Integrating Science, Technology, Engineering and Mathematics Education

Articulating a Vision and Opportunities for a California STEM Innovation and Learning Network

May 2009 • CCST Symposium Summary

INTEGRATING SCIENCE, TECHNOLOGY, ENGINEERING, AND MATHEMATICS EDUCATION: ARTICULATING A VISION AND OPPORTUNITIES FOR A CALIFORNIA STEM INNOVATION AND LEARNING NETWORK

Symposium Summary
February 18 - 19, 2009

Convened by:
National Academy of Engineering
National Research Council (Center for Education)
California Council on Science and Technology

Sponsored by:
S.D. Bechtel, Jr. Foundation

Acknowledgements

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CCST is a non-profit organization established in 1988 at the request of the California state government and sponsored by the major public and private postsecondary institutions of California and affiliate federal laboratories, in conjunction with leading private-sector firms. CCST's mission is to improve science and technology policy and application in California by proposing programs, conducting analyses, and recommending public policies and initiatives that will maintain California's technological leadership and a vigorous economy.

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Executive Summary

On February 18-19, 2009, the National Academy of Engineering (NAE) and the National Research Council (NRC) Center for Education convened a strategic visioning meeting to address integrating science, technology, engineering, and mathematics (STEM) education through an innovation and learning network in California. The meeting was designed to guide and inform the work of leaders from the California Council on Science Technology (CCST) and the California State University (CSU) who are planning a process to establish a California STEM Innovation Network (CSI-N) and framework for advocacy in the state. This effort is supported by the S.D. Bechtel, Jr. Foundation and the Bill and Melinda Gates Foundation.

The meeting goals were:

1. By using reports and experts from relevant NRC and NAE education-related studies, assist the network planning team to develop a vision for truly integrated STEM education in California and to explore the challenges, opportunities, and implications of doing so.
2. By involving representatives from other states (Ohio, North Carolina, Texas) in which similar STEM education networks are being developed with support from the Gates Foundation, leverage the lessons learned from these efforts and explore how they might become more connected.
3. By surfacing key opportunities and challenges, pave the way for a future convocation at a later date that would engage a broader set of stakeholders.

The meeting agenda, meeting participants, and summaries of key Academies reports are included as appendices. Further information and links to presentations can be found at the CCST website http://www.ccst.us.

A series of presentations by members of relevant Academies study committees that authored seminal STEM education reports, members of existing study panels engaged in relevant education work, and representatives from other projects that are engaged in similar STEM education networks provided a basis for the meeting discussions.

A diverse group of approximately 35 individuals representing higher education, K-12, government, business/industry, philanthropic, and informal education organizations involved in STEM education both from policy and practice disciplines were briefed on eight Academy studies.

Participants also received staff-authored summaries of 11 Academies reports and received PDF copies of more than 30 National Academies Press reports on education. Building on a common foundation of the Academies' K-20 STEM education research, the meeting attendees focused the dialogue and assessment around 3 common themes:

1. Curriculum, Instruction and Assessment
2. Teacher Education and Professional Development
3. Systems issues (e.g., articulation, accreditation, certification, funding, facilities)

Representative examples of specific observations in these common themes that emerged during the discussions included:

Curriculum, Instruction and Assessment

- Districts and the state need to allow schools to be innovative on their own and allow them to share lessons learned with guidance from districts/state (think globally; act locally); design globally and implement locally with stakeholders who will sustain the new systems approach to STEM education.
- Greater emphasis should be placed on measuring learning through multiple assessments rather than relying only on end-of-course examinations.
- Educational change will require changing classroom practices such as the inclusion of inquiry based learning techniques.
- Learners should be able to integrate and apply their knowledge; this could occur not necessarily through integrated curriculum, but through the application of integrated standards.
- The scientific method of discovery is often taught; however, the engineering method of designing, building, and testing often is not taught and needs to be paired with the scientific method of teaching and learning.

Teacher Education and Professional Development

- Teaching needs to be viewed and valued as a highly regarded and respected profession with the attributes and career development of other professions.
- STEM faculties in colleges and universities need to assume greater responsibility for the pre-service and in-service education of P-12 teachers.
- California's community college system is a critical path element for students entering or currently in the workforce. The community college route is a primary route for teachers beginning their post-secondary education and who are ultimately assigned to high-need schools.

Systems Issues (e.g., articulation, accreditation, certification, funding facilities)

- System change requires implementing strategies that include meaningful STEM learning experiences and technological literacy for all students.
- The need for coherence across the education and learning system: curriculum/syllabus; teacher pre-and in-service professional development; infrastructure support; assessment. Alignment across these elements could result in an effective and coherent system for student learning.
- The system needs to address how students learn as well as what they learn in order to ensure that student learning outcomes focus on the kinds of performance characteristics that are needed in the future STEM workforce.
- Networks could serve as a high level catalyst – connecting schools to learning communities in the states; community activity (regional focus) heightens and highlights student/teacher achievement; a network structure could provide common goals of working together as a unit and building model behaviors and practice.

Building on these common themes that emerged from the report recommendations and the resulting dialogue the participants began a "reverse design" exercise which resulted in a model for a framework. This reverse design exercise was done by first determining the long-term outcomes as defined by a desired state being accomplished. Then participants worked backwards to determine how to achieve these goals and measure success. As shown in Appendix 3, participants identified the following categories to be considered:

1. Audiences
2. Outputs/Activities (beyond the planning meeting)
3. Measurable Short-term Outcomes
4. Mid-Term Outcomes (1-6 months)
5. Long term Outcomes (desired state)

Given the outcomes presented in the preliminary "Reverse Design" charts, several characteristics emerged in understanding the scope of the California STEM education:

1. Quality: the readiness of California students to enter higher education or the workforce is not on a par nationally or internationally with their peers; the coherence of curriculum, instruction and assessment are critical to producing STEM college and/or workforce ready individuals
2. Teacher Education and Professional Development: the number of teachers proficient in STEM fields, the professional standing of teachers (including compensation and professional development), and the system for attracting, producing, and retaining STEM-proficient teachers needs to be transformed to deliver a pipeline of students who are 21st century college ready and workforce ready
3. Quantity: the number of California STEM graduates continues to decline (leaking pipeline) despite diverse population growth in the state; 21st economic viability requires an increase in STEM ready learners
4. Systems approach: one that captures the continuum of articulation, accreditation, certification, funding, and facilities is essential

Although there appeared to be a general consensus among the participants that templates for the tactical implementation of STEM education reform (in the classroom, informal education settings, higher education, etc.) exist and can be adopted into practice, fundamental policy components (such as the definition of STEM, the language of STEM, the ordering of STEM versus SMET [science and mathematics as fundamental underpinnings to education with engineering as an implementation process and technology as a tool], etc.) or the plausibility of a systems approach are not yet on a sound footing. The California Public Education "Landscape" (see figure 1) depicts the current environment where teachers' and students' interactions are constrained and sub-optimized by a top-heavy, bureaucratic governance system; the CSI-N envisions a paradigm shift to an innovative, systems model where teachers and students are at the center of the California Public Education "Universe" where the governance system supports, nurtures, an enables an agile, 21st century STEM education process and that each student is a product of such a process.

The meeting participants expressed a willingness to continue to contribute to the California STEM Innovation and Learning Network planning process through:

- Interviews and benchmarking
- Document/concept review and feedback
- Subsequent convocations and meetings

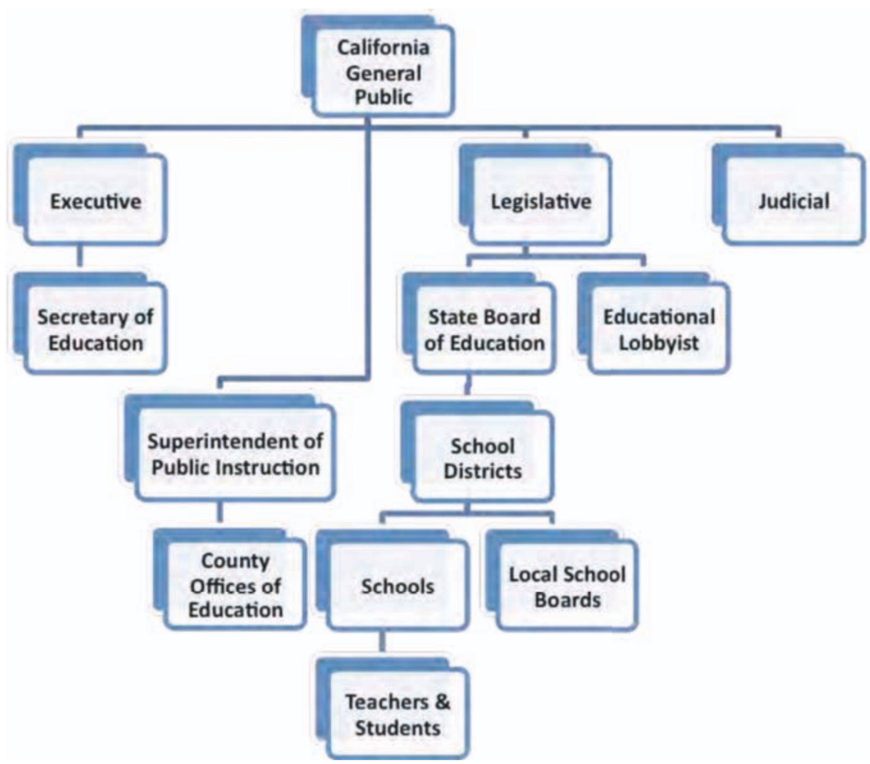


Figure 1. K-12 Governance System in California

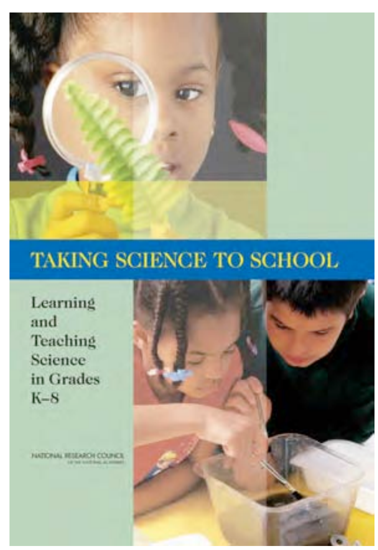
**INTEGRATING SCIENCE, TECHNOLOGY, ENGINEERING, AND MATHEMATICS EDUCATION:
ARTICULATING A VISION AND OPPORTUNITIES FOR A CALIFORNIA STEM INNOVATION AND LEARNING NETWORK**

Background

Staff from the National Academy of Engineering and the National Research Council's Center for Education provided a synthesis and compendium of 30 seminal STEM education reports published over the past decade by the National Academies to serve as a foundation for the meeting discussions. The meeting agenda, meeting participants, and summaries of 11 key Academies reports are included as appendices. Further information and links to presentations can be found at the CCST website (http://www.ccst.us). The presentations and subsequent content discussions demonstrated clear themes requiring attention in order to achieve meaningful and sustainable improvements to STEM education in California.

The meeting focused on three primary goals:

1. By using reports and experts from relevant NRC and NAE education-related studies, assist the leaders of the California Council on Science and Technology and the California State University planning team to develop a vision for truly integrated STEM education plan in California and to explore the challenges, opportunities, and implications of doing so.
2. By involving representatives from other states (i.e., Ohio, North Carolina, Texas) in which similar STEM education networks are being developed with support from the Gates Foundation, leverage the lessons learned from these efforts and explore how they might become more connected.
3. By surfacing key opportunities and challenges, pave the way for a larger convocation 6-8 months later that would engage a broader set of stakeholders.



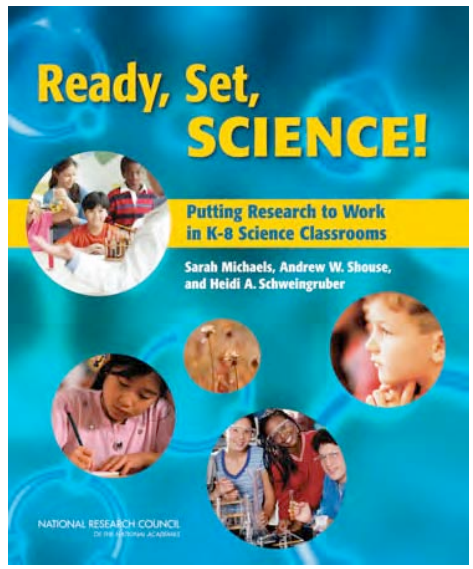
The meeting participants and presenters included members of Academies study committees that authored seminal reports on STEM education as well as members of existing study panels engaged in relevant work. It also included senior staff from the NAE and NRC, who recruited the appropriate experts and leaders from California higher education institutions (2-year and 4-year public/private), non-governmental organizations, business, and philanthropic organizations (Beckman Foundation, Gates Foundation, Samueli Foundation).

Presentations included:

- Relevant statewide STEM education initiatives in California, North Carolina, Ohio (via telephone), and Texas
- Examination and discussion of relevant National Academies reports regarding effective STEM education programs in Grades P-20
- Implications of these reports for planning the California STEM Innovation and Learning Network

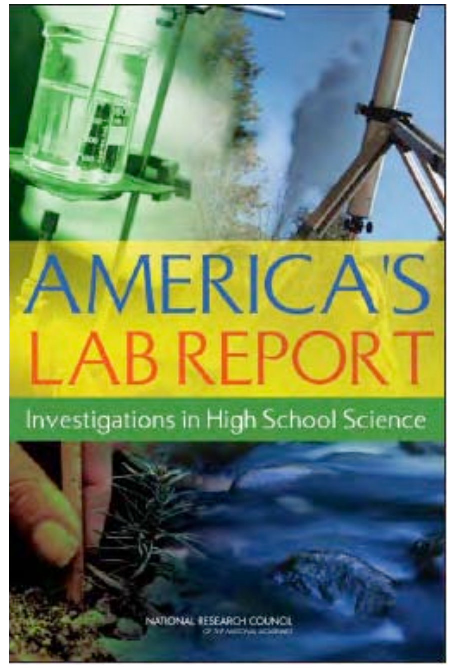
Dialogue and a "Reverse Design" exercise leveraged the breadth and depth of knowledge and experience of the meeting attendees. Topics of discussion included articulating a vision, changes, and change agents for an integrated STEM education system including:

1. Curriculum, Instruction and Assessment
2. Teacher Education and Professional Development
3. Systems Issues (e.g., articulation, accreditation, certification, funding, facilities)



While federal and state governments, the education community, and industry have touted the importance of STEM education for more than a decade, it remains unclear what STEM education actually encompasses. For example, efforts to improve pre-college STEM education have to a great extent focused on science and mathematics. Much less attention has been paid to K-12 technology and engineering education. In addition, each subject within STEM is usually treated as a separate silo of knowledge and practice, especially at the secondary and postsecondary levels. The inherent inter-connections among the subjects are rarely exploited in curriculum materials, teacher education, standards, or assessments. Also lacking are comprehensive knowledge and research bases about how to measure academic achievement and other outcomes in STEM education. One important question is whether integrated STEM programs result in higher levels of student learning and achievement than the current system of mostly unconnected science and mathematics programs.

In short, currently there is little common understanding or agreement about the scope of STEM education and the systemic challenges and opportunities that are involved with integrating these subjects. One likely result is that individual attempts to develop STEM education programs will create or perpetuate disparities in student learning and achievement. This is the current situation in science and mathematics education across the states, in part due to states' inconsistent adoption of national standards.

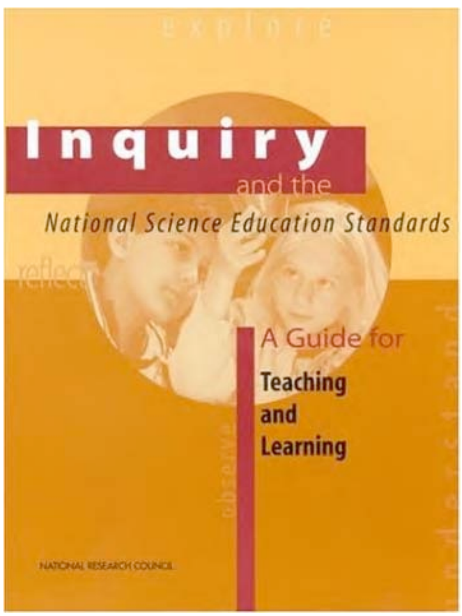


Through leadership from CCST and CSU, California is embarking on a year-long planning process followed by implementation of a statewide STEM innovation and learning network. The very short timeline for planning and implementing a STEM education network in a state as large, diverse, and heterogeneous as California will require that the leadership and other participants understand at the inception the implications, opportunities, and challenges for developing the network. Key players in the initiative also will need a working knowledge of the evidence that has been collected to date about structuring effective education in science, mathematics, technology, and engineering.

The Bill and Melinda Gates Foundation co-funder of the California planning effort with the S.D. Bechtel, Jr. Foundation is supporting similar STEM education improvement projects in Ohio, North Carolina, and Texas and, like California, offering planning grants for the development of such networks in New York and the State of Washington. To prevent these efforts from becoming idiosyncratic and thus resistant to scaling up, some level of coordination and networking from the outset will be important.

National Academies Role

Both the NRC's Center for Education and the National Academy of Engineering (NAE) have been at the forefront of studies and conversations about effective science, technology, mathematics, and engineering education at the K-12 and postsecondary levels. The Academies invited the input of the leading experts on these issues and have published numerous reports that could help inform the planning effort in California. The strategic visioning meeting has helped the California STEM Innovation and Learning Network leaders become more knowledgeable about the findings, conclusions, and recommendations in these Academies' reports and has facilitated subsequent conversations about how the evidence and recommendations contained in them can be used to inform the year-long planning phase and follow-on implementation phase.



The National Research Council's Center for Education and the National Academy of Engineering's Program Office provided meeting participants with 30 reports on improving education that have been published by the National Academies Press, staff summaries of a subset of these reports (see Table 1 and Appendix 4), and several other documents of potential interest e.g. "*The Missing Piece of the Proficiency Puzzle: Recommendations for Involving Families and Community in Improving Student Achievement,"* (Commissioner's Parents Advisory Council Final Report to the Kentucky Department of Education, 2007).

A series of presentations by members of relevant Academies study committees that authored some of these STEM education reports and members of existing study panels engaged in ongoing relevant work provided a basis for the meeting discussion. A diverse group of approximately 35 individuals involved in STEM education both from policy and practice disciplines were briefed on eight Academies studies and recommendations.

What does the evidence tell us about effective STEM Education Programs? An examination and discussion of relevant National Academies' reports included the following:

Table 1. National Academies STEM Education Reports Summarized and Used to Inform Symposium

Taking Science to School: Learning and Teaching Science in Grades K-8 (2007)

Ready, Set, Science!: Putting Research to Work in K-8 Science Classrooms (2007)

America's Lab Report: Investigations in High School Science (2005)

Inquiry and the National Science Education Standards: A Guide for Teaching and Learning (2000)

Learning and Understanding: Improving Advanced Study of Mathematics and Science in U.S. High Schools (2002)

Adding It Up: Helping Children Learn Mathematics (2001)

Tech Tally: Approaches to Assessing Technological Literacy (2006)

Technically Speaking: Why All Americans Need to Know More About Technology (2002)

Educating the Engineer of 2020: Adapting Engineering to the New Century (2005)

How People Learn: Brain, Mind, Experience, and School—Expanded Edition (2000)

Educating Teachers of Science, Mathematics, and Technology: New Practices for the New Millennium (2000)

Similar State STEM Education Network Initiatives

Gates STEM education network grantee leaders from Ohio, North Carolina and Texas shared the scope, history, and challenges of their respective initiatives. Links to their presentations are available at the CCST website. The Ohio initiative is the most mature of the three states. Each network has its own unique characteristics, funding profile, etc. There are lessons to be learned from each state's experience, and the CSI-N team will work closely with these "sister" Gates grantees to build on that rich experience. In its own right, CSI-N will be forging new ground given California's geographic size, diversity, and heterogeneity.

California has been given an opportunity to envision what it wants to do for its children without preconceived notions. The CSI-N work could be a STEM community leading STEM education – collapsing into a single entity around a community for practice (Table 2). CSI-N and the other participants were encouraged by the Gates Foundation and the Bechtel Fund as part of the open exchange to "try to set aside history of what you think works to listen to new things."

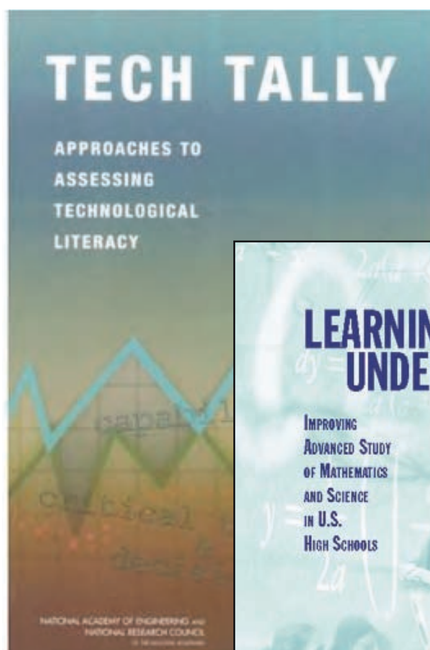
A networking of these individual state networks is under discussion.

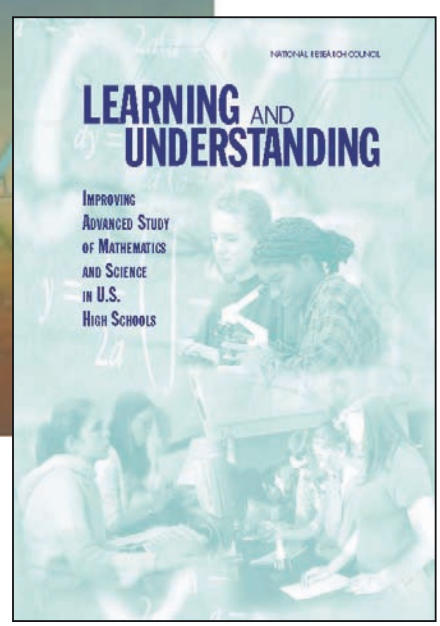
Table 2. Key questions that could inform the CSI-N process

- What should constitute success in education?
- Will we need new definitions and metrics of success?
- How do we overcome the tension of design for scale?
- How can a network accelerate success?
- How do we build capacity and develop potential?

Shared characteristics of the individual State STEM Education Network initiatives include:

- Vision
- Innovation
- Leadership
- Partnerships
- Resources
- Technology
- Knowledge capture
- Communication
- Advocacy





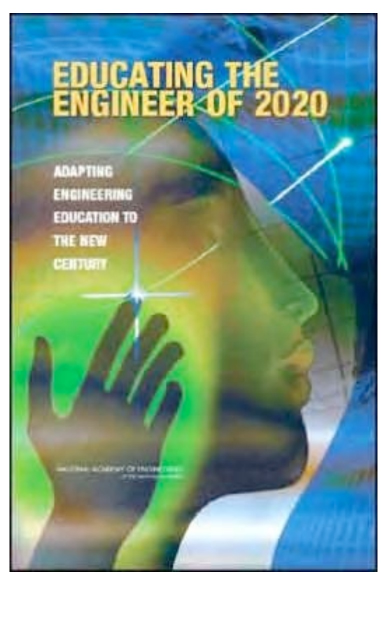
Challenges and Opportunities

STEM education transformation in California faces challenges, e.g.

- Balancing STEM education will require a significant paradigm shift from the current situation where mathematics and science are usually considered separate and engineering and technology have little place in the curriculum to a more interconnected STEM education enterprise where the science, technology, engineering, and mathematics components are all included to varying degrees as appropriate.
- Standards of learning, instructional materials, teacher professional development and assessments need to be created, updated, revised, and coordinated.
- Education policy makers and school administrators need to view STEM literacy as a unified and coordinated goal.
- Colleges and universities need to revise entrance requirements and adjust to student expectations which run counter to traditional discipline-based views of courses and degrees.
- Inquiry-based approaches to teaching and learning can reach and engage students of diverse backgrounds and levels of interest yet common definitions for what constitutes inquiry-based approaches to teaching and learning have not been determined; it is more difficult and expensive to assess learning through inquiry-based teaching and learning.
- Issues of the quality and quantity of STEM learners has to be understood in terms of the demographics of California, and particularly the fact that the large majority of students in the state come from ethnic groups that have and continue to be seriously under-represented in STEM fields.

However, there are considerable opportunities:

- While no one method of teaching and learning is effective for all students, large numbers of students learn and understand more deeply when they have the opportunity to actively engage with STEM subjects.
- The paradigm change that could result from looking at STEM education as a system – the Business Higher Education Forum and Raytheon have undertaken efforts to use systems engineering to model K-12 education (see



http://www.stemnetwork.org/?utm_source=srmn_newsletter&utm_medium=email&utm_campaign=march09 for additional information).

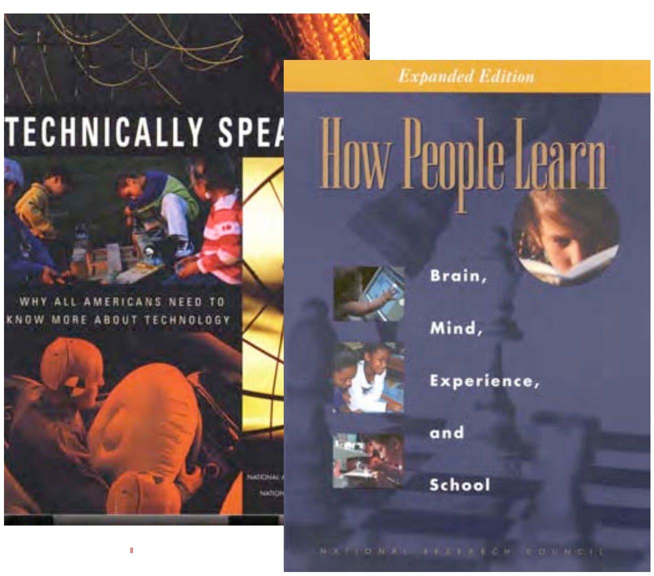
- Applying "network" (connection) characteristics to education and learning.
- Identify system barriers, eliminate them, and redefine incentives
- Produce an educated and skilled community that provides a qualified workforce for the continued economic well-being and improved quality of life for all residents of California.

There was a general consensus that the current state of public education in the state of California is a traditional, top down hierarchical structure where teachers and students are at the bottom (See The California Public Education "Landscape"). The goal is to create a paradigm shift to a system of support where teachers and students are at the center (see The California Public Education "System").

Next Steps

This strategic visioning meeting was a key convening of STEM education leaders in California and nationally to inform the construct of the California STEM Innovation Network planning process through:

- State-of-the art information and innovation sharing grounded in peer reviewed research
- Identification of key themes, metrics, and milestones for consideration in constructing the "Blueprint"
- Creation of a foundation to inform planning for a future convocation at a later date designed to engage a broader spectrum of stakeholders in the California STEM initiative



The meeting participants expressed a willingness to continue to contribute to the California STEM Innovation and Learning Network planning process through:

- Interviews and benchmarking
- Document/concept review and feedback
- Subsequent convocations and meetings

Appendix 1

PLANNING MEETING

ARTICULATING A VISION AND OPPORTUNITIES FOR A CALIFORNIA STEM INNOVATION NETWORK

The Hyatt Regency
Sacramento, CA
February 18-19, 2009

AGENDA

Day 1 (All working sessions in the Golden State Room)

Approx. Time:	Topics for Discussion:	Speaker(s)/Moderators
2:45 PM	Welcome and Introduction of Participants Goals of Planning Meeting Review Briefing Materials Review Agenda	• Greg Pearson and Jay Labov
3:00 PM	The California STEM Innovation and Learning Network: Background and Hoped-For Outcomes	[Note taking: Michael Masterson] • Susan Hackwood, Marilyn Edling, Susan Elrod, and Angela Diaz (Leadership Team) • Jan Morrison, Gates Foundation (*by phone*)
3:15 PM	Descriptions and discussion of other relevant state STEM-reform initiatives: 1. California: Qualitative Examination of the Preparation of Elementary School Teachers to Teach Science in California (10 minutes) 2. Convocation on Sustaining Elementary Science Education (10 minutes) 3. Texas, Ohio, and North Carolina STEM Improvement Efforts (40 minutes)	[Note taking: Sue Elrod] • Eilene Cross • Jay Labov • Cindi Jolly (North Carolina STEM), Ana Tilton and Brenda Wojnowski (Texas STEM), Sonya Pryor-Jones (Ohio STEM)
4:15 PM	Break	
4:30 PM	What Does the Evidence Tell Us About Effective STEM Education Programs? An Examination and Discussion of Relevant Reports from the National Academies.	[Note taking: Angela Diaz] Moderators: Greg Pearson and Jay Labov • Helen Quinn/*Taking*

	1. Science and Mathematics Education: Pre-K-8 *Taking Science to School: Learning and Teaching Science in Grades K-8* *Ready, Set, Science* *Adding It Up: Helping Children Learn Mathematics* 2. Science and Mathematics Education: High School/College *America's Lab Report* *Learning and Understanding* *Transforming Undergraduate Education in SMET* *Bio2010* *Educating Teachers of Science, Mathematics and Technology*	*Science to School* • Kevin Miller, U. Mich./ *Adding it Up* [Note taking: Eilene Cross and Michael Masterson] • William Sandoval, UCLA/*America's Lab Report* • Jay Labov/*Transforming Undergraduate Education, Learning and Understanding, Bio2010* • Herb Brunkhorst, CSU San Bernardino/*Educating Teachers of SMT*
5:45 PM	Recapping the Afternoon: Questions and General Discussion - Instructions for Day 2	Greg Pearson and Susan Hackwood
6:15 PM	Adjourn	
6:30 PM	Reception	
7:00 PM	Dinner	

Day 2 (All sessions in the Big Sur):

Approx. Time:	Topics for Discussion:	Speaker(s)/Moderators
7:00 AM	Buffet Breakfast in Hyatt Restaurant	
8:30 AM	Overview of Reports (continued): 3. Engineering and Technology Education: K-12 *Technically Speaking* *Educating the Engineer of 2020: Adapting Engineering Education to the New Century* Forthcoming Academies reports on K-12 Engineering Education	[Note taking: Donna King] • Ethan Lipton, CSU-LA/ *Technically Speaking* • Alfred Moyé, HP (ret.)/ *Educating the Engineer of 2020* • Rollie Otto, UC Berkeley/NAE/NRC K-12 engineering education study
9:15 AM	Implications of These Reports for Planning the California STEM Innovation and Learning Network Part 1: Moderated Panel Discussion with Invited Experts and Meeting Participants: Can we agree on a common definition of STEM Education? What characteristics would a truly interconnected system of STEM education have? What changes will be needed to move toward a system of interconnected STEM education?	[Note taking: Sue Elrod] Panel Moderator: Karl Pister Panel Members: • Helen Quinn, Stanford Linear Accelerator: *Curriculum and Instruction* • Ann Marie Bergen, Oakdale Joint Unified School District: *Teacher Professional Development*
10:15 AM	Break	
11:00 AM	Implications of These Reports for Planning the California STEM Innovation and Learning Network: Part 2: Articulating a vision, changes, and change agents for an education system in which STEM is truly Integrated Breakout sessions will focus on: Session 1: Curriculum, Instruction and Assessment Session 2: Teacher Education and Professional Development Session 3: Systems issues (e.g., articulation, accreditation, certification, funding, facilities)	Breakout Moderators: Session 1: Marilyn Edling (Note taking: Eilene) Session 2: Angela Diaz (Note taking Donna) Session 3: Sue Elrod (Note taking: Michael)
12:00 PM	Lunch	Using a "reverse design" process, rapporteurs from the three breakouts and project staff develop a preliminary

		summary of important breakout topics
12:45 PM	Putting the pieces of the system together: the beginnings of a roadmap for the California STEM Education Network	[Note taking: Eilene Cross, Donna King and Michael Masterson] Discussion Leaders: Jay Labov and Marilyn Edling
2:15 PM	Closing thoughts - Possible follow-on activities: a larger convocation; additional roadmap development; periodic topic-specific webinars; other (?)	Greg Pearson, Jay Labov, and Susan Hackwood
2:30 PM	Adjourn	

Appendix 2

Articulating a Vision and Opportunities for a California STEM Innovation and Learning Network

National Research Council - National Academy of Engineering

February 18-19, 2009

Participants

CCST Board and Council Members

Warren Baker, President, Cal Poly, San Luis Obispo
Steve Bruckman, Executive Vice Chancellor, CCC
Milton Gordon, Chancellor, California State University, Fullerton
Susan Hackwood, Executive Director, CCST
Alice Huang, Senior Faculty Associate in Biology, Caltech
Randy Hall, Vice Provost for Research Advancement, USC
Charles Kennel, Professor, Scripps Institution of Oceanography
Karl Pister, Chancellor Emeritus, UC Santa Cruz
Stephen Rockwood, Executive Vice President, Science Applications International Corp
Julie Meier Wright, President and CEO, San Diego Economic Dev. Corp.

National Academy of Engineering (invited speakers/moderators)

Herb Brunkhorst, Professor of Science Education and Biology, CSUSB
Eilene Cross, Consultant, CCST
Angela Phillips Diaz, Special Assistant to the Chancellor, UC Riverside
Marilyn Edling, Program Manager, CA STEM Innovation Network (CSI-N)
Susan Elrod, Director, Center for Excellence in Science and Mathematics Education, Cal Poly, San Luis Obispo
Cindi Jolly, TIES, North Carolina
Sonya Pryor-Jones, Ohio STEM (by phone)
Jay Labov, Senior Advisor for Education and Communication, The National Academies
Ethan Lipton, Professor, Department of Technology, CSULA
Kevin Miller, Professor, Combined Program in Education and Psychology, Departments of Educational Studies and Psychology, University of Michigan
Jan Morrison, TIES (by phone)
Alfred Moyé, Director of University Affairs, Hewlett-Packard Company, and

Former Deputy Assistant Secretary for Higher and Continuing Education, Carter Administration
Roland "Rollie" Otto, Coordinator, Teacher Academy Program, Berkeley Center for Cosmological Physics, University of California, Berkeley
Greg Pearson, Senior Program Officer, National Academy of Engineering
Helen Quinn, Professor of Physics, Stanford Linear Accelerator Center
William Sandoval, Associate Professor, University of California, Los Angeles
Susan Singer, Lawrence McKinley Gould Professor of Natural Sciences, Department of Biology, Carleton College
Ana Tilton, Chief Program Officer, Texas High School Project, Communities Foundation of Texas
Brenda Wojnowski, Senior Program Officer, Texas Science Technology Engineering and Math, Communities Foundation of Texas

Guests

Dan Aldrich, Sr. Development Associate, University of California
Patricia Beckman, Arnold and Mabel Beckman Foundation
Ann Marie Bergen, Cal TAC Chair & Teacher, Oakdale Joint Unified School District
Ken Burtis, Dean, College of Biological Sciences, UC Davis
Dan Howard-Greene, Executive Assistant to the President, Cal Poly San Luis Obispo
John Knezovich, Director, UC Toxic Substances Research and Teaching Program, Lawrence Livermore National Laboratory
Donna King, Sr. Project Coordinator, CCST
Michael Masterson, Researcher/Consultant, K-6 Science Teacher Preparation Project, CCST
Gisele Ragusa, Director, Center for Outcomes Research and Evaluation, USC
Karen Scott, Manager, Government Relations, Sandia/California National Laboratories
Diane Siri, Director, Alliance for Regional Collaboration for Educational Success (ARCHES)
Gerald Solomon, Executive Director, Samueli Foundation
Susan Wood, Executive Director, Children’s Center, Caltech

Appendix 3

"REVERSE DESIGN": GOALS, STRATEGIES, AND METRICS FOR CSI PLANNERS
Curriculum and Assessment

Audience(s)	Outputs/Activities (Beyond the Planning Meeting)	Measurable Short-Term Outcomes	Mid-Term Outcomes (1-6 Months)	Long-Term Outcomes (Desired State)
Teacher networks Local business & community organizations – how they impact STEM education CA Dept. of Education CTC Legislature CA Chamber of Commerce National Organizations District and School Leaders Private funders	Formative Assessments Identify models that work for developing 21st century skills for work and higher education. Develop operational working definition and characteristics of STEM literacy so that other parts of initiative can be aligned. Examine availability and management of materials, spaces and expendables across the state.		What does someone who is STEM literate look like throughout grades K-16? How does this literacy comport with the broader strands of competencies in *Adding It Up* and *Taking Science to School*?	Formative assessments that are from classroom experiences. Assessments, curriculum, and PD must be driven from different sources, not just from state standards. High school graduates will have the skills and knowledge to enter college (**2- and 4-year**) <u>and</u> the workforce with 21st century skills that don't require remediation. Policy relief from narrow constraints of assessment, curriculum as it relates to standards, and actual classroom practices.

Teacher Education and Professional Development

Audience(s)	Outputs/Activities (After Planning Meeting)	Measurable Short-Term Outcomes	Mid-Term Outcomes (1-6 Months)	Long-Term Outcomes (Desired State)
Institutions of Higher Ed. (2 and 4 year) National Laboratories CTC K-12 Districts District Leadership Parents (helping to understand the roles of teachers especially in inquiry-based approaches and their roles in environments outside of classrooms) Informal Education Professional Organizations CSTA, NSTA, Scientific and Mathematics and Engineering and Technology Societies. Legislature State Dept. of Education Teachers and Prospective Teachers.	What can each of the stakeholders contribute to reaching the long term goals? What are achievements, gaps, etc.? How would the structures and management and perceptions need to change to provide authentic, empowering PD for teachers? How much does society have to invest in improving STEM education? What needs to be provided in addition to money?			Much improved ability of K-6 teachers to teach science Mechanism of coping with ESL students so that they can read at 3rd grade – and so learn STEM subjects Engineering and technology taught to pre-service science and math teachers Fully integrated system of teacher ed. and PD that is redirected toward career-long development of teaching as a profession vs. separate pre-service education and PD. View the process as a continuum and a process of empowerment. Development of partnerships between K-12 districts and higher education. Better integration of content and pedagogy within higher ed.

Others with money and authority. Teacher Unions				Reinvigoration of accountability systems for oversight of teacher continuing education. Less top-down direction for credentialing and PD. Support of PD by district leadership. Make time available for authentic, ongoing professional development.

Systems Issues

Audience(s)	Outputs/Activities (Beyond)	Measurable Short-Term Outcomes	Mid-Term Outcomes (1-6 Months)	Long-Term Outcomes (Desired State)
	Actively engage parents into system improvements and introducing their children to opportunities in STEM. Use existing research, decide how to address problems, e.g., working with teacher unions, provide incentives to encourage best teachers to teach where most needed. Have students go to internships, jobs, so they			Have a simple system that puts teachers at the focal point of support Have simplified accountability system All students will be STEM-capable Local coalitions (apply "think globally, implement locally") Create frameworks to support and foster local success of coalitions,

	can associate with other good students. Examine scale and sustainability of education policy in promoting successful STEM education. How can there be enough flexibility to allow local and regional empowerment?			business, education, and philanthropy to create a community of regional stakeholders (e.g., Santa Ana) Focus on seven areas of CA where student achievement is especially low. Lift constraints on teachers, especially in these 7 districts, so they can be creative. Use metrics to judge and guide local experimentation Help districts that are especially needy without harming progress of successful districts – unintended consequences. Use A-G curriculum to do reverse design to pre-K, e.g., to address English language literacy.

Appendix 4

Summary Statements and Annotated Recommendations from Selected Academies Reports

Jay B. Labov and Greg Pearson

1. Taking Science to School: Learning and Teaching Science in Grades K-8 (2007)

General Description

What is science for a child? How do children learn about science and how to do science? Drawing on a vast array of evidence from neuroscience to classroom observation, *Taking Science to School* provides a comprehensive picture of what we know about teaching and learning science from kindergarten through eighth grade. This book provides a basic foundation for guiding science teaching and supporting students in their learning developed around three fundamental questions:

1. How is science learned, and are there critical stages in children's development of scientific concepts?

2. How should science be taught in K-8 classrooms?

3. What research is needed to increase understanding about how students learn science?

This book also offers recommendations on professional development. How science is taught ultimately depends on the teachers. Extensive rethinking of how teachers are prepared before they begin teaching and as they continue teaching—and as science changes—is critical to improving K-8 science education

This book offers a new framework for what it means to be proficient in science. This framework rests on a view of science as both a body of knowledge and an evidence-based, model-building enterprise that continually extends, refines, and revises knowledge. This framework moves beyond a focus on the dichotomy between either content knowledge or process skills because content and process are inextricably linked in science. In this framework, students who are proficient in science:

1. know, use, and interpret scientific explanations of the natural world;
2. generate and evaluate scientific evidence and explanations;
3. understand the nature and development of scientific knowledge; and
4. participate productively in scientific practices and discourse.

Relevance to the California STEM Innovation Network

This book is directly relevant to researchers and practitioners alike. A separate, more practitioner-oriented, volume *Ready, Set Science!* has been developed based on its content and is reviewed separately. The book is important because it makes clear that effective science education requires a complex interplay between the content knowledge, and investigation, reflection and discourse skills. Development of these skills is influenced by maturation, experience, prior instruction and opportunities to learn as well as gender, ethnicity, socioeconomic status, and cultural experiences. Research makes clear that many children arrive at school already able to understand concepts and think at a level that many educators had previously thought to be impossible. Younger students are capable of engaging with concepts and interacting with each other in ways that allow them to develop all four strands of scientific capability. The book calls on the education community to rethink what constitutes effective science education for all children based on the growing body of knowledge in human learning generally and early childhood learning and education more specifically.

Recommendations (Key Recommendations Highlighted)[1]

1: Developers of standards, curriculum, and assessment should revise their frameworks to reflect new models of children's thinking and take better advantage of children's capabilities.

2: The next generation of standards and curricula at both the national and state levels should be structured to identify a few core ideas in a discipline and elaborate how those ideas can be cumulatively developed over grades K-8.

3: Developers of curricula and standards should present science as a process of building theories and models using evidence, checking them for internal consistency and coherence, and testing them empirically. Discussions of scientific methodology should be introduced in the context of pursuing specific questions and issues rather than as templates or invariant recipes.

4: Science instruction should provide opportunities for students to engage in all four strands of science proficiency. If these four strands are realized, children will be able to:

1. know, use, and interpret scientific explanations of the natural world;
2. generate and evaluate scientific evidence and explanations;
3. understand the nature and development of scientific knowledge; and
4. participate productively in scientific practices and discourse.

[1] Recommendations with direct relevance to the California STEM Education Initiative are highlighted in blue.

5: State and local leaders in science education should provide teachers with models of classroom instruction that provide opportunities for interaction in the classroom, where students carry out investigations and talk and write about their observations of phenomena, their emerging understanding of scientific ideas, and ways to test them.

6: State and local school systems should ensure that all K-8 teachers experience sustained science-specific professional development in preparation and while in service. Professional development should be rooted in the science that teachers teach and should include opportunities to learn about science, about current research on how children learn science, and about how to teach science.

7: University-based science courses for teacher candidates and teachers' ongoing opportunities to learn science in service should mirror the opportunities they will need to provide for their students, that is, incorporating practices in the four strands that constitute science proficiency and giving sustained attention to the core ideas in the discipline. The topics of study should be aligned with central topics in the K-8 curriculum.

8: Federal agencies that support professional development should require that the programs they fund incorporate models of instruction that combine the four strands of science proficiency, focus on core ideas in science, and enhance teachers' science content knowledge, knowledge of how students learn science, and knowledge of how to teach science.

2. *Ready, Set, Science!: Putting Research to Work in K-8 Science Classrooms* (2007)

General Description

What types of instructional experiences help K-8 students learn science with understanding? What do science educators teachers, teacher leaders, science specialists, professional development staff, curriculum designers, school administrators need to know to create and support such experiences?

Directed toward education practitioners and filled with classroom case studies that bring to life research findings and help readers to replicate success, *Ready, Set, Science!* provides an overview of the groundbreaking and comprehensive synthesis of research into teaching and learning science in kindergarten through eighth grade that is detailed in *Taking Science to School: Learning and Teaching Science in Grades K-8*. This practitioner-oriented volume summarizes a rich body of findings from the learning sciences and presents detailed cases of science educators at work to make the implications of research clear, accessible, and stimulating for a broad range of science educators. It richly illustrates the four strands of learning that are featured in *Taking Science to School,* i.e. that children will be able to:

1. know, use, and interpret scientific explanations of the natural world;
2. generate and evaluate scientific evidence and explanations;
3. understand the nature and development of scientific knowledge; and
4. participate productively in scientific practices and discourse.

The examples presented are based on real classroom experiences that illustrate the complexities with which teachers grapple every day. They show how expert teachers work to select and design rigorous and engaging instructional tasks, manage classrooms, orchestrate productive discussions with culturally and linguistically diverse groups of students, and help students make their thinking visible using a variety of representational tools.

<u>Relevance to the California STEM Innovation Network</u>

As summarized on page 3 of this book, there are many reasons that science must be taught and learned in ways that encourage younger children to become interested in this subject area:

1. Science is an enterprise that can be harnessed to improve quality of life on a global scale.
2. Science may provide a foundation for the development of language, logic, and problem-solving skills in the classroom.
3. A democracy demands that its citizens make personal, community-based, and national decisions that involve scientific information.
4. For some students, science will become a lifelong vocation or avocation.

   New research points toward a kind of science education that differs substantially from what occurs in most science classrooms today. This new vision of science education embraces different ways of thinking about science, different ways of thinking about students, and different ways of thinking about science education.

Given that the California STEM Education Network is attempting to embrace all of these goals and to think much more deeply about the role of science education in furthering the development of California's students and of California itself, and the interconnections between science and other subject domains, this book offers those who are tasked with implementing this vision with the background and resources they will need to do so effectively.

Key Themes

Because this is a practitioner volume that is a derivative of *Taking Science to School*, it does not include specific findings, conclusions or recommendations. That information can be found in the more technical *Taking Science to School*. Instead this volume contains the following themes organized as chapters and appendices; all sections of the book are directly relevant to the California STEM Education initiative.

1. A New Vision of Science in Education
2. Four Strands of Science Learning
3. Foundational Knowledge and Conceptual Change
4. Organizing Science Education Around Core Concepts
5. Making Thinking Visible: Talk and Argument
6. Making Thinking Visible: Modeling and Representation
7. Learning from Science Investigations
8. A System That Supports Science Learning

Notes
Appendix A - Questions for Practitioners
Appendix B - Assessment Items Based on a Learning Progression for Atomic-Molecular Theory
Appendix C - Academically Productive Talk
Appendix D - Biographical Sketches of Oversight Group and Coauthors

3. *America's Lab Report: Investigations in High School Science* (2005)

General Description

> Since the late 19th century, high school students in the United States have carried out laboratory investigations as part of their science classes. Educators and policy makers have periodically debated the value of laboratories in helping students understand science, but little research has been done to inform those debates or to guide the design of laboratory education.
>
> Executive Summary, p. 1

Laboratory experiences have been a part of most U.S. high science curricula for decades, but rarely have they have been carefully examined for their role in enhancing teaching and learning of science. What do laboratory experiences actually contribute to science learning? What could they contribute if they were to be structured differently? What is the current status of labs in our nation s high schools as a context for learning science, and especially for the majority of students who are not enrolled in advance science courses?

This book looks at a range of questions about how laboratory experiences fit into U.S. high schools. The current research literature suggests that high schools science laboratories are utilized for a variety of objectives:

- enhancing mastery of subject matter;
- developing scientific reasoning;
- understanding the complexity and ambiguity of empirical work;
- developing practical skills;
- understanding the nature of science;
- cultivating interest in science and interest in learning science; and
- developing teamwork abilities.

Given all of these roles for science laboratories, what constitutes effective laboratory teaching? What does research tell us about learning that is occurring now in high school science labs? How should student learning in laboratory experiences be assessed? Do all students have access to laboratory experiences? What changes need to be made to improve laboratory experiences for high school students? How can the organizational structure of schools contribute to more effective teaching and learning in science laboratories?

With increased attention to student outcomes and accountability in the U.S. education system, no part of the high school curriculum should escape scrutiny. This book investigated factors that influence a high school laboratory experience, looking closely at what currently takes place and what the goals of those experiences are and should be. Science educators, school administrators, policy makers, and parents can use this book to gain a better understanding of the need for laboratory experiences to be an integral part of the science curriculum and how that can be accomplished.

Relevance to the California STEM Innovation Network:

An overarching consensus of the NRC reports that have been summarized for this meeting and numerous other studies is that while no one method of teaching and learning is effective for all students, large numbers of students learn and understand more deeply when they have the opportunity to actively engage with STEM subjects. Laboratories are one way that educators have attempted to provide this engagement for students, especially in high school. But as this report and others have concluded (e.g., see findings about Advanced Placement and International Baccalaureate laboratory experiences in the NRC report *Learning and Understanding: Improving Advanced Study of Mathematics and Science in U.S. High Schools* – see separate overview for this report), laboratory experiences too often emphasize rote learning and memorization or "cookbook" exercises with "discovery" of results that are already well known. When the outcomes of laboratory exercises are known and anticipated in advance, then anomalous results may lead to students thinking that they have failed rather than to asking the next set of questions to explore the anomaly more deeply.

Thus, a major challenge for the California STEM Education Network will be to examine how laboratories can become more integral to and integrated with broader learning goals for a given course or program. In addition, if the STEM Education Network is to meaningfully interconnect the disciplines covered by STEM, how can those interconnections become clearer to students and instructors through the laboratory experience?

Finally, the California STEM Education Network envisioned here is likely to forge deeper connections not only among disciplines but across grade levels. While this report focused on the high school laboratory experience in science, it has important implications for how students engage with STEM in the elementary and middle grades. It also provides insights for the postsecondary community in thinking about the roles of laboratories in 2- and 4-year college and university settings, and especially in introductory courses. It is in these courses where many future teachers in Grades K-8 and others who do not pursue careers in science (but may have important roles to play in supporting and funding science education) may encounter their only postsecondary laboratory experiences.

Conclusions and Questions (Key Conclusions and Questions Highlighted)

Unlike many NRC reports, the authoring committee for *America's Lab Report* decided that it could not issue recommendations because it found that the state of the research literature on this topic is not yet robust enough. Instead, the committee proposed the following set conclusions and questions that could serve both as the basis of discussion among school leaders and as a catalyst for helping set the directions for future research in this realm:

Conclusions

1: Researchers and educators do not agree on how to define high school science laboratories or on their purposes, hampering the accumulation of evidence that might guide improvements in laboratory education. Gaps in the research and in capturing the knowledge of expert science teachers make it difficult to reach precise conclusions on the best approaches to laboratory teaching and learning

2: Four principles of instructional design can help laboratory experiences achieve their intended learning goals if: (1) they are designed with clear learning outcomes in mind, (2) they are thoughtfully sequenced into the flow of classroom science instruction, (3) they are designed to integrate learning of science content with learning about the processes of science, and (4) they incorporate ongoing student reflection and discussion.

3: The quality of current laboratory experiences is poor for most students.

4: Improving high school science teachers' capacity to lead laboratory experiences effectively is critical to advancing the educational goals of these experiences. This would require major changes in undergraduate science education, including providing a range of effective laboratory experiences for future teachers and developing more comprehensive systems of support for teachers.

5: The organization and structure of most high schools impedes teachers' and administrators' ongoing learning about science instruction and ability to implement quality laboratory experiences.

6: State science standards that are interpreted as encouraging the teaching of extensive lists of science topics in a given grade may discourage teachers from spending the time needed for effective laboratory learning.

7: Current large-scale assessments are not designed to accurately measure student attainment of the goals of laboratory experiences. Developing and implementing improved assessments to encourage effective laboratory teaching would require large investments of funds

Questions

1. *Assessment of student learning in laboratory experiences*—What are the specific learning outcomes of laboratory experiences and what are the best methods for measuring these outcomes, both in the classroom and in large-scale assessments?

2. *Effective teaching and learning in laboratory experiences*—What forms of laboratory experiences are most effective for advancing the desired learning outcomes of laboratory experiences? What kinds of curriculum can support teachers in students in progress toward these learning outcomes?

3. *Diverse populations of learners*—What are the teaching and learning processes by which laboratory experiences contribute to particular learning outcomes for diverse learners and different populations of students?

4. *School organization for effective laboratory teaching*—What organizational arrangements (state and district policy, funding priorities and resource allocation, professional development, textbooks, emerging technologies, and school and district leadership) support high-quality laboratory experiences most efficiently and effectively? What are the most effective ways to bring those

organizational arrangements to scale?

5. *Continuing learning about laboratory experiences*—How can teachers and administrators learn to design and implement effective instructional sequences that integrate laboratory experiences for diverse students? What types of professional development are most effective to help administrators and teachers achieve this goal? How should laboratory professional development be sequenced within a teacher's career (from pre-service to expert teacher)?

4. Inquiry and the National Science Education Standards: A Guide for Teaching and Learning **(2000)**

General Description

"Inquiry" refers to the diverse ways in which scientists study the natural world and in which students grasp science knowledge and the methods by which that knowledge is produced. *Inquiry and the National Science Education Standards* offers a practical guide to teaching inquiry and teaching through inquiry, as recommended by the *National Science Education Standards*. This resource can assist educators who must help school boards, parents, and teachers understand the nature and process of inquiry in science education and the kinds of resources that are required to sustain and nurture it.

This book explains and illustrates how inquiry helps students learn science content, master how to do science, and understand the nature of science. It explores the dimensions of teaching and learning science as inquiry for K-12 students across a range of science topics. Detailed examples help clarify when teachers should use the inquiry-based approach and how much structure, guidance, and coaching they should provide for students.

The book dispels myths that may have discouraged some educators from the inquiry-based approach and elucidates the interplay between concepts, processes, and science as it is experienced in the classroom. *Inquiry and the National Science Education Standards* offers a number of classroom vignettes that explore different kinds of inquiries for elementary, middle, and high school. A section of Frequently Asked Questions addresses teachers' common concerns such as obtaining appropriate supplies for this kind of pedagogy.

In addition, the book discusses why assessment is important, looks at existing schemes and formats, and addresses how to involve students in assessing their own learning. This book also discusses administrative assistance, communication with parents, appropriate teacher evaluation, and other avenues to promoting and supporting this new teaching and learning paradigm.

Relevance to the California STEM Innovation Network

If California is to adopt a statewide STEM education network in which these disciplines are truly interconnected, research indicates that multiple approaches to teaching must be employed to truly engage students from diverse backgrounds and levels of interest in these subject areas. While the evidence suggests that a variety of inquiry-based approaches to teaching and learning can indeed reach and engage students who otherwise tune STEM subjects, major problems remain with its implementation, including:

- The education community has not settled on common definitions for what constitutes inquiry-based approaches to teaching and learning.
- Many teachers have not experienced inquiry-based approaches to science when they themselves were students and thus may not know how to begin to do so. This problem may increase in the higher grades of K-12 education and especially at the postsecondary level, where few faculty have received professional development in its use and implementation.
- To school officials and parents who have not experienced this approach, inquiry-based science may give the impression that little learning is actually occurring. It may be viewed as unstructured and even chaotic to the casual observer. Thus, there are concerns about what students are and are not learning.
- Because of the traditional dichotomy that has existed in the minds of many science educators between content and. process in science education, an emphasis on inquiry is viewed by some as a diminution of content at a time when high stakes tests seem to emphasize mastery of content.
- It is much more difficult and expensive to assess learning through inquiry-based approaches than more traditional routes of teaching.

Thus, this book, written primarily for the practitioner and teacher educator audiences, can provide very helpful insights about ways to implement inquiry-based teaching and learning throughout the California STEM Education Network.

Report Table of Contents

Like *Ready, Set Science* is a derivative of *Taking Science to School*, this book is a derivative of and supplement to the National Research Council's *National Science Education Standards*. Thus, there are no specific policy recommendations in this book beyond those in the *National Science Education Standards*. To give participants a better sense of the scope of *Inquiry and the*

National Science Education Standards, the Table of Contents is reproduced here. Each chapter and appendix is directly relevant to the California STEM Education initiative.

5. *Learning and Understanding: Improving Advanced Study of Mathematics and Science in U.S. High Schools* (2002)

General Description

Learning and Understanding is the result of a study that was requested by the National Science Foundation and the U.S. Department of Education after the publication of results for 12th graders on the Third International Math and Science Study (TIMSS), which showed that U.S. seniors in high school fared poorly in science and mathematics when compared to their counterparts in many other nations. Further, U.S. students who reported that they had taken calculus or advanced physics also scored below similar students in other parts of the world.

This book took a fresh look at programs for advanced studies for high school students in the U.S., with a particular focus on the Advanced Placement (AP) and the International Baccalaureate (IB) programs in biology, chemistry, calculus and physics. In addition to the primary report, there are also separate reports from expert panels in these subject areas. Equally important, *Learning and Understanding* looked at how advanced studies can be significantly improved in general. It also examined in detail three of the core issues surrounding these programs:

- They can have a profound impact on other components of the education system (in the middle and secondary grades as well as in postsecondary education);

- Participation in the programs has become key to admission at selective institutions of higher education with a number of resulting, sometimes unintended consequences; and
- The current AP and IB programs are very different from how they were first envisioned. Because these programs have become perceived as gateways to college admission and placement, the number of students who enroll and take the standardized tests have increased exponentially. This growth has brought into focus issues surrounding access, opportunity, and success for all of the students who enroll and maintaining the perceived quality of these programs.

By looking at what could enhance the quality of high school advanced study programs as well as what precedes and comes after these programs, this report provides teachers, parents, curriculum developers, administrators, college science and mathematics faculty, and the educational research community with a detailed assessment that can be used to guide change within advanced study programs.

As a result of the publication of this book, the National Science Foundation has given the College Board (the parent organization for AP) a large grant to substantially revise AP science courses.

Relevance to the California STEM Innovation Network

The AP and IB programs are microcosms for both the potential and the problems associated with education programs that permeate a variety of disciplines and grade levels. The report emphasizes the critical interdependence of the four foundations of successful education programs: instruction, curriculum, assessment, and professional development and provides evidence about the strengths and limitations of each of these components in the AP and IB science and mathematics programs. Access and equity are issues that the book addresses forthrightly in a variety of contexts.

The authoring committee also approached its task by looking at the emerging evidence about how people learn and the science of assessment. It then used that evidence as a lens to examine the various aspects of the AP and IB programs. This approach provided much greater clarity about the strengths and limitations of each program.

Changes to AP science courses that are now being formulated as a result of this book could have enormous implications for the work of the California STEM Education Network. If the revisions follow the recommendations in *Learning and Understanding*, there will likely be a much greater emphasis on depth over breadth and on authentic assessments of learning. These changes could ultimately affect instruction in middle school and the lower grades in high school as well as what colleges and universities consider for acceptance and placement of students. The College Board already recognizes the implications for providing professional development to both AP and pre-AP teachers of science.

Recommendations (Key Recommendations Highlighted)

1: The Primary Goal of Advanced Study. The primary goal of advanced study in any discipline should be for students to achieve a deep conceptual understanding of the discipline's content and unifying concepts. Well-designed programs help students develop skills of inquiry, analysis, and problem solving so that they become superior learners. Accelerating students' exposure to college-level material, while appropriate as a component of some advanced study programs, is not by itself a sufficient goal.

2: Access and Equity. Schools and school districts must find ways to integrate advanced study with the rest of their program by means of a coherent plan extending from middle school through the last years of secondary school. Course options in grades 6–10 for which there are reduced academic expectations (i.e., those that leave students unprepared for further study in a discipline) should be eliminated from the curriculum. An exception might be made for courses designed to meet the needs of special education students.

3: Learning Principles. Programs of advanced study in science and mathematics must be made consistent with findings from recent research on how people learn. These findings include the role of students' prior knowledge and misconceptions in building a conceptual structure, the importance of student motivation and self-monitoring of learning (metacognition), and the substantial differences among learners.

4: Curriculum. Curricula for advanced study should emphasize depth of understanding over exhaustive coverage of content. They should focus on central organizing concepts and principles and the empirical information on which those concepts and principles are based. Because science and technology progress rapidly, frequent review of course content is essential.

5: Instruction. Instruction in advanced courses should engage students in inquiry by providing opportunities to experiment, analyze information critically, make conjectures and argue about their validity, and solve problems both individually and in groups. Instruction should recognize and take advantage of differences among learners by employing multiple representations of ideas and posing a variety of tasks.

6: Assessment, Teachers of advanced study courses should employ frequent formative assessment of student learning to guide instruction and monitor learning. External, end-of-course examinations have a different purpose: they certify mastery. Both types of assessment should include content and process dimensions of performance and evaluate depth of understanding, the primary goal of advanced study (see Recommendation 1).

7: Qualified Teachers and Professional Development. Schools and districts offering advanced study must provide frequent opportunities for continuing professional development so teachers can improve their knowledge of both content and pedagogy. National programs for advanced study should clearly specify and monitor the qualifications expected of teachers. Professional development activities must be adequately funded and available to all teachers throughout their teaching careers.

8: Alternative Programs. Approaches to advanced study other than AP and IB should be developed and evaluated. Such alternatives can help increase access to advanced study for those not presently served and result in the emergence of novel and effective strategies.

9: The Secondary–College Interface.
9(a): When awarding credit and advanced placement for courses beyond the introductory college level, institutions should base their decisions on an assessment of each student's understanding and capabilities, using multiple sources of information. National examination scores alone are generally insufficient for these purposes.

9(b): College and university scientists and mathematicians should modify their introductory courses along lines similar to those proposed in this report for high school advanced study. Departments should carefully advise undergraduates about the benefits and costs of bypassing introductory courses.

10: Changes in the AP and IB Programs. The following substantial changes in the AP and IB programs are recommended:

10(a): The College Board should abandon its practice of designing AP courses in most disciplines primarily to replicate typical introductory college courses.

10(b): The College Board and the IBO should evaluate their assessments to ensure that they measure the conceptual understanding and complex reasoning that should be the primary goal of advanced study. Programs of validity research should be an integral part of assessment design.

10(c): Both the College Board and the IBO should take more responsibility for ensuring the use of appropriate instructional approaches. Specifying the knowledge and skills that are important for beginning teachers and providing models for teacher development are likely to advance teacher effectiveness.

10(d): The College Board should exercise greater quality control over the AP trademark by articulating standards for what can be labeled an AP course, desirable student preparation for each course, strategies for ensuring equity and access, and expectations for universal participation in the AP examinations by course participants. When necessary, the College Board should commission experts to assist with these tasks.3 These standards should apply whether AP is offered in schools or electronically.

10(e): The College Board and the IBO should provide assistance to schools in their efforts to offer high-quality advanced courses. To this end, the College Board should provide more detailed curriculum, information about best practices for instruction and classroom assessment, and strategies for enhancing professional development opportunities.

10(f): The College Board and the IBO should offer more guidance to educators, policymakers, and the general public concerning proper uses of their examination scores for admission, placement, and teacher evaluation. They should also actively discourage misuse of these scores.
10(g): The College Board and the IBO should develop programs of research on the implementation and effectiveness of their programs.

6. *Adding It Up: Helping Children Learn Mathematics* (2001)

General Description
The first two paragraphs of the executive summary for *Adding it Up* provides a clear and compelling rationale of new ways of thinking about and learning mathematics for younger children:

> Mathematics is one of humanity's great achievements. By enhancing the capabilities of the human mind, mathematics has facilitated the development of science, technology, engineering, business, and government. Mathematics is also an intellectual achievement of great sophistication and beauty that epitomizes the power of deductive reasoning. For people to participate fully in society, they must know basic mathematics. Citizens who cannot reason mathematically are cut off from whole realms of human endeavor. Innumeracy deprives them not only of opportunity but also of competence in everyday tasks.

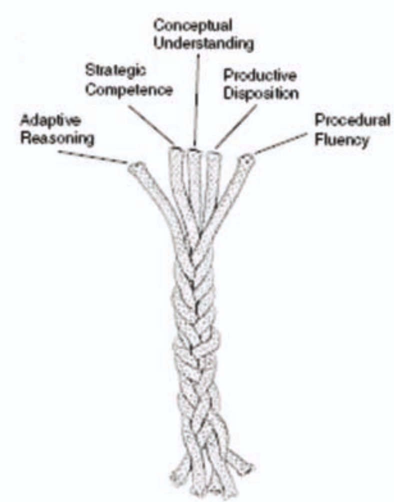
The mathematics students need to learn today is not the same mathematics that their parents and grandparents needed to learn. When today's students become adults, they will face new demands for mathematical proficiency that school mathematics should attempt to anticipate. Moreover, mathematics is a realm no longer restricted to a select few. *All young Americans must learn to think mathematically, and they must think mathematically to learn.*

p.1

Adding It Up explores how students in pre-K through 8th grade learn mathematics and recommends how teaching, curricula, and teacher education should change to improve mathematics learning during these critical years.

The committee identified five interdependent components of mathematical proficiency and described how students develop this proficiency, all of which must be woven together and interconnected (see the braid metaphor). They include:

- **Conceptual understanding**—comprehension of mathematical concepts, operations, and relations
- **Procedural fluency**—skill in carrying out procedures flexibly, accurately, efficiently, and appropriately
- **Strategic competence**—ability to formulate, represent, and solve mathematical problems
- **Adaptive reasoning**—capacity for logical thought, reflection, explanation, and justification
- **Productive disposition**—habitual inclination to see mathematics as sensible, useful, and worthwhile, coupled with a belief in diligence and one's own efficacy.



Intertwined Strands of Proficiency

With examples and illustrations, the book presents a portrait of mathematics learning, including:

Research findings on what children know about numbers by the time they arrive in pre-K and the implications for mathematics instruction.

Details on the processes by which students acquire mathematical proficiency with whole numbers, rational numbers, and integers, as well as beginning algebra, geometry, measurement, and probability and statistics.

The committee also discussed what is known from research about teaching for mathematics proficiency, focusing on the interactions between teachers and students around educational materials and how teachers develop proficiency in teaching mathematics.

Relevance to the California STEM Innovation Network

Adding It Up emphasizes the coherence and interconnectedness of mathematical concepts for children and how they might be taught most effectively. Because the concept of number is used so broadly for mathematics education in the early grades, this book also focuses on that concept but shows how students can be provided with rich experiences in mathematics that build on this basis concept that goes well beyond the operational aspects of arithmetic that often are the primary components of mathematics education in the elementary and early middle grades. For example, students can understand that it is possible to communicate about numbers through graphical representations and systems of notation. Students can appreciate and understand that numbers and the operations that are typically emphasized in elementary school mathematics are organized as number systems, such as the whole numbers, and there are regularities of each system that can be discerned. Numerical computations require algorithms—step-by-step procedures for performing the computations, that can be more or less useful to students depending on how it works and how well it is understood. And finally, the domain of number both supports and is supported by other branches of mathematics, including algebra, measure, space, data, and chance.

Adding It Up also was the first of a series of seminal reports from the National Academies that used knowledge and evidence from the growing research base on human learning and cognition (as described in the NRC report *How People Learn: Brain Mind, Experience, and School* – see separate review for an overview of this report) as the basis for its findings, conclusions, and recommendations. Others include *Taking Science to School*; *Ready, Set, Science!*; and *Learning and Understanding: Improving Advanced Study of Mathematics and Science in U.S. High Schools* (see separate summaries of these books). The general agreement of the recommendations in this and those subsequent reports strongly suggest that there are fundamental approaches to improving education that are supported by a growing body of research. While learning in specific disciplines may require somewhat different approaches (and there is now a growing area called discipline based education research), there are also fundamental principles for improving aspects of education such as teacher professional development that appear to transcend disciplines.

Recommendations (Key Recommendations Highlighted)
The overriding premise of *Adding It Up* is that throughout the grades from pre-K through 8 *all* students can and should be mathematically proficient.

1. The integrated and balanced development of all five strands of mathematical proficiency (conceptual understanding, procedural fluency, strategic competence, adaptive reasoning, and productive disposition) should guide the teaching and learning of school mathematics. Instruction should not be based on extreme positions that students learn, on one hand, solely by internalizing what a teacher or book says or, on the other hand, solely by inventing mathematics on their own.

2. Teachers' professional development should be high quality, sustained, and systematically designed and deployed to help all students develop mathematical proficiency. Schools should support, as a central part of teachers' work, engagement in sustained efforts to improve their mathematics instruction. This support requires the provision of time and resources.

3. The coordination of curriculum, instructional materials, assessment, instruction, professional development, and school organization around the development of mathematical proficiency should drive school improvement efforts.

4. Efforts to improve students' mathematics learning should be informed by scientific evidence, and their effectiveness should be evaluated systematically. Such efforts should be coordinated, continual, and cumulative.

5. Additional research should be undertaken on the nature, development, and assessment of mathematical proficiency.

7. Tech Tally: Approaches to Assessing Technological Literacy (2006)

General Description
In a broad sense, technology is any modification of the natural world made to fulfill human needs or desires. Although people tend to focus on the most recent technological inventions, technology includes a myriad of devices and systems that profoundly affect everyone in modern society. Technology is pervasive; an informed citizenry needs to know what technology is, how it works, how it is created, how it shapes our society, and how society influences technological development. This understanding depends in large part on an individual level of technological literacy.

Unfortunately, no one really knows the level of technological literacy among people in this country—or for that matter, in other countries. Although many concerns have been raised that Americans are not as technologically literate as they should be, these statements are based on general impressions with little hard data to back them up. Therefore, the starting point for improving technological literacy must be to determine the current level of technological understanding and capability, which areas require improvement first, and how technological literacy varies among different populations—children and adults, for instance.

Tech Tally: Approaches to Assessing Technological Literacy uses the metaphor of design to talk about how an assessment of technological literacy might be constructed, includes a primer on educational assessment issues for non experts, and reviews several dozen assessment instruments that directly or indirectly measure some aspect of technological literacy for students, teachers, or out-of-school adults. The book also:

- examines opportunities and obstacles to developing scientifically valid and broadly applicable assessment instruments for technological literacy in the three target populations;
- includes several sample case studies, one at the state level, of how assessment in this domain might be done;
- proposes a assessment matrix that suggests how content areas and cognitive domains of technology might be accounted for in an assessment of technological literacy; and
- explores computer-based assessment methods that might be particularly suited to assessment of technological literacy.

<u>Relevance to the California STEM Network</u>

If technology and technological literacy are to be meaningful components of the California STEM effort, attention will need to be paid to assessment issues. As *Tech Tally* makes clear, however, assessment in this domain poses significant challenges, and to date there are no ready-made assessment instruments available. One chapter of the report and a related recommendation suggest the potential value of computer-based assessment methods. Given the concentration of academic and industrial activity in California related to computer technology and software, and given the stated aim of the STEM planning effort to be innovative, research on computer-based assessment for STEM achievement could be a valuable component of the overall planning. Finally, in response to *Tech Tally*, the National Assessment Governing Board (the overseers of the National Assessment of Education Progress) has begun a feasibility study of the assessment of technological literacy. The pilot will be fielded in 2012 and, depending on the result, NAGB may add an assessment of technological literacy to its portfolio of national and state tests.   This could have implications for California.

Recommendations (Key Recommendations Highlighted)

Recommendation 1. The National Assessment Governing Board, which oversees the National Assessment of Educational Progress (NAEP), should authorize special studies of the assessment of technological literacy as part of the 2009 NAEP mathematics and science assessments and the 2010 NAEP U.S. history assessment. The studies should explore the content connections between technology, science, mathematics, and U.S. history to determine the feasibility of adding technology-related items to future NAEP assessments in these subjects.

Recommendation 2. The U.S. Department of Education and National Science Foundation should send a recommendation to the International Association for the Evaluation of Educational Achievement and the Trends in Mathematics and Science Study (TIMSS) governing board encouraging them to include technological literacy items in TIMSS assessments as a context for assessments of science and mathematics. The U.S. Department of Education and National Science Foundation should send a recommendation to the Organization for Economic Cooperation and Development and the governing board for the Programme for International Student Assessment (PISA) supporting the inclusion of technological literacy items as a cross-curricular competency.

Recommendation 3. The National Science Foundation should fund a number of sample-based studies of technological literacy in K–12 students. The studies should have different assessment designs and should assess different population subsets, based on geography, population density, socioeconomic status, and other factors. Decisions about the content of test items, the distribution of items among the three dimensions of technological literacy, and performance levels should be based on a detailed assessment framework.

Recommendation 4. When states determine whether teachers are "highly qualified" under the provisions of the No Child Left Behind Act (NCLB), they should ensure—to the extent possible—that assessments used for this purpose include items that measure technological literacy. This is especially important for science, mathematics, history, and social studies teachers, but it should also be considered for teachers of other subjects. In the review of state plans for compliance with NCLB, the U.S. Department of Education should consider the extent to which states have fulfilled this objective.

Recommendation 5. The National Science Foundation and U.S. Department of Education should fund the development and pilot testing of sample-based assessments of technological literacy among pre-service and in-service teachers of science, technology, English, social studies, and mathematics. These assessments should be informed by carefully developed assessment frameworks. The results should be disseminated to schools of education, curriculum developers, state boards of education, and other groups involved in teacher preparation and teacher quality.

Recommendation 6. The International Technology Education Association should continue to conduct a poll on technological literacy every several years, adding items that address the three dimensions of technological literacy, in order to build a database that reflects changes over time in adult knowledge of and attitudes toward technology. In addition, the U.S. Department of Education, working with its international partners, should expand the problem-solving component of the Adult Literacy and Lifeskills Survey to include items relevant to the assessment of technological literacy. These items should be designed to gauge participants' general problem-solving capabilities in the context of familiar, relevant situations. Agencies that could benefit by knowing more about adult understanding of technology, such as the National Science Foundation, U.S. Department of Education, U.S. Department of Defense, and National Institutes of Health, should consider funding projects to develop and conduct studies of technological literacy. Finally, opportunities for integrating relevant knowledge and attitude measures into existing studies, such as the General Social Survey, the National Household Education Survey, and Surveys of Consumers, should be pursued.

Recommendation 7. The National Science Foundation or U.S. Department of Education should fund a synthesis study focused on how children learn technological concepts. The study should draw on the findings of multidisciplinary research in mathematics learning, spatial reasoning, design thinking, and problem solving. The study should provide guidance on pedagogical, assessment, teacher education, and curricular issues of interest to educators at all levels, teacher-education providers and licensing bodies, education researchers, and federal and state education agencies.

Recommendation 8. The National Science Foundation (NSF) and U.S. Department of Education should support a research-capacity-building initiative related to the assessment of technological literacy. The initiative should focus on supporting graduate and postgraduate research related to how students and teachers learn technology and engineering concepts. Funding should be directed to academic centers of excellence in education research—including, but not limited to, NSF-funded centers for learning and teaching—whose missions and capabilities are aligned with the goal of this recommendation. To the committee's knowledge, no rigorous efforts have been made to ascertain how adults acquire and use technological knowledge. School and work experience could affect their performance, but adults who are no longer in the formal education system are also influenced by a variety of free-choice learning opportunities, including popular culture, the news media, and museums and science centers.

Recommendation 9. The National Science Foundation should take the lead in organizing an interagency federal research initiative to investigate technological learning in adults. Because adult learning is continuous, longitudinal studies should be encouraged. Informal learning institutions that engage broad populations, such as museums and science centers, should be considered important venues for research on adult learning, particularly related to technological capability. To ensure that the perspectives of adults from a variety of cultural and socioeconomic backgrounds are included, studies should also involve community colleges, nonprofit community outreach programs, and other programs that engage diverse populations.

Recommendation 10. The National Institute of Standards and Technology, which has a broad mandate to promote technology development and an extensive track record in organizing research conferences, should convene a major national meeting to explore the potential of innovative, computer-based techniques for assessing technological literacy in students, teachers, and out-of-school adults. The conference should be informed by research related to assessments of science inquiry and scientific reasoning and should consider how innovative assessment techniques compare with traditional methods.

Recommendation 11. Assessments of technological literacy in K–12 students, K–12 teachers, and out-of-school adults should be guided by rigorously developed assessment frameworks, as described in this report.

- **For K–12 students,** the National Assessment Governing Board, which has considerable experience in the development of assessment frameworks in other subjects, should commission the development of a framework to guide the development of national and state-level assessments of technological literacy.
- **For K–12 teachers,** the National Science Foundation and U.S. Department of Education, which both have programmatic interests in improving teacher quality, should fund research to develop a framework for an assessment of technological literacy in this population. The research should focus on (1) determining how the technological literacy needs of teachers differ from those of student populations and (2) strategies for implementing teacher assessments in a way that would provide useful information for both teachers and policy makers. The resulting framework would be a prerequisite for assessments of all teachers, including generalists and middle- and high-school subject-matter specialists.

• **For out-of-school adults,** the National Science Foundation and U.S. Department of Education, which both have programmatic activities that address adult literacy, should fund research to develop a framework for the assessment of technological literacy in this population. The research should focus on determining thresholds of technological literacy necessary for adults to make informed, everyday, technology-related decisions.

Recommendation 12. The U.S. Department of Education, state education departments, private educational testing companies, and education-related accreditation organizations should broaden the definition of "technological literacy" to include not only the use of educational technologies (computers) but also the study of technology, as described in the International Technology Education Association *Standards for Technological Literacy* and the National Academy of Engineering and National Research Council report *Technically Speaking*.

8. Technically Speaking: Why All Americans Need to Know More About Technology (2002)

General Description
The United States is riding a whirlwind of technological change. To be sure, there have been periods, such as the late 1800s, when new inventions appeared in society at a comparable rate. But the pace of change today, and its social, economic, and other impacts, are as significant and far reaching as at any other time in history. And it seems that the faster we embrace new technologies, the less we re able to understand them. What is the long-term effect of this galloping technological revolution? In today's world, it is nothing less than a matter of responsible citizenship to grasp the nature and implications of technology.

Technically Speaking provides a blueprint for bringing us all up to speed on the role of technology in our society, including understanding such distinctions as technology versus science and technological literacy versus technical competence. It clearly and decisively explains what it means to be a technologically literate citizen. The book goes on to explore the social, historical, political, and educational contexts of technological literacy.

This readable overview highlights specific issues of concern: the state of technological studies in K-12 schools, the reach of the Internet into our homes and lives, and the crucial role of technology in today's economy and workforce. Three case studies, related to car airbags, genetically modified foods, and the 2001 California energy crisis, illustrate why ordinary citizens need to understand technology to make responsible decisions.

Relevance to the California STEM Innovation Network:

Technically Speaking is relevant to the proposed California STEM network because it clearly explains and makes the case for the "T" in STEM. As the report points out, policy makers, educators, and the public alike tend to think of technology quite narrowly, as either computers and other electronics or as educational technology—a tool for classroom learning. This vision of technology, while not wrong, is quite limited in scope, as *Technically Speaking* makes clear. A broader view of technology, as the human-built world, is consistent with how engineers and scientists see the world and gives technology equal-partner status within the STEM quartet of subjects. The report also defines and presents a conceptual model for "technological literacy," a quality that captures a complex mix of knowledge, capability, and ways of thinking and acting that are very consistent with the vision established by the leadership of the California STEM network.

Recommendations (Key Recommendations Highlighted)

Recommendation 1 Federal and state agencies that help set education policy should encourage the integration of technology content into K-12 standards, curricula, instructional materials, and student assessments in non-technology subject areas.

Recommendation 2 The states should better align their K-12 standards, curriculum frameworks, and student assessment in the sciences, mathematics, history, social studies, civics, the arts, and language arts with national educational standards that stress the connections between these subjects and technology. National Science Foundation (NSF)- and Department of Education (DoEd)-funded instructional materials and informal-education initiatives should also stress these connections.

Recommendation 3 NSF, DoEd, state boards of education, and others involved in K-12 science education should introduce, where appropriate, the word "technology" into the titles and contents of science standards, curricula, and instructional materials.

Recommendation 4 NSF, DoEd, and teacher education accrediting bodies should provide incentives for institutions of higher education to transform the preparation of all teachers to better equip them to teach about technology throughout the curriculum.

Recommendation 5 The National Science Foundation should support the development of one or more assessment tools for monitoring the state of technological literacy among students and the public in the United States.

Recommendation 6 The National Science Foundation and the Department of Education should fund research on how people learn about technology, and the results should be applied in formal and informal education settings.

Recommendation 7 Industry, federal agencies responsible for carrying out infrastructure projects, and science and technology museums should provide more opportunities for the nontechnical public to become involved in discussions about technological developments.

Recommendation 8 Federal and state government agencies with a role in guiding or supporting the nation's scientific and technological enterprise, and private foundations concerned about good governance, should support executive education programs intended to increase the technological literacy of government and industry leaders.

Recommendation 9 U.S. engineering societies should underwrite the costs of establishing government- and media-fellow programs with the goal of creating a cadre of policy experts and journalists with a background in engineering.

Recommendation 10 The National Science Foundation, in collaboration with industry partners, should provide funding for awards for innovative, effective approaches to improving the technological literacy of students or the public at large.

Recommendation 11 The White House should add a Presidential Award for Excellence in Technology Teaching to those that it currently offers for mathematics and science teaching.

9. Educating the Engineer of 2020: Adapting Engineering to the New Century (2005)

General Description

This report is the result of an initiative of the National Academy of Engineering that attempts to prepare for the future of engineering by asking the question, "What will or should engineering education be like today, or in the near future, to prepare the next generation of students for effective engagement in the engineering profession in 2020?"[2] It accepts as a given that, first and foremost, engineering education must produce technically excellent and innovative graduates, but it does not attempt to define a "core" curriculum, recognizing that individual institutions need to design their own. It asks, rather, how to enrich and broaden engineering education so that those technically grounded graduates will be better prepared to work in a constantly changing global economy. It notes the importance of improving the recruitment and retention of students, and making the learning experience more meaningful to them. It discusses the value of considering changes in engineering education in the broader context of enhancing the status of the engineering profession and improving the public understanding of engineering.

Although certain basics of engineering will not change, the explosion of knowledge, the global economy, and the way engineers will work will reflect an ongoing evolution that began to gain momentum a decade ago. The economy in which we will work will be strongly influenced by the global marketplace for engineering services, evidenced by the outsourcing of engineering jobs, a growing need for interdisciplinary and system-based approaches, demands for new paradigms of customization, and an increasingly international talent pool. The steady integration of technology in our public infrastructures and lives will call for more involvement by engineers in the setting of public policy and in participation in the civic arena. The external forces in society, the economy, and the professional environment will all challenge the stability of the engineering workforce and affect our ability to attract the most talented individuals to an engineering career. However, amid all these challenges, exciting opportunities also will exist if the engineering community takes the initiative to prepare for the future.

Relevance to the California STEM Network

Although the focus of the California STEM Network is on grades K-12, there is a good case to be made for having a broader view that encompasses not only elementary and secondary schools, teachers, and students, but also two-year (i.e., community colleges) and four-year higher education institutions. A truly integrated and coordinated "system" of K-16 STEM education at the state level will need to take account of the connections, or articulation, between and among these subparts. It is important for the leadership of the STEM network planning effort to recognize that engineering education is in flux at many institutions. As *Educating the Engineer of 2020* suggests, some of these changes, such as the incorporation of design activities earlier in the curriculum, bring engineering almost down to the high school level. A number of engineering

[2] The report is grounded by the observations, questions, and conclusions presented in an earlier report, *The Engineer of 2020: Visions of Engineering in the New Century* (2004).

schools are reaching out, as never before, into K-12 education, for example through the development of engineering-focused curriculum. Though not addressed in the 2020 report, the opportunity to enhance the technological savvy of newly minted K-12 teachers could be realized through partnerships between schools of education and engineering.

Recommendations (Key Recommendations Highlighted)

1. The baccalaureate degree should be recognized as the "pre-engineering" degree or bachelor of arts in engineering degree, depending on the course content and reflecting the career aspirations of the student.

2. ABET should allow accreditation of engineering programs of the same name at the baccalaureate and graduate levels in the same department to recognize that education through a "professional" master's degree produces an AME, an accredited "master" engineer.

3. Engineering schools should more vigorously exploit the flexibility inherent in the outcomes-based accreditation approach to experiment with novel models for baccalaureate education. ABET should ensure that evaluators look for innovation and experimentation in the curriculum and not just hold institutions to a strict interpretation of the guidelines as they see them.

4. Whatever other creative approaches are taken in the four-year engineering curriculum, the essence of engineering—the iterative process of designing, predicting performance, building, and testing—should be taught from the earliest stages of the curriculum, including the first year.

5. The engineering education establishment, for example, the Engineering Deans Council, should endorse research in engineering education as a valued and rewarded activity for engineering faculty as a means to enhance and personalize the connection to undergraduate students, to understand how they learn, and to appreciate the pedagogical approaches that excite them.

6. Colleges and universities should develop new standards for faculty qualifications, appointments, and expectations, for example, to require experience as a practicing engineer, and should create or adapt development programs to support the professional growth of engineering faculty.

7. As well as delivering content, engineering schools must teach engineering students how to learn, and must play a continuing role along with professional organizations in facilitating lifelong learning, perhaps through offering "executive" technical degrees similar to executive MBAs.

8. Engineering schools should introduce interdisciplinary learning in the undergraduate environment, rather than having it as an exclusive feature of the graduate programs.

9. Engineering educators should explore the development of case studies of engineering successes and failures and the appropriate use of a case-studies approach in undergraduate and graduate curricula.

10. Four-year engineering schools must accept it as their responsibility to work with their local community colleges to ensure effective articulation, as seamless as possible, with their two-year programs.

11. U.S. engineering schools must develop programs to encourage/reward domestic engineering students to aspire to the M.S. and/or Ph.D. degree.

12. Engineering schools should lend their energies to a national effort to improve math, science, and engineering education at the K-12 level.

13. The engineering education establishment should participate in a coordinated national effort to promote public understanding of engineering and technology literacy of the public.

14. NSF should collect and/or fund collection, perhaps through ASEE or the Engineering Workforce Commission, of comprehensive data by engineering department/school on program philosophy and student outcomes such as, but not exclusively, student retention rates by gender and ethnicity, common reasons why students leave, where they go, percent of entering freshman that graduate, time to degree, and information on jobs and admission to graduate school.

10. How People Learn: Brain, Mind, Experience, and School—Expanded Edition (2000)

General Description

> Learning research suggests that there are new ways to introduce students to traditional subjects, such as mathematics, science, history and literature, and that these new approaches make it possible for the majority of individuals to develop a deep understanding of important subject matter.
>
> *How People Learn*, p. 6

> The new science of learning does not deny that facts are important for thinking and problem solving. Research on expertise in areas such as chess, history, science, and mathematics demonstrate that experts' abilities to think and solve problems depend strongly on a rich body of knowledge about subject matter…However, the research also shows clearly that "usable knowledge" is not the same as a mere list of disconnected facts. Experts' knowledge is connected and organized around important concepts (e.g., Newton's second law of motion); it is "conditionalized" to specify the contexts in which it is applicable; it supports understanding and transfer (to other contexts) rather than only the ability to remember.
>
> *How People Learn,* p. 9

How People Learn offers a detailed review, synthesis, and analysis of exciting research about the brain and human learning that provides answers to a number of compelling questions. When do infants begin to learn? How do experts learn and how is this learning different from that of novices? What happens to how people process information when they move from being a novice to an expert in some subject domain? Does expertise in one subject area allow experts to also better understand other subject areas more quickly? What can teachers and schools do—with curricula, classroom settings, and teaching methods—to help children learn most effectively?

New evidence from many branches of science has significantly added to our understanding of what it means to know, from the neural processes that occur during learning to the influence of culture on what people see and absorb. *How People Learn* examines these findings and their implications for what we teach, how we teach it, and how we assess what our children learn. The book uses exemplary teaching to illustrate how approaches based on what we now know result in in-depth learning. This new knowledge calls into question concepts and practices firmly entrenched in our current education system.

Topics in this book include:

- How learning actually changes the physical structure of the brain.
- How existing knowledge affects what people notice and how they learn.
- What the thought processes of experts tell us about how to teach.
- The amazing learning potential of infants.
- The relationship of classroom learning and everyday settings of community and workplace.
- Learning needs and opportunities for teachers.

- A realistic look at the role of technology in education.

Originally released in hardcover in the 1999, *How People Learn* was expanded in 2000 to show how the theories and insights from the original book can translate into actions and practice, thus making a real connection between classroom activities and learning behaviors.

Relevance to the California STEM Innovation Network

As noted in the next section by the highlighting of all *Key Findings* and *Implications*, the rich set of evidence presented, findings, and conclusions that are found *How People Learn* have direct application and important implications for the California STEM Education Network. Indeed, this book resulted in expert committees of the National Academies refocusing much of the subsequent education work that was published after *How People Learn* to use the evidence and thinking from this report as the basis on which to build in other subject areas.

How People Learn will provide a vitally important guide to the kinds of research evidence in human learning and cognition and can serve as a very useful guide to the leaders of the California STEM Education Network in planning this initiative in ways that are steeped in solid research evidence.

Like other Academies reports, a "practitioner volume" (*How Students Learn: History, Mathematics, and Science in the Classroom*) was published in 2005 and is available as a PDF on this CD-ROM.

Recommendations (Key Recommendations Highlighted)

Unlike other NRC studies that include specific recommendations, this committee of experts instead decided to present implications of the research and evidence on human learning for teachers, school, and the larger education system. They offer conclusions that are dispersed throughout the book and too numerous to list in their entirety here. The major set of implications for education is provided below. The book provides much more detail about each of these statements:

Key Findings:

1. Students come to the classroom with preconceptions about how the world works. If their initial understanding is not engaged, they may fail to grasp the new concepts and information that are taught, or they may learn them for purposes of a test but revert to their preconceptions outside the classroom.

2. To develop competence in an area of inquiry, students must: (a) have a deep foundation of factual knowledge, (b) understand facts and ideas in the context of a conceptual framework, and (c) organize knowledge in ways that facilitate retrieval and application.

3. A “metacognitive” approach to instruction can help students learn to take control of their own learning by defining learning goals and monitoring their progress in achieving them.

Implications for Teaching:

1. Teachers must draw out and work with the preexisting understandings that their students bring with them [pre- and misconceptions].

2. Teachers must teach some subject matter in depth, providing many examples in which the same concept is at work and providing a firm foundation of factual knowledge.

3. The teaching of metacognitive skills should be integrated into the curriculum in a variety of subject areas.

Implications for Designing Classroom Environments

1. Schools and classrooms must be learner centered.

2. To provide a knowledge-centered classroom environment, attention must be given to what is taught (information, subject matter), why it is taught (understanding), and what competence or mastery looks like.

3. Formative assessments—ongoing assessments designed to make students' thinking visible to both teachers and students—are essential. They permit the teacher to grasp the students' pre-conceptions, understand where the students are in the “developmental corridor” from informal to formal thinking, and design instruction accordingly. In the assessment-centered classroom environment, formative assessments help both teachers and students monitor progress.

4. Learning is influenced in fundamental ways by the context in which it takes place. A community-centered approach requires the development of norms for the classroom and school, as well as connections to the outside world, that support core learning values.

11. Educating Teachers of Science, Mathematics, and Technology: New Practices for the New Millennium (2000)

General Description

Written by a committee that included experts in science, mathematics, and technology education at both the K-12 and postsecondary levels (including teacher practitioners at various grade levels), *Educating Teachers of Science,* *Mathematics, and Technology* synthesized what was known at the time about the quality of math and science teaching in the U.S., drawing conclusions about why teacher preparation needs to change, and then outlining recommendations for accomplishing those changes.

Educating Teachers addresses the issues associated with teacher education and professional development from a variety of contexts. It begins by helping readers understand the kinds of challenges that teachers often routinely face in their classrooms and in their schools and districts. It compares and contrasts teaching as a profession with other professions in the United States.

The book then synthesizes the research literature about the importance of having effective teachers in classrooms and what might constitute more effective teacher education. One of the important insights from this report is that, rather than being seen as distinctive entities that are controlled and managed very differently from each other, pre- and in-service education of teachers should instead be viewed as a seamless continuum that begins when a student makes decisions about whether to become a teacher (similar to pre-law or premedical advising) through a professional career that progresses from induction to experienced teacher to master teacher. It suggests instead that increased emphasis be placed on career-long *teacher education*.

Also examined are important issues in teacher professionalism: what teachers should be taught about their subjects, the usefulness of in-service education to novice and experienced teachers, the challenge of program funding, and the merits of various kinds of credentialing. Professional Development Schools are reviewed and vignettes are presented that describe exemplary teacher development practices.

As a framework for addressing the task of revamping teacher education, the book (and especially Chapter 6) offers a vision for fundamentally different relationships than currently exist among most school districts, two- and four-year colleges, and universities. It also offers recommendations about how teachers can experience professional growth throughout their careers that may help them stay in the classroom rather than feeling compelled to move to other areas of education (e.g., school administration) in order to advance in their careers.

Relevance to the California STEM Innovation Network

The ultimate success of the California STEM Education Network will likely be determined to a large extent by the time, resources, and knowledge base that are devoted to preparing California's current workforce of teachers of science and mathematics to approach their craft differently. It also will be determined in part by the ability of the Network to 1) convince postsecondary faculty (both in the STEM disciplines and in schools of education) and the leaders of colleges and universities that teacher education is an inherent and primary responsibility of those institutions and 2) to work in partnership with higher education to foster more effective education of teachers at all levels of the professional continuum.

Layered upon the well-known issues surrounding teacher education in science, mathematics, and technology are the issues of

> 1) preparing both future and currently practicing teachers to focus on new approaches and techniques to promote more inquiry by students in classrooms and laboratories (see also the overviews of *Inquiry and the National Science Education Standards*, *Adding It Up*, and *Ready, Set, Science!*), especially when too few teachers have personally experienced these approaches to STEM education when they were students, and
>
> 2) developing new approaches to the continuum of teacher education that helps future and currently practicing teachers more deeply understand the interconnections among the STEM disciplines and how those interconnections can be used to approach teaching and learning of these disciplines in fundamentally different ways. This challenge is likely to be especially difficult because most teachers have not had courses or professional development experiences that help to interconnect science and mathematics, let alone the additional connections of technology and engineering.

Educating Teachers of Science, Mathematics, and Technology can provide the leadership of the California STEM Education Network with new perspectives about approaches to teacher education and how new relationships among the various stakeholders might be developed and nurtured.

Recommendations (Key Recommendations Highlighted)

The authoring committee offered an extensive set of general and then more specific recommendations, all of which are provided below:

General Recommendations

1. Teacher education in science, mathematics, and technology [should] be viewed as a continuum of programs and professional experiences that enables individuals to move seamlessly from college preparation for teaching to careers in teaching these subject areas.

2. Teacher education [should] be viewed as a career-long process that allows teachers of science, mathematics, and technology to acquire and regularly

update the content knowledge and pedagogical tools needed to teach in ways that enhance student learning and achievement in these subjects.

3. Teacher education [should] be structured in ways that allow teachers to grow individually in their profession and to contribute to the further enhancement of both teaching and their disciplines.

Specific Recommendations:

For Governments:
Local, state, and federal governments should recognize and acknowledge the need to improve teacher education in science and mathematics, as well as assist the public in understanding and supporting improvement. Governments should understand that restructuring teacher education will require large infusions of financial support and make a strong commitment to provide the direct and indirect funding required to support local and regional partnerships for improving teacher education in these disciplines. They also should encourage the recruitment and retention of teachers of science and mathematics—particularly those who are "in-field"—through financial incentives, such as salaries that are commensurate and competitive with those in other professions
in science, mathematics, and technology; low-interest student loans; loan forgiveness for recently certified teachers in these disciplines who commit to teaching; stipends for teaching internships; and grants to teachers, school districts, or teacher education partnerships to offset the costs of continual professional development.

For Collaboration Between Institutions of Higher Education and the K-12 Community: Two- and four-year institutions of higher education and school districts that are involved with partnerships for teacher education should—working together—establish a comprehensive, integrated system of recruiting and advising people who are interested in teaching science, mathematics, and technology.

For the Higher Education Community:
1. Science, mathematics, and engineering departments at two- and four year colleges and universities should assume greater responsibility for offering college-level courses that provide teachers with strong exposure to appropriate content and that model the kinds of pedagogical approaches appropriate for teaching that content.

2. Two- and four-year colleges and universities should reexamine and redesign introductory college-level courses in science and mathematics to better accommodate the needs of practicing and future teachers.

3. Universities whose primary mission includes education research should set as a priority the development and execution of peer-reviewed research studies that focus on ways to improve teacher education, the art of teaching, and learning for people of all ages. New research that focuses broadly on synthesizing data across studies and linking it to school practice in a wide variety of school settings would be especially helpful to the improvement of teacher education and professional development for both prospective and experienced teachers. The results of this research should be collated and disseminated through a national electronic database or library.

4. Two- and four-year colleges and universities should maintain contact with and provide guidance to teachers who complete their preparation and development programs.

5. Following a period of collaborative planning and preparation, two- and four-year colleges and universities in a partnership for teacher education should assume primary responsibility for providing professional development opportunities to experienced teachers of science, mathematics, and technology. Such programs would involve faculty from science, mathematics, and engineering disciplines and from schools of education.

For the K-12 Education Community

1. Following a period of collaborative planning and preparation, school districts in a partnership for teacher education should assume primary responsibility for providing high quality practicum experiences and internships for prospective teachers.

2. School districts in a partnership for teacher education should assume primary responsibility for developing and overseeing field experiences, student teaching, and internship programs for new teachers of science, mathematics, and technology.

3. School districts should collaborate with two- and four-year colleges and universities to provide professional development opportunities to experienced teachers of science, mathematics, and technology. Such programs would involve faculty from science, mathematics, and engineering disciplines and from schools of education. Teachers who participate in these programs would, in turn, offer their expertise and guidance to others involved with the partnership.

For Professional and Disciplinary Organizations

1. Organizations that represent institutions of higher education should assist their members in establishing programs to help new teachers. For example,

databases of information about new teachers could be developed and shared among member institutions so that colleges and universities could be notified when a newly certified teacher was moving to their area to teach. Those colleges and universities could then plan and offer welcoming and support activities, such as opportunities for continued professional and intellectual growth.

2. Professional disciplinary societies in science, mathematics, and engineering, higher education organizations, government at all levels, and business and industry should become more engaged as partners (as opposed to advisors or overseers) in efforts to improve teacher education.

3. Professional disciplinary societies in science, mathematics, and engineering, and higher education organizations also should work together to align their policies and recommendations for improving teacher education in science, mathematics, and technology.

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