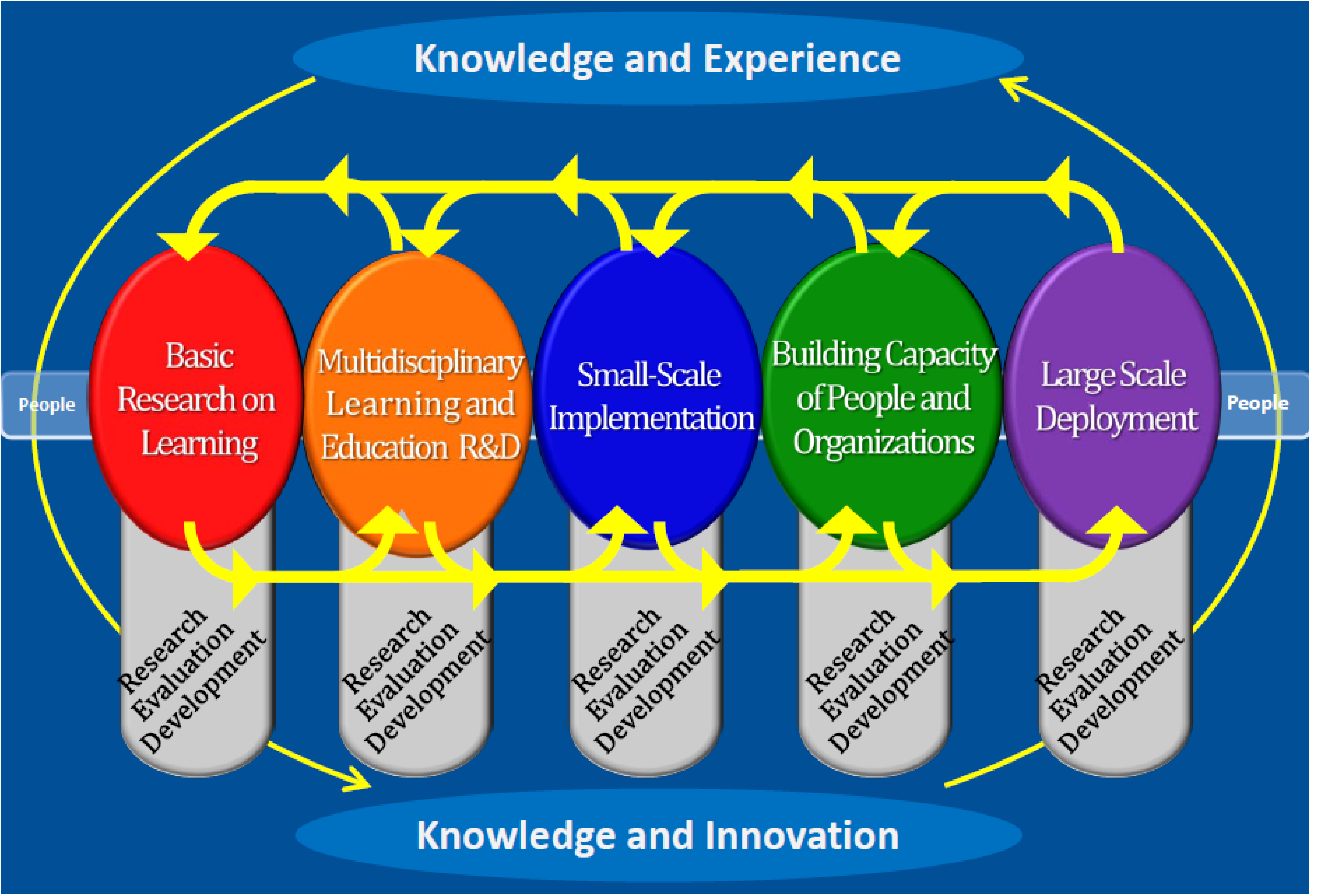
Physics interactive engagement classroom, Western Kentucky University: Students in Dr. Scott Bonham's College Physics I (PHYS 201) course studying collisions using an internet-based physics java applet (called a Physlet).

4. You, the NSF, and many other stakeholders are positioned to make progress.


Knowledge and Experience
People
Basic Research on Learning
Multidisciplinary Learning and Education R&D
Small-Scale Implementation
Building Capacity of People and Organizations
Large Scale Deployment
People
Research Evaluation Development
Research Evaluation Development
Research Evaluation Development
Research Evaluation Development
Research Evaluation Development
Knowledge and Innovation

BEST PRACTICES

The evidence base for what works, for whom and under what conditions is growing

Geoscience research near NSF's McMurdo Station

shethought.com

The Teaching Center at Washington University in St. Louis

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DISCIPLINE-BASED EDUCATION RESEARCH

- The National Science Foundation has funded a synthesis study on the status, contributions, and future direction of discipline-based education research (DBER) in physics, biological sciences, geosciences, and chemistry.
- DBER combines knowledge of teaching and learning with deep knowledge of discipline-specific science content. It describes the discipline-specific difficulties learners face and the specialized intellectual and instructional resources that can facilitate student understanding.

From the Board of Science Education, Center for Education DBER Homepage. Available at http://www7.nationalacademies.org/bose/DBER_Homepage.html

THE NATIONAL ACADEMIES
Advisers to the Nation on Science, Engineering, and Medicine

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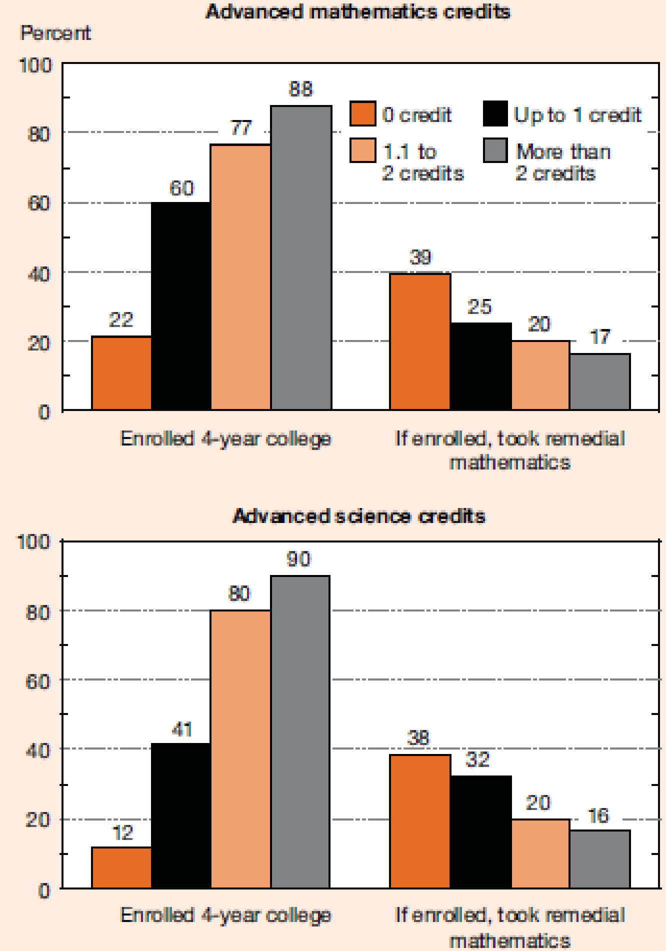
COLLEGE READINESS MATTERS

"Among high school graduates in 2004, earning credits for advanced science and mathematics courses was linked to higher rates of postsecondary enrollment at 4-year colleges and lower rates of postsecondary remediation, confirming the results of earlier studies."

Figure 1-15
Postsecondary experiences of the class of 2004, by advanced mathematics and science credits in high school: 2006



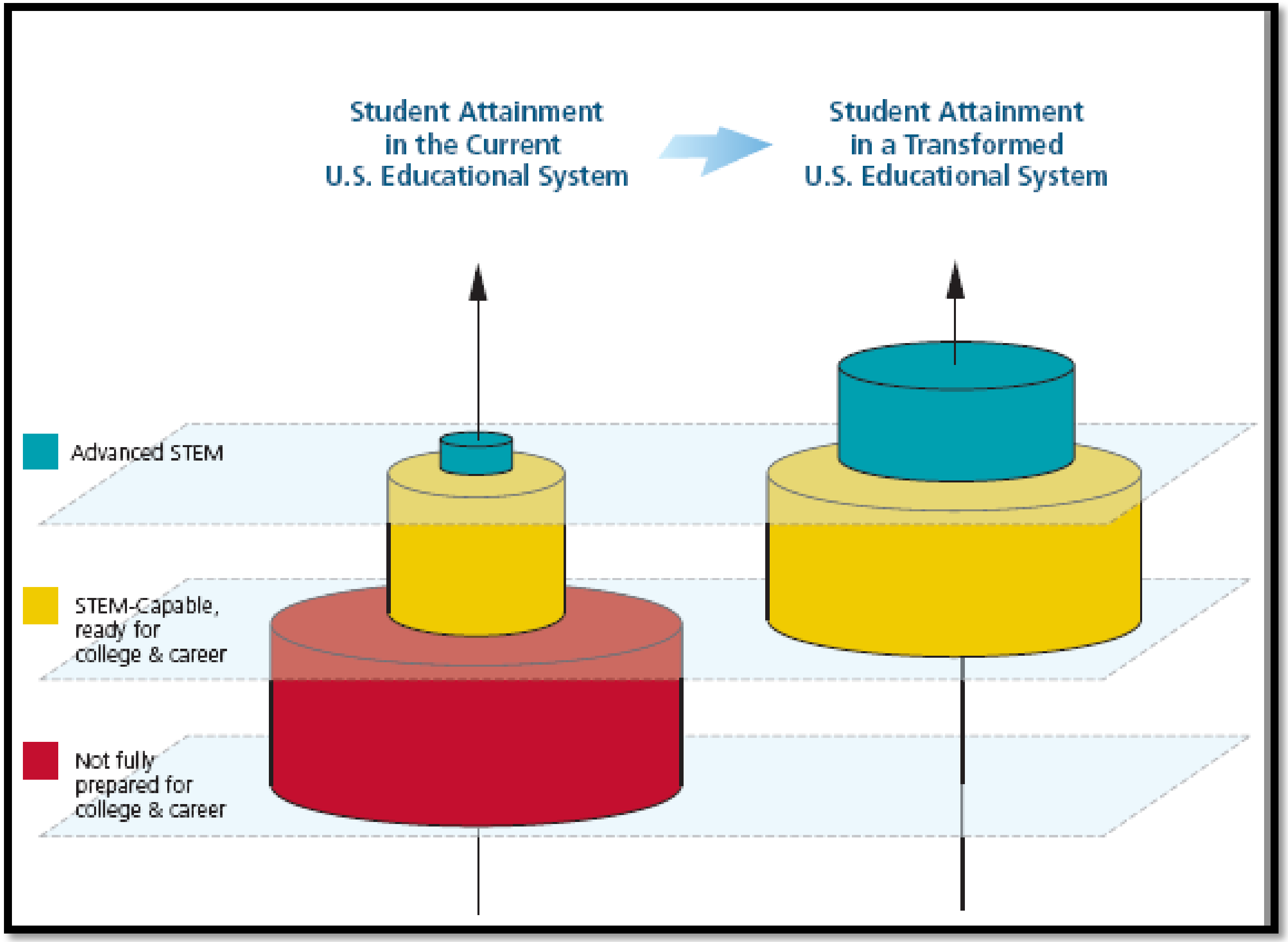
SOURCE: National Center for Education Statistics, Education Longitudinal Study of 2002, 2006 followup (ELS: 2002/06). See appendix table 1-20.

Science and Engineering Indicators 2010

EDUCATION IMPLICATIONS

Goal:

Much higher levels of mathematics and science learning for American Students



Source: *The Opportunity Equation*

Education Week

Better Data Urged to Link K-12 and Postsecondary

October 6, 2011
By Caralee J. Adams

"If high schools are going to better prepare students for college and careers, experts say they need to track graduates enrolling in higher education, whether they take remedial courses to get up to speed, and whether they earn a degree. . . . Lyndsay Pinkus, Director of national and federal policy initiatives for the Data Quality Campaign, said that momentum around this issue is accelerating. In 2005, 12 states were reporting the capacity to link K-12 and higher education systems, and by 2010, the number had leaped to 44."

"Demand is growing for linking performance between education systems, the speakers suggested. A 2010 survey of high school educators by Deloitte, a finance-consulting company, found that 92 percent felt having data on students' academic performance in college was critical for evaluating the effectiveness of high school curricula and instruction. Yet only 13 percent of educators say they get postsecondary data for all their school's graduates."

CCSS FOR MATH

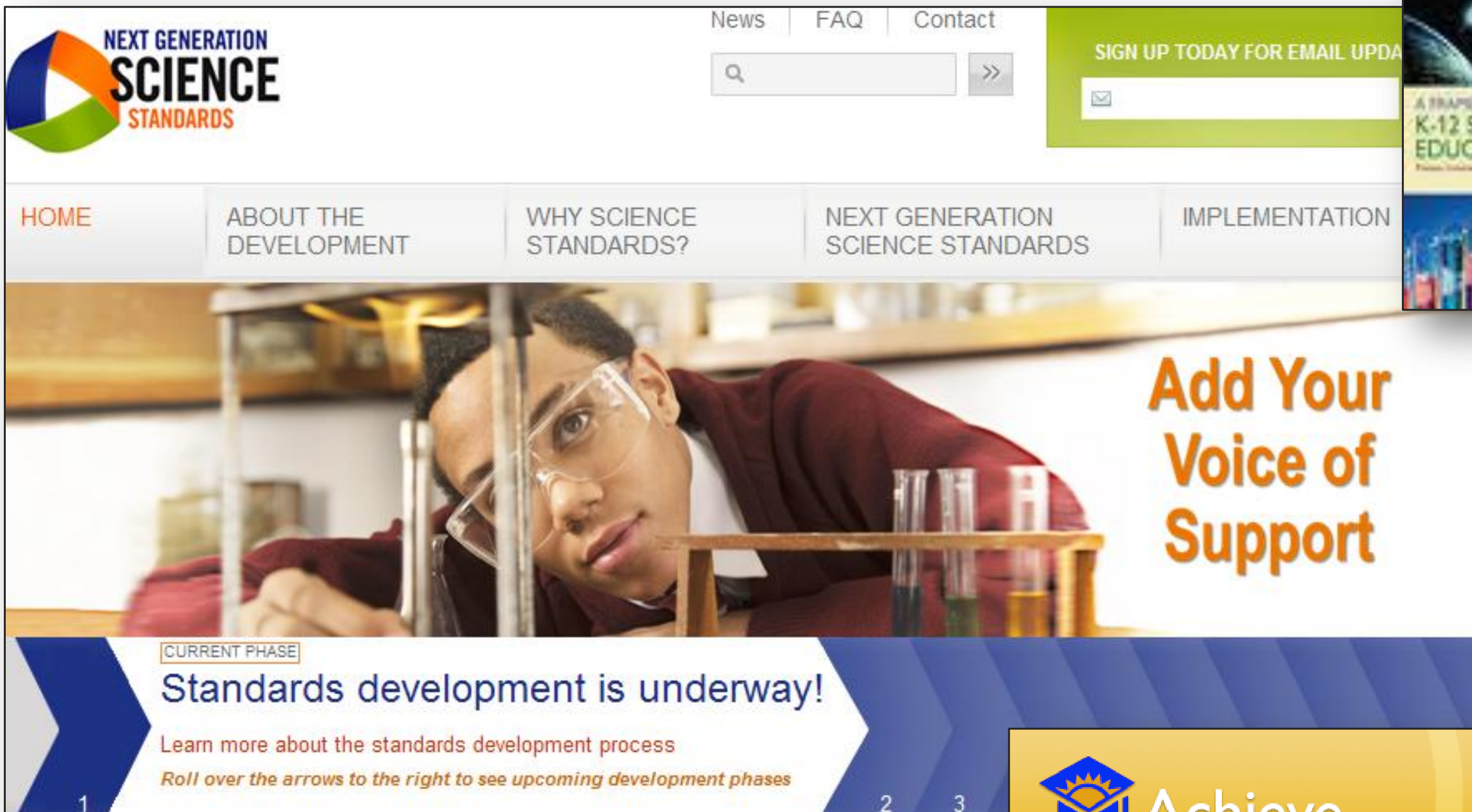
"The Common Core State Standards (CCSS) provide a consistent, clear understanding of what students are expected to learn, so teachers and parents know what they need to do to help them. ***The standards are designed to be robust and relevant to the real world, reflecting the knowledge and skills that our young people need for success in college and careers.*** With American students fully prepared for the future, our communities will be best positioned to compete successfully in the global economy."

Learning Progressions in the Common Core State Standards in Math

"The Common Core State Standards in mathematics were built on progressions: narrative documents describing the progression of a topic across a number of grade levels, informed both by research on children's cognitive development and by the logical structure of mathematics."

http://ime.math.arizona.edu/progressions/

NEXT GENERATION SCIENCE STANDARDS



Achieve

Learning Progressions in the Next Generation Science Standards

The Consortium for Policy Research (CPRE) at Teachers College, Columbia University is developing learning progressions (LPs) to help guide the new CCSS for science. The framework calls for standards that are organized around learning progressions (LPs) that address "big" ideas in science that go across grades to assist teachers both in assessing students' current learning status and in developing appropriate and differentiated instruction to support student progress. CPRE's LPs will serve as a critical tool to states, districts, and instructional developers as they plan for using the next generation of CCSS for science. For more information, visit the CPRE homepage at: www.cpre.org. (Award #1051144)

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INNOVATING FOR SOCIETAL IMPACT: CLICKERS

Presently-Clickers use is expanding to activities outside of lectures, such as facilitating authentic web-based research and sending data between groups

~2006-Vast inventories of Clicker questions and answers across fields, from Physics to Economics. Answers used to increase efficiency and effectiveness of teaching

~2001-NSF investments in the use and assessment of clickers in diverse classroom settings

~1991-DUE grant to Eric Mazur of Harvard University research on and assessment of peer-led instruction

Thanks to Susan Hixson et al., DUE

Images retrieved from http://certi.mst.edu/teachsupport/assessment.html and http://www.valdosta.edu/distance/clickers/students.shtml.

Force Concept Inventory in Physics

- A multiple-choice test of qualitative knowledge in mechanics.
- Developed by David Hestenes and colleagues at Arizona State University (with support from NSF). [For information on this work, please see: http://modeling.asu.edu/R&E/Research.html]
- Validated, reliable, reproducible; useful for measuring the effect of curricular changes in teaching mechanics.
- Given before a course and after instruction in mechanics.
- Differences in scores can be used as a measure of student learning in a class.
- Widely used in introductory physics at the university level (also some high school data); data collected centrally and available to researchers.
- Some types of instruction show a clear advantage, especially interactive engagement courses over traditional lecture.

FORCE CONCEPT INVENTORY IN PHYSICS

Red: 14 traditional lecture courses; **Green**: 48 interactive engagement courses.

Results Based on 62 Courses - 6,542 Students

Horizontal scale measures pre- and post-test difference for the class (Hake gain).

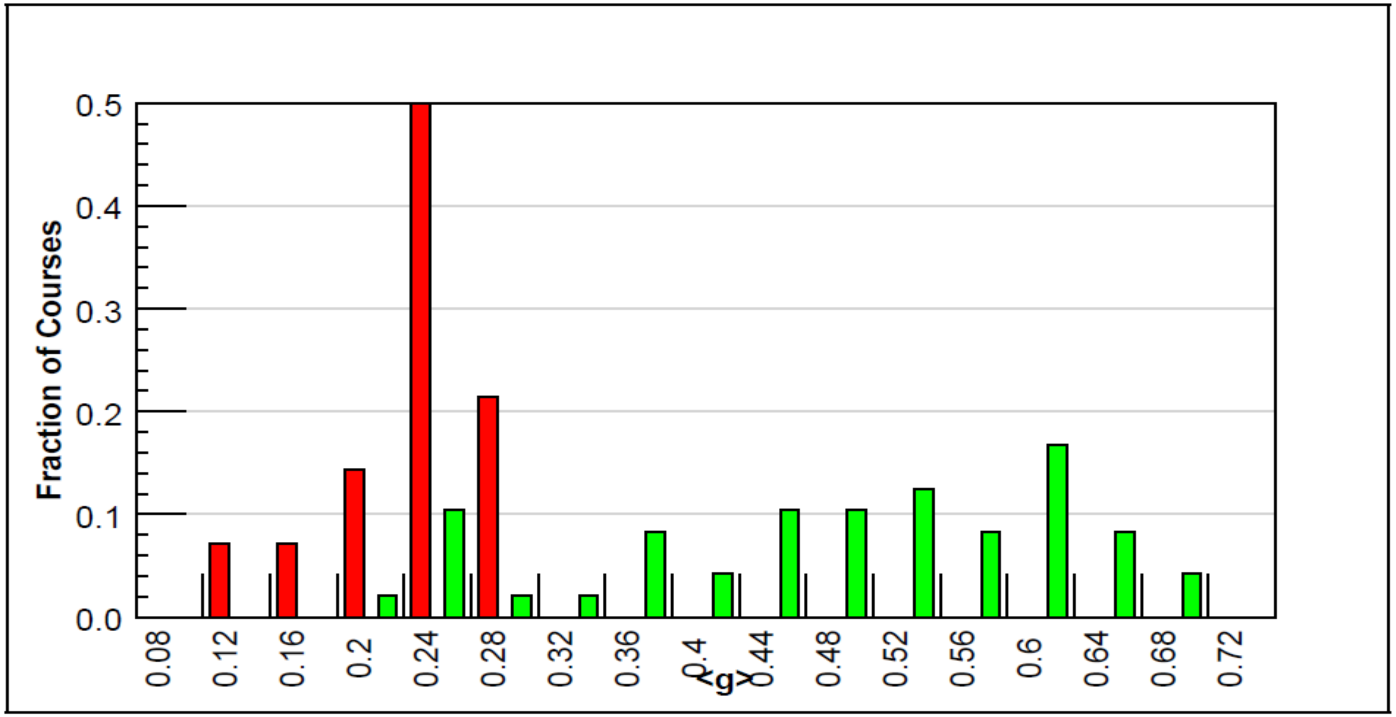


Fig. 2. Histogram of the average normalized gain <g>: dark (red) bars show the *fraction* of 14 traditional courses (N = 2084), and light (green) bars show the *fraction* of 48 interactive engagement courses (N = 4458), both within bins of width δ<g> = 0.04 centered on the <g> values shown.

Figure from Hake, R., *American Journal of Physics*, 66(1), 64-74 (1998)

Innovating for Societal Impact: Critical Thinking Assessment Test

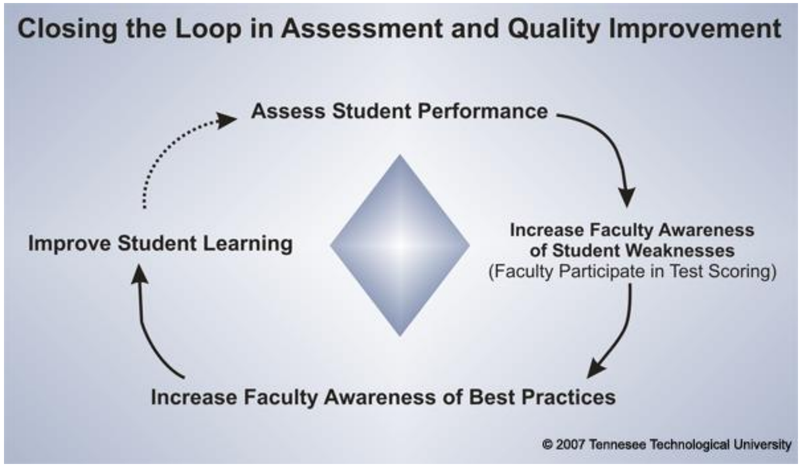
CRITICAL THINKING ASSESSMENT TEST

~2004-ASA grant to Barry Stein at Tennessee Technological University to refine validity, cultural sensitivity, and reliability via multi-institutional pilot study

~2007-National dissemination across diverse institutions via train-the-trainer and workshops

~2010-Expand institutional use of CAT, web-based training and support, expand new test questions

Presently-More than 64 institutions are participating in CAT development and testing



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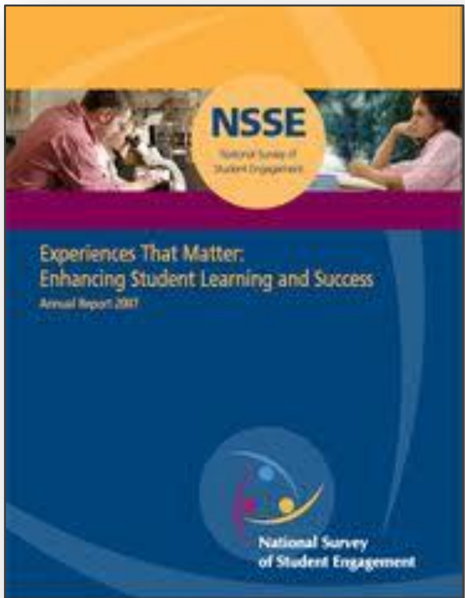
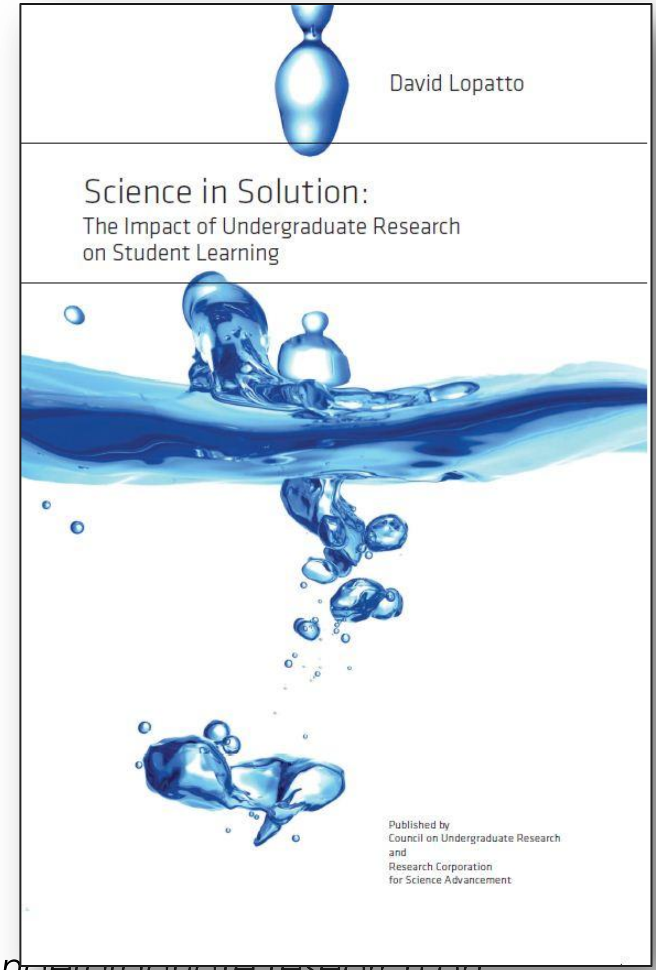
RESEARCH EXPERIENCES



Students doing research with faculty are more likely to persist, gain more intellectually and personally, and choose a research related field as a career. NSSE 2007 results show that they also more frequently used deep approaches to learning and report more learning and growth from their college years. Yet, most students do not have such opportunities.

"Students doing research with faculty are more likely to persist, gain more intellectually and personally, and choose a research-related field as a career.*



*Lopatto, David. (2010) *Science in solution: The impact of undergraduate research on student learning*. Council on Undergraduate Research/Research Corporation for the Advancement of Science.

SYNTHESIS OF STUDIES ON RESEARCH APPRENTICESHIPS

- Sadler, Burgin, McKinney, & Ponjuan (2009). Learning Science through Research Apprenticeships: A Critical Review of the Literature. *Journal of Research in Science Teaching.*
- 53 reports of empirical research on research apprenticeships, 1961-2008
  – 22 focused on undergraduate programs

Research Apprenticeships Outcome Variables

- Retention
- Desire to go to graduate school
- Perceived readiness for graduate school
- Interest in scientific research careers
- Understanding the nature of science
    - Complexity and uncertainty in scientific research
    - Role of social aspects, collaboration, in science
    - Link between knowledge claims and empirical data

Research Apprenticeships Outcome Variables (cont'd)

- Self-perceptions of knowledge gains
- Faculty perception of knowledge gains
- Content knowledge gains
- Confidence
- Self-efficacy
- Development of reasoning ability
- Skills (research process, communication, technical)

Summary of Results on Research Apprenticeships

- Participants enjoy the experiences and believe they are valuable
- Patterns of increased interest, retention, desire to attend graduate school, some deeper understanding of "Nature of Science"
- "The question of how much science is learned by participants is left largely unanswered."

MATHEMATICS FOR THE 21ST CENTURY

- Climate Change
- Health
- Environment and Natural Resources
- World Hunger
- Energy
- Development

"Mathematical competence is no longer needed only by some; knowing and being able to use mathematics is increasingly seen as an essential form of literacy and that, additionally, some occupations will continue to require even higher levels of mathematical skill."

Deborah Loewenberg Ball, Commissioned Paper, *The Opportunity Equation* (2008)

GROWING THE GEOSCIENCES WORKFORCE

"….research approaches in the geosciences must broaden to further include the integration of the biological, engineering, social, and economic sciences…

New curricular waters must be charted to find the proper balance between educating students about fundamental Earth system processes and learning how to facilitate application of this knowledge to problems faced by society."*

Sub-seafloor Core Extractions on-board the NSF-funded Ocean Drillship *JOIDES Resolution*

*NSF Advisory Committee for Geosciences. (2009) Geovision report. pp. 14-15.

Interdisciplinary Education

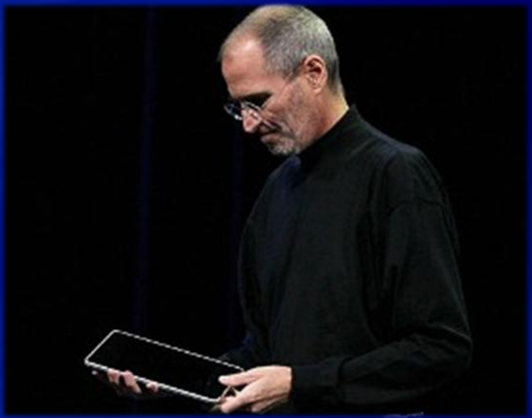
The scientific community increasingly views interdisciplinary research as critical to innovation and scientific advance and as a means to respond to emerging complex problems (COSEPUP 1995, 2004; NSF/DGE 2009). Over the past decade, academic institutions and federal funding agencies have made efforts to promote interdisciplinary education and research. Although new programs and efforts have arisen, academic institutions and funding agencies remain for the most part organized around disciplines; thus, university structures, evaluation and promotion practices, and funding opportunities often do not facilitate interdisciplinary research (NSF/DGE 2009).

2-21 SE Indicators

TRANSFORMATION

1977: Steve Jobs with First Successful Personal Computer

1966 Chemistry Classroom
Bellevue Community College



Steve Jobs with iPad Tablet

Second Life, Virtual Classroom

S. Jobs photos retrieved from http://abcnews.go.com/Technology/steve-jobs-death-top-10-products-including-apple/story?id=14680924#9

- Faculty preparation
- High school experience and teaching
- Integr … cation
- Innov … curricula
- Resea … ning
- Policy

- Adequ … on
- Evider … actice
- Oppo … science
Role m … peers
- Financ … ervices
- Scale-up of best practices

✓Retention and STEM degree completion

✓Student learning and preparation

FUTURE AND FOCUS

- Understand the changing nature and practice of science and transform the nature of STEM learning
- Study innovation processes and map to educational experiences
- Conduct longitudinal work to examine the role of "inspiration/ engagement" experiences on future career choice and workforce readiness
- Reform undergraduate curriculum to feature emerging science
- Examine impact of policy change for broadening participation

Highlights from FY 2012 NSF Budget Request

- 23 Undergraduate STEM Education Program areas across the agency
- FY10 Omnibus actual: $486.92 M
- Number of undergraduate students involved in NSF activities: FY10 estimate, 33,324

NSF LEARNING PORTFOLIO: UNDERGRADUATE EDUCATION

BIO

TUBE: Transforming Undergraduate Biology Education

CISE

Computing Workforce (BPC, CPATH and CE21)

ENG

Engineering Education Research

GEO

OEDG: Opportunities for Enhancement of Diversity in Geosciences (OEDG)

OCI

CI-TEAM: Cyberinfrastructure Training, Education, Advancement & Mentoring

OISE

IRES: International Research Experiences for Students

EHR

- TLF: Teacher Learning for the Future
- HBCU-UP: Historically Black Colleges and Universities Undergraduate Program
- LSAMP: Louis Stokes Alliances for Minority Participation
- TCUP: Tribal Colleges and Universities Program
- ATE: Advanced Technological Education Program
- TUES: Transforming Undergraduate Education in Science, Technology, Engineering and
- Mathematics Program
- CCE: Climate Change Education Program
- NOYCE: Robert Noyce Teacher Scholarship Program
- S-STEM: Scholarships in Science, Technology, Engineering, and Mathematics Program
- STEP: Science, Technology, Engineering and Mathematics Program
- REU: Research Experiences for Undergraduates Program–Sites and Supplements

Improve S&E research outcomes by engaging with STEM education.

Improve STEM education outcomes by engaging with S&E research.

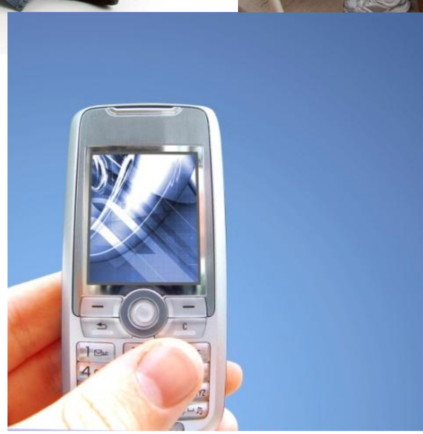
INTERACTING WITH NSF

- Attend NSF days and outreach activities in your region, or arrange one
- Volunteer to review for programs that are of interest
- Read the annual President's budget request
- Consider some of our more flexible mechanisms: EAGER, RAPID, conference proposals
- Longer term: consider coming to NSF as a program officer as a part of your career trajectory

Expeditions in Education – E²
Engage, Empower, Energize







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THANK YOU!

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Keyword: EHR

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