Regarding 21st Century Content Standards for Science and Engineering in Virginia's K-12 Curriculum – Report of the Engineering Panel

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Contents

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And last but not least all the panel participants and their organizations which allowed these highly skilled professionals two days away from their primary jobs to carry out this work. The Engineering Team members and their organizations are:

Dr. John Bean	University of Virginia
Mr. George Biallas	Department of Energy – Jefferson Lab
Dr. Charlie Camarda	NASA – Johnson Space Center
Mr. Alan Dean	Naval Surface Warfare Center – Dahlgren
Dr. Doug Dwoyer	NASA – Langley Research Center
Mr. Roger Hunt	Jamestown High School
Dr. Bob Kolvoord	JMU

Dr. Bob Lindberg	National Institute of Aerospace
Mr. Matt Miller	Micron Technology Virginia
Dr. Marie Paretti	Virginia Tech
Mr. Jerry Robertson	ODU
Mr. Marty Rothwell	Chantilly Academy - Fairfax
Ms. Cheryl Simmers	Appomattox Governor's School
Dr. Mohammad Takallu	Lockheed Martin Mission Services

Executive Summary

Three panels of practicing scientists and engineers were assembled in the Summer of 2007 for the purpose of reviewing the current Virginia Standards of Learning (SOL) in physics and chemistry and Virginia's K-12 program in engineering. Members of the panels were drawn from university physics and chemistry departments, schools of engineering, government research laboratories, and industry from across the Commonwealth. This diversity of membership provided background at all technology readiness levels from basic research to technology and development to manufacturing and operations.

The panels did not focus on advanced science content but rather were asked to answer the question: What are the physics (chemistry/engineering) essential content to reach 80% – 90% of all high school students to help them become productive citizens in the 21st Century? Or: **What is the essential physics (chemistry/engineering) knowledge that citizens should have to understand the world around them, to make decisions on political questions that more and more involve understanding of science and technology, to triage and understand the plethora of news and information that is available by the current World Wide Web and will be available on the next generation Internet?**

This is the final report of the Panel on *Engineering* which met at the National Institute of Aerospace in Hampton, Virginia, June 5-6, 2007.

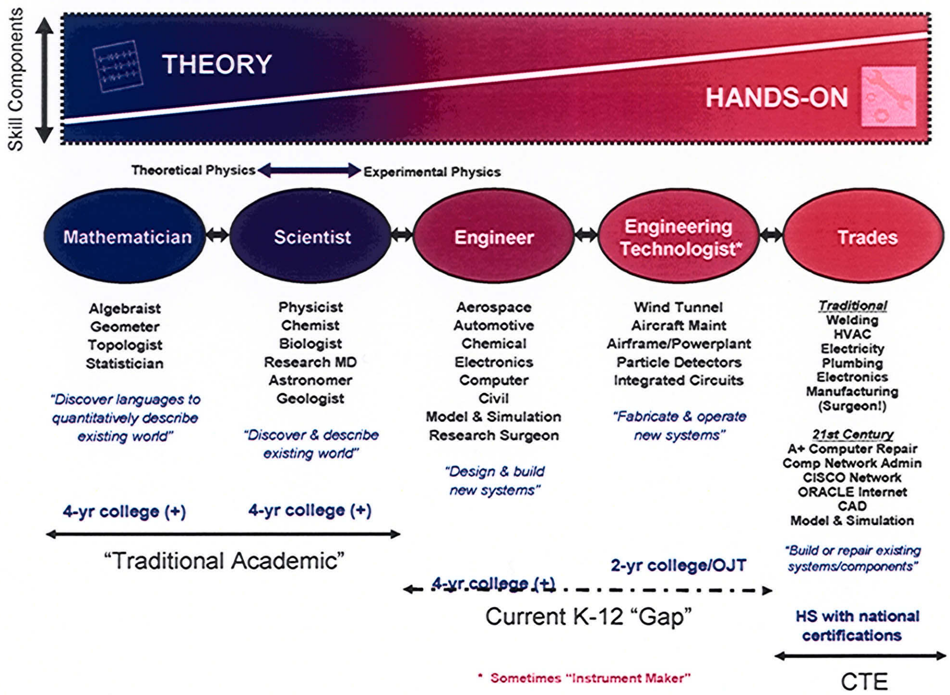
Four weeks prior to the meeting, panel members were provided materials on proposed national science standards, including those developed by the National Research Council and Project 2061 of the American Association for the Advancement of Science, and information on a selection of K-12 engineering programs that are in use nationally.

After working in facilitated sessions as subgroups and a committee of the whole, the Engineering Panel developed the following findings:

- General:
  - Because engineering is often conflated with science and mathematics, the panel developed a working definition: "Engineers identify human needs and wants, then creatively apply mathematics, science, technology, and other disciplines in (e.g., aesthetics, urban studies, operations, etc.) and impose relevant constraints (e.g., cost, schedule, redundancy, etc.) to design and evaluate innovative products and systems that address those needs and wants." (Engineering is inherently interdisciplinary and creates new value to satisfy a stated need while science discovers relationships in and characterizes the existing world.)
  - The two major strands identified as "The Designed World" and "The Nature of Technology" in the American Association for the Advancement of Science's Project 2061 "Benchmarks" are not adequately addressed in Virginia's current required K-12 curriculum. The engineering design

process, including the problem definition and the role of multiple constraints, is a critical component of engineering knowledge, and understanding that process as well as the ways in which engineering impacts public life are critical to helping Virginia's citizens make informed decisions.
  - To prepare for the 21st Century, students need to have more application-oriented work in science and mathematics, either by integrating engineering into the current science strands, through a separate engineering strand, or through some combination of the two to help K-12 teachers use examples from "the designed world" to demonstrate applications of science, technology and mathematics to the designed world including the political, economic, environmental, sociological, and technological ramifications.
- Student Success
  - Engineering bridges a gap between the mostly theoretical current K-12 mathematics and science curriculum and the traditional and 21st century trades areas of the K-12 Career and Technical Education Program (see figure on page 6).
  - Because women and minorities continue to be underrepresented in engineering, efforts to address K-12 engineering should incorporate specific activities to reach these underrepresented groups regarding careers in engineering to ensure that 21st century engineers are drawn from the largest possible workforce pool.
- Specific Implementation
  - Any implementation of an engineering curriculum must have teacher training and on-going support as a required component.
  - The teaching of engineering processes and principles should begin in K-5.
  - Required engineering modules should be integrated into 6-8 curriculum
  - Any discussion of engineering modules, outcomes, and standards must include a discussion of appropriate methods of assessment that move beyond multiple choices tests (which do not effectively capture engineering knowledge, particularly with respect to the design process and the impact of engineered technologies on society). Effectively designed assessment processes, along with the investment required to sustain those assessments, are central to the successful inclusion of engineering in the K-12 curriculum.
  - Engineering courses that prepare students for a career in engineering should be available to all high school students.
  - The nationally available program, Project Lead The Way (PLTW) satisfies almost all of the panels requirements for an engineering preparatory program and should be considered as basic high school engineering program to be implemented "as is" or used as a basis while customizing and continuously improving a school's engineering offerings.

Figure. Engineering bridges a gap between the mostly theoretical current K-12 mathematics and science curriculum and the traditional and 21st century trades areas of the K-12 Career and Technical Education Program



Introduction and Background

In the Fall of 2006, NASA engaged in discussions with the Office of the Secretary of Education in Virginia with regard to partnering for the development of a workforce skilled in the capabilities needed by NASA for the 21st century. With many of its staff nearing or past retirement age, NASA was particularly concerned about its next-generation workforce while the Office of the Secretary of Education was interested in having a STEM[1]-capable team examine the current content of the STEM curriculum in the state and carry out an independent "gap analysis". A recent study[2] published by Achieve, Inc., showed that many graduates go into the workplace or further education after high school graduation feeling unprepared, identified by their employers as unprepared, or requiring remedial, not-for-credit courses. An agreement[3] was reached whereby NASA would provide a scientist/engineer to the Secretary's office for nine months during which, he/she would lead a review of the physics, chemistry, and engineering[4] programs in Virginia. The reviews would be carried out by panels or teams of practicing scientists and engineers, drawn from research university content area departments, government research laboratories, and industry. The output from each review panel would be a white paper deliverable to the Secretary of Education and publicly available.

Over the past twenty years, two well-respected national organizations, the National Research Council of the National Academies of Science and the American Association for the Advancement of Science have developed documents that lay out *potential* national standards and benchmarks for Science in the Nation's schools K-12[5].

In addition to these two national efforts, the past fifteen years has seen individual states develop their own standards in a number of academic disciplines. Virginia began its standards development under Governor George Allen around 1994. The focus of these first standards was school *accountability*. In an effort to assure accountability of all of Virginia's public schools with respect to some common course content, the Virginia Standards of Learning (SOL) were created. These SOL are implemented as *outcome*

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[1] STEM is an acronym for Science, Technology, Engineering, Mathematics.
[2] "Rising to the Challenge: Are High School Graduates Prepared for College Work? A Study of Recent High School Graduates, College Instructors, and Employers". Conducted for Achieve, Inc. by Peter D. Hart Research Associates (February 2005).
[3] Intergovernmental Personnel Act (IPA)
[4] While NASA has an interest in all STEM areas, it has a particular interest in physics and chemistry, the science basis for new and exotic materials that would be required to carry out its Exploration mandate, and engineering which is the basis for the development of these materials into useful structures and the spaceflight capabilities to use them. Follow-on panels to similarly review the other science areas are a possible future activity.
[5] *National Science Education Standards* (National Academy Press, 1996) and *Project 2061: Science for All Americans* and *Benchmarks for Science Literacy* (American Association for the Advancement of Science, 1990).

standards in that the assessments or tests associated with them identify whether the material was *learned* by students (as opposed to simply *taught* by teachers).

To further clarify what the SOL are intended to be and what they are not intended to be, we can look at two excerpts from the Introduction to Virginia's Science SOL:

- "The Science Standards of Learning for Virginia's Public Schools identify academic content for essential components of science curriculum at different grade levels." and;
- "The Standards of Learning are not intended to encompass the entire science curriculum for a given grade level or course or to prescribe how the content should be taught. Teachers are encouraged to go beyond the standards and select instructional strategies and assessment methods appropriate for their students."

While conceived as minimal accountability standards (a floor), the content of the SOL soon became the course outline for many teachers. As fiscal pressure, particularly through the No Child Left Behind (NCLB) Federal legislation, increased for students to pass these state assessments, school administrators put more pressure on teachers to assure that their students would indeed pass. This pressure along with the large breadth of the SOL for some courses, has precluded many teachers from "go(ing) beyond the standards".

The standards are revised every seven years as a part of the formal review process approved by the State Board of Education – science undergoes its next revision in 2010. *The output from the physics and chemistry panels is intended to inform that review process.*

The job of Physics Team and Chemistry Team was to develop some consensus around the essentials of citizen knowledge in (physics)/(chemistry) for the next 25 years. That is, what is the essential physics or chemistry knowledge that citizens of the Commonwealth should have to understand the world around them, to make decisions on political questions that more and more involve understanding of science and technology, to triage and understand the plethora of news and information that is available by the current World Wide Web and will be available on the next generation Internet. The task of the Engineering Team was not too much different but was a bit more broadly defined in terms of what engineering program would be most appropriate for our students in the 21st century. Engineering is not a part of the traditional curriculum for which there are SOL; it has developed in the CTE (Career and Technical Education) division of the Virginia Department of Education. Thus the panel could not look at an SOL content set for engineering, but, rather, looked at various programs that Virginia teachers have created, some "turn-key" national programs that have been created and are available for purchase, and the K-12 SOL for engineering in the state of Massachusetts.

Finally, a reminder that these panels were NOT defining advanced course content – that work is being done nationally and it focuses on the top 10% of our students[6]. The panel's focus was on ALL students in laying out a safety net of science (physics/chemistry) and engineering content that the remaining 90% of Virginia's high school students need to be economically and politically productive citizens of Virginia in the 21st Century.

The expression "STEM" is often used rather loosely to describe any curriculum that is science or math related. For the purposes of understanding the engineering panel's output, it is important to differentiate between the four STEM components. We will assume the following descriptive definitions:

- Science is the **study** of the existing physical world and its manifestations, especially through systematic observation and experiments. Science explains the world that is.
- Technology is the application of scientific and engineering knowledge to achieve a **practical result**.
- Engineering is the creation or development of new devices and objects that are of **importance or value** to humans and society.
- Mathematics is a branch of pure science or philosophy (logic) that in its **applied** state can be used to help make quantitative analyses and predictions for science, technology, and engineering.

This report presents the results from the Engineering Panel in its consideration of what engineering knowledge 90% of Virginia's students need to be economically and politically productive citizens of the Commonwealth for the 21st century. The panel also reports on what programs should be available to those students who are considering a career in engineering.

[6] In Virginia (2004 data), approximately 10% of students in grades 9-12 were taking one or more Advanced Placement courses; 1% were in Governor's Schools, and 0.25% were in International Baccalaureate (IB) programs. The College Boards are working on aligning AP courses and the American Institute of Physics and NRC have developed reports on advanced needs in physics and chemistry respectively.

Philosophy for Selecting Team Membership

Because many previous SOL content development teams were made up with a preponderance of K-12 science educators, with some practicing scientists only as advisors or reviewers, this team was designed to complement and supplement the content-area expertise of those teams. The Engineering Team was designed to have subject matter expertise across a large range of engineering activities and endeavors from basic research through technology and development to operations and production. To this end, members were solicited from university engineering schools, government research laboratories, industry, and K-12. Three Virginia K-12 teachers who were currently teaching engineering in their schools were solicited. There was an attempt to get a diverse mix of members and a mix of government laboratories that spanned the Department of Energy, NASA, and the Department of Defense.

Members of the Engineering Team[7] and their major affiliation were:

Dr. Marie Paretti	Virginia Tech
Dr. John Bean	University of Virginia
Mr. Jerry Robertson	ODU
Dr. Bob Kolvoord	JMU
Dr. Bob Lindberg	National Institute of Aerospace
Dr. Charlie Camarda	NASA – Johnson Space Center
Dr. Doug Dwoyer	NASA – Langley Research Center
Mr. George Biallas	Department of Energy – Jefferson Lab
Mr. Alan Dean	Naval Surface Warfare Center – Dahlgren
Dr. Mohammad Takallu	Lockheed – Martin
Mr. Matt Miller	Micron Technology Virginia
Mr. Marty Rothwell	Chantilly Academy Fairfax County
Mr. Roger Hunt	Jamestown High School Williamsburg
Ms. Cheryl Simmers	Appomattox Governor's School Petersburg

What this team brought to the scene was unique – not claimed to be better or worse just unique - from previous SOL and curriculum work in three ways:

- They were a team of content-centric practitioners – not education specialists.
- They had available descriptions of a selection of K-12 engineering programs that were already in place across Virginia and the Nation.
- They brought a range of perspective from university *research and technology* through government laboratory *technology and development* to industry *development and production.*

[7] A short biography for each member is in Appendix A

Preparation for Meeting

Because the team was developed for its engineering content-area expertise and came from diverse backgrounds across the research, technology, development, and production compass, a set of documents was prepared to provide background on the current state of K-12 engineering in the United States and some national thinking about what science should be in the 21st century. The full set of documentation is Appendix B and a summary is given here.

Members were provided information from three nationally available engineering programs: *Project Lead The Way (PLTW);* Texas Instrument's *The Infinity Project*; and Ford Motor Company's *Partnership for Advanced Study (PAS).* They also received a copy of the Standards of Learning (SOL) for the K-12 engineering program that was instituted in Massachusetts in 2001.

Project Lead The Way (PLTW) was first created in New York State to fill a curriculum gap in engineering for high schools. It is administered nationally through a non-profit corporation and program integrity is ensured in each state through an "affiliate" university school of engineering which provides training, support, and on-going validation of PLTW-offering schools in that state. Old Dominion University's Batten School of Engineering is the affiliate in Virginia (Duke is the affiliate in North Carolina) and offers a two-week residential summer teacher training program that is required of teachers for each course. PLTW provides a complete traditional 4-year engineering program that begins with "Introduction to Engineering" in the ninth grade, "Principles of Design" in tenth grade, a specific focus course such as "Aerospace", "Computer Integrated Manufacturing", "Biotechnology", etc in 11th grade, and a capstone team design/build/operate course in 12th grade. PLTW also has a middle school curriculum called "Gateways to Technology".

The Infinity Project was developed by Texas Instruments Corporation to fill a gap in the development of Digital Design Engineers for TI's next generation workforce. It is administered through Southern Methodist University where a one-week residential training program is offered to prepare Infinity Project teachers. The course focuses on digital electronic engineering as the course textbook, "Engineering Our Digital Future" indicates. The final chapter of the textbook does address other engineering disciplines in "The Big Picture". A laboratory activity kit can be purchased along with the book.

The Ford PAS program is designed from Ford's global needs in engineering capability with understanding of markets, economies, social interactions, and technology. It is made up of five semester-long courses, each of which is made up of three modules. The course can be taught as designed or some of the individual modules can be integrated into U.S. History, Statistics, Physics, Economics, and Engineering. The courses are Building Foundations (problem solving, communication, research skills); Adapting to Change (careers, companies, communities, environment, efficiency); Managing and Marketing with Data (business success, quality, data to knowledge); Designing for Tomorrow (reverse engineering, different by design, energy for the future); and Understanding the

Global Economy (wealth of nations, markets without borders, global citizens). Training and teacher development is available from Ford.

Team members also received a copy of the *"Kentucky Survey of Critical Technologies: Highlights"* from June of 2004. This document reports on the results of a survey of some 500 middle and high school science teachers in Kentucky regarding their awareness and comfort with contemporary and emerging technologies. As an example, while 99% of those surveyed were aware of the concept of "stem cells", only 47% said that they understood that concept, and 24% taught it. Sixty per cent of these teachers were aware of "nanotechnology", but only 18% said that they understood it, and 7% replied that they taught it. Thirty-eight percent of these teachers also said that their preferred source of content training was the web with only 8% preferring "In-service" programs at their schools.

The Commonwealth of Massachusetts recently put in place a complete K-12 engineering curriculum and the standards of learning (SOL) for that program were provided to panel members.

They were also given selections from the National Research Council's "*National Science Education Standards"* and complete copies of two books: The American Association for the Advancement of Science Project 2061 *"Science for All Americans"* and *"Benchmarks".*

Science for All Americans differentiates mathematics, science, and engineering as follows: *"Scientists see patterns in phenomena as making the world understandable; engineers also see them as making the world manipulable. Scientists seek to show that theories fit the data; mathematicians seek to show proof of abstract connections; engineers seek to demonstrate that designs work..."*

Two specific chapters of *Science for All Americans* were a focus for the engineering panel: The Nature of Technology and The Designed World.

From The Nature of Technology, *"In the broadest sense, technology extends our abilities to change the world, to cut, shape, or put together materials; to move things from one place to another; to reach farther with our hands, voices, senses. We use technology to try to change the world to suit us better. The changes may relate to survival needs such as food, shelter, or defense or they may relate to human aspirations such as knowledge, art, or control. But the results of changing the world are often complicated and unpredictable. They can include unexpected benefits, unexpected costs, and unexpected risks – any of which may fall on different social groups at different times. Anticipating the effects of technology is therefore as important as advancing its capabilities"*

From The Designed World: *"The world we live in has been shaped in many important ways by human action. We have created technological options to prevent, eliminate, or lessen threats to life and the environment and to fulfill social needs. We have damned rivers and cleared forests, made new materials and machines, covered vast areas with*

cities and highways, and decided – sometimes willy-nilly – the fate of many other living things.
In a sense then many parts of the world are designed – shaped and controlled, largely through the use of technology – in light of what we take our interests to be. We have brought the earth to a point where our future well-being will depend heavily on how we develop and use and restrict technology. In turn, that will depend heavily on how well we understand the workings of technology and the social, cultural, economic, and ecological systems within which we live.

While Science for All Americans is written from a holistic science viewpoint, the issues that humans have control over in the two excerpts above – the development of technologies and their applications - are controlled through *engineering*.

Meeting Place and Process (Agenda)

The Engineering Panel met on June 5-6, 2007 at the National Institute of Aerospace in Hampton, Virginia. Members had received their preparation reading four weeks in advance of the meeting. The agenda was structured to get the participants first to talk about their own engineering expertise, background, and any initial thoughts they had on the preparatory material or the problem in front of the panel.

Next, the participants were put into four smaller homogeneous breakout groups to consider (brainstorm) the main question before them: **What is the engineering essential content to reach 80% – 90% of all high school students to help them become productive citizens[8] in the 21st Century?** The four homogeneous groups were broken out as:

- University representatives
- Government laboratory representatives
- Industry representatives
- K-12 representatives

The four homogeneous groups then reported out to the entire panel, with all panel members engaging in discussion for clarification.

Next, the participants were grouped into three "mixed groups" wherein each group had a mix of membership from each of industry, K-12, university, and government lab. The three mixed groups were asked to develop a draft of recommendations based on their earlier homogeneous group discussions and report-out. These groups reported out to the entire panel and their ideas were catalogued (like-things combined) and prioritized.

Finally, the whole group was asked about what engineering courses should be available to potential engineering majors – the first day and a half having been devoted to the engineering needs of ALL students.

[8] What is the essential engineering knowledge that citizens should have to understand the world around them, to make decisions on political questions that more and more involve understanding of science and technology, to triage and understand the plethora of news and information that is available by the current World Wide Web and will be available on the next generation Internet.

Results

Participants began the meeting by introducing themselves, their particular area of engineering expertise, and their thoughts based on their expertise and preliminary reading material. Among the issues raised were:

- Training of engineering teachers.
- How to provide engineering classes in rural as well as urban areas.
- Who would be willing to teach K-12 engineering with the pay difference between engineering jobs and K-12 teachers' salaries?[9]
- Consider the ethics of engineering.
- Differentiate "engineering" from "technology".
- What are U.S. engineering needs in the current world of offshore outsourcing? (Innovation?)
- At what age should engineering be introduced?

The team then broke out into four homogeneous groups – groups whose members shared similar affiliation as:

- University
- Government Lab
- Industry
- K-12

These groups worked independently on the first fundamental question: **What is the engineering essential content to reach 80% – 90% of all high school students to help them become productive citizens in the 21st Century?**

The groups then reported out their findings to the whole team. While there was some overlap in the products between teams, some of the outputs of this first brainstorming session were as follows:

- University
    - Need for definition and clarification of "engineering"
    - What aspects of engineering should students have by the completion of high school? (decision-making, assessment of problems/finding solutions)
    - Make science SOL more applications oriented.
    - Do not underestimate younger children's ability to understand engineering principles – they are not too abstract.
- Government Lab
    - Tried to answer the question: What information is necessary to carry us into the future – engineering for society?

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[9] Entry level to 10 years experience salary range for engineers ($53K - ~$100K); Entry level to 10 years experience salary range for K-12 teachers ($35K - ~$43K). National salary data from Salary.Com

- Skills: Graphical representation, draw a picture, modeling, understand technology and its limits.
  - Basic knowledge: the sciences and probability/statistics.
  - Abilities: Logical thinking, understanding components/integration, analysis, understanding boundaries of problems and impact of potential solutions, oral and written communication
  - What is lacking in current education?: Not enough creativity, mechanical thinking dominates originality and imagination, few open ended problems, low long-term retention of material, inability to deal with ambiguity.
- Industry
  - Math and science provide tools used by engineers to analyze "manmade" world
  - Engineering provides tools for scientists to understand the natural world.
  - Engineering/Science relationship should be understandable to middle and high school students
  - Provide broad overview of field of engineering
  - Industry needs: technologically literate workers/public; ability to work independently and in groups; good citizens; a large pool of qualified engineers.
  - Engineering process impacts life skills of decision-making
- K-12
  - Research process remains the same throughout disciplines but is a difficult process for students to grasp due to lack of integration and a lack of time for teachers to discuss it.
  - SOL put high demand on teachers to teach specifically to SOL material so they try to cram additional material in after the SOL testing
  - Students often are intent on reaching an endpoint – makes schools a task instead of a journey.

The second day opened with a review of overnight thoughts on the matter before the team and a second breakup into three smaller groups. These groups were mixed or heterogeneous with each group having a mix of university, government lab, K-12, and industry perspectives. These groups continued to work the output of the homogeneous groups and reported out as follows:

- Group 1:
  - Definition of "engineering" – Engineers identify human needs/wants
  - Content offered to the 90% - design experience and comprehension; understanding life-cycles; how engineered products/systems change life; fundamental principles such as stress analysis and statistics.
- Group 2:
  - Cyclical engineering design process
  - Definition of engineering: "Engineers are individuals who combine knowledge of multiple disciplines to solve problems that confront society, and to utilize methods, materials, and forces of nature for the benefit of all humans"

- Group 3:
  - Proposal: Implement Project Lead The Way (PLTW) Statewide (use same approach as South Carolina)
    - National existing curriculum
    - Has assessment tools
    - In 14 Virginia school divisions today
    - Engages a vast majority of the issues brought up in the panel discussion
  - Use PLTW "Gateway" programs in middle school for "90%"

Finally, the full team addressed the **second issue: that of preparing students to major in engineering in college** – though this had been touched on by some breakout groups earlier. Discussions among the whole group brought out the following points:

- Skills
  - Motivated
  - See big picture
- Supporting math
  - Applied algebra
  - Data analysis
  - Software package such as MATLAB
  - Show work – don't just test getting answer
- Ideal engineer
  - See NAS Engineer 2020 Report
  - Strong analytical skills
  - Practical ingenuity
  - Creativity, innovation
  - Good communication
  - Leadership
  - High ethics, professionalism
  - Life-long learners
  - Able to solve open-ended problems in high school
  - Drawn to majors by inspiring faculty
  - American students have career choices throughout formal education process
  - Tolerance of ambiguity
- Create hands-on/open-end design project
  - FIRST series (FIRST Lego League, VEX, FIRST Robotics)
  - Destination Imagination
  - Odyssey of the Mind
  - Mentors from engineering but trained in pedagogy to inspire
  - Innovative and culturally relevant
  - Manageable challenges, low-cost, fun
  - Digital libraries or open-source materials reviewed by users
  - Possibly introduced in a pre/intro to engineering course that is design focused, somewhat math based, uses state-of-the-practice software

In summarizing the material and discussion brought out during the two days of working in facilitated sessions as subgroups and a committee of the whole, the Engineering Panel output can be presented in the following findings and recommendations:

- General:
  - Because engineering is often conflated with science and mathematics, the panel developed a working definition: "Engineers identify human needs and wants, then creatively apply mathematics, science, technology, and other disciplines in (e.g., aesthetics, urban studies, operations, etc.) and impose relevant constraints (e.g., cost, schedule, redundancy, etc.) to design and evaluate innovative products and systems that address those needs and wants." (Engineering is inherently interdisciplinary and creates new value to satisfy a stated need while science discovers relationships in and characterizes the existing world.)
  - The two major strands identified as "The Designed World" and "The Nature of Technology" in the American Association for the Advancement of Science's Project 2061 "Benchmarks"are not adequately addressed in Virginia's current required curriculum. The engineering design process, including the problem definition and the role of multiple constraints, is a critical component of engineering knowledge, and understanding that process as well as the ways in which engineering impacts public life are critical to helping Virginia's citizens make informed decisions.
  - To prepare for the 21st Century, students need to have more application-oriented work in science and mathematics, either by integrating engineering into the current science strands, through a separate engineering strand, or through some combination of the two to help K-12 teachers use examples from "the designed world" to demonstrate applications of science, technology and mathematics to the designed world including the political, economic, environmental, sociological, and technological ramifications.
- Student Success
  - Engineering bridges a gap between the mostly theoretical current K-12 mathematics and science curriculum and the traditional and 21st century trades areas of the K-12 Career and Technical Education Program (see figure below)
  - Because women and minorities continue to be underrepresented in engineering, efforts to address K-12 engineering should incorporate specific activities to reach these underrepresented groups regarding careers in engineering to ensure that 21st century engineers are drawn from the largest possible workforce pool.
- Specific Implementation
  - Any implementation of an engineering curriculum must have teacher training and on-going support as a required component.
  - The teaching of engineering processes and principles should begin in K-5.
  - Required engineering modules should be integrated into 6-8 curriculum

- Any discussion of engineering modules, outcomes, and standards must include a discussion of appropriate methods of assessment that move beyond multiple choices tests (which do not effectively capture engineering knowledge, particularly with respect to the design process and the impact of engineered technologies on society). Effectively designed assessment processes, along with the investment required to sustain those assessments, are central to the successful inclusion of engineering in the K-12 curriculum.
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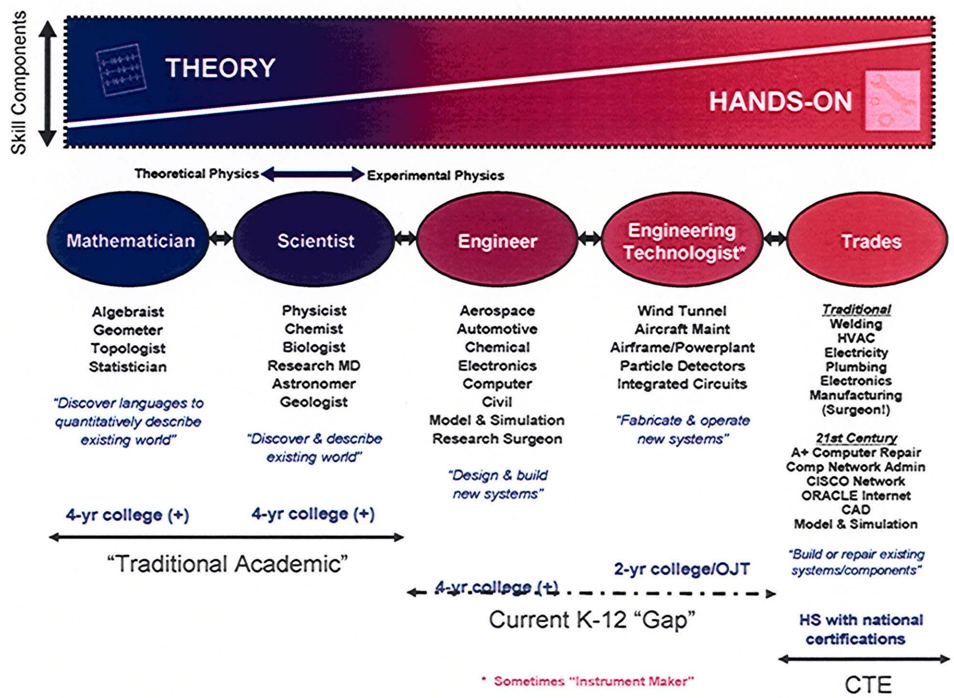
- The nationally available program, Project Lead The Way (PLTW) satisfies almost all of the panels requirements for an engineering preparatory program and should be considered as basic high school engineering program to be implemented "as is" or used as a basis while customizing and continuously improving a school's engineering offerings.

Figure. Engineering bridges a gap between the mostly theoretical current K-12 mathematics and science curriculum and the traditional and 21st century trades areas of the K-12 Career and Technical Education Program



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APPENDIX A

Short Biographies of Engineering Team Members:

Dr. John Bean, J.M. Money Professor of Engineering and Applied Science, University of Virginia. BS (Applied Physics) Caltech; MS and Ph.D. (Applied Physics) Stanford. Previously, Dr. Bean was Head of the Material Science Research Department at Bell Labs in Murray Hill, N.J. His most recent research interests have been in the self-assembly of semiconductor nanostructures and the development of new techniques for the fabrication of molecular electronic devices. He initiated the UVA Virtual Lab public science education website and has received the UVA "All University Teaching Award".

Mr. George Biallas, Senior Staff Engineer, Jefferson Lab-Department of Energy. BSME University of Illinois; Registered Professional Engineer. Mr. Biallas is responsible for the concepts, design, and construction of high energy beam transport systems, target systems, and infrastructure including superconducting magnets and cryostats for state-of-the-art national accelerator facilities. Previously, he was a staff engineer at Enrico Fermi Institute and Fermi National Accelerator Laboratory.

Dr. Charlie Camarda, Astronaut and Deputy Director for Advanced Projects, NASA – Johnson Space Center. BS (Aerospace Engineering) Polytechnic Institute of Brooklyn; MS (Mechanical Engineering) George Washington University; Ph.D. (Aerospace Engineering) Virginia Tech. Previously, Dr. Camarda carried out materials research and was Head of the Thermal Structures Branch at NASA Langley Research Center and served as Director of Engineering at NASA Johnson. He was selected to be an astronaut in 1996 and flew on the return-to-flight mission of the Space Shuttle, STS-114 in 2005.

Mr. Alan Dean, Deputy NAVSEA Warfare Center Workforce Executive, Naval Surface Warfare Center – Dahlgren, VA. BS (Electrical Engineering) Lowell Technological Institute; MS (Electronics Engineering) Virginia Tech; MA Mary Washington College and a graduate of Naval War College. Previously, Mr. Dean served as Branch Head for the Submarine Launch Ballistic Missile Program and the Anti-Submarine Program as well as Senior Staff Scientist in Computer Engineering. He has carried out research on Expert Systems and the modeling and simulation of microprocessors.

Dr. Doug Dwoyer, Project Director Hampton Roads Research Partnership – a consortium of research universities in the Hampton Roads VA area. BS, MS, Ph.D. (Aerospace Engineering) Virginia Tech. Dr. Dwoyer formerly served as Associate Director for Operations and Director of Research & Technology for NASA Langley Research Center. He has carried out research in Computational Fluid Dynamics at Wright-Partterson Air Force Base, United Technologies Research Center, and NASA Langley Research Center.

Mr. Roger Hunt – Teacher (Project Lead The Way), Jamestown High School, Williamsburg, VA. BS (Vocational Education) Virginia Tech; MS (Human Resources Development) Clemson. Before teaching, Mr. Hunt worked for Fluor Corporation on planning, design, and construction of large domestic and international facilities such as the 5th terminal at London's Heathrow Airport. He also was Director of Performance and Learning for the Americas in Arthur Anderson's Global Corporate Division.

Dr. Bob Kolvoord, Professor of Integrated Science and Technology and Educational Technologies, James Madison University. BA (Physics) University of Virginia; MS (Material Science) University of Virginia; Ph.D. (Theoretical and Applied Mathematics) Cornell University. Previously Dr Kolvoord served as Senior Research Associate at the Lunar and Planetary Laboratory at the University of Arizona and was co-founder of the Center for Image Processing in Education. His current research specialty is visualization and geospatial modeling applications for STEM education.

Dr. Bob Lindberg, President and Executive Director, National Institute of Aerospace. BS (Physics with Distinction) Worcester Polytechnic Institute; MS (Engineering Physics) University of Virginia; Eng.Sc.D. (Mechanical Engineering) Columbia University. Previously Dr. Lindberg served in executive and program management positions at Orbital Sciences Corporation including Sr. Vice President for Defense Programs and Program Manager for X-34. Earlier he served as a research physicist and Branch Head at Naval Research Laboratory and currently holds a concurrent post as Research Professor in Mechanical and Aerospace Engineering at the University of Virginia.

Mr. Matt Miller, Senior R&D Process Development Engineer, Micron Technology Inc., Manassas, VA. BS (Chemical Engineering) University of Idaho. Mr. Miller currently works with advanced thin film processing for DRAM and Flash semiconductor devices. His area of engineering expertise is in metal deposition for sub-70nm process technology nodes.

Dr. Marie Paretti, Assistant Professor of Engineering Education, Virginia Tech. BS (Chemical Engineering) Virginia Tech; MA (English) Virginia Tech; Ph.D. (English) University of Wisconsin – Madison. Dr. Paretti is currently Director, MSE/ESM Engineering Communications Program and Co-Director of the Virginia Tech Engineering Communications Center. Her current research focuses on professional practices (communication, teaming, ethical behavior, cross-discipline and cross-cultural collaboration) in both engineering workplaces and engineering curricula.

Mr. Jerry Robertson, Executive Director Virginia Applied Technology & Professional Development Center at Old Dominion University. BS and MS (Mechanical Engineering) Old Dominion University. Mr. Robertson is a registered Professional Engineer in Virginia and a Certified Manufacturing Engineer by SME. He currently leads all Project Lead The Way (PLTW) teacher training and is the professional engineer PLTW resource for Virginia.

Mr. Marty Rothwell, Engineering Systems and Engineering Physics Teacher, Chantilly Academy, Fairfax County Public Schools. BS (Physics) Mary Washington College; MBA Averett College. He currently teaches engineering physics, engineering systems, advanced engineering/robotics. Mr. Rothwell also serves as adjunct professor for George Mason University and is mentor for Chantilly's award-winning FIRST Robotics Competition Team.

Ms. Cheryl Simmers, Engineering Teacher, Appomattox Governor's School for Arts & Technology. BS (Industrial Engineering and Operations Research) Virginia Tech; MS (Industrial & Systems Engineering) Virginia Tech. She previously worked as a Project Engineer at Naval Weapons Station Yorktown and as a Research Associate at the Virginia Productivity Center. Ms. Simmers has been a public school teacher since 1994.

Dr. Mohammad Takallu, Senior Staff Aeronautical Engineer, Lockheed Martin Mission Services. Diploma Ingeneur (Mechanical/Aerospace Engineering) University of Aachen (Germany); Ph.D. (Mechanical/Aerospace Engineering) North Carolina State University. He has worked on a wide range of aeronautical engineering topics including aerodynamics, aeroacoustics, wake vortex and aircraft spacing, and flight deck ergonomics/human factors. As an active pilot and certified flight instructor, he has mentored many high school and college students in the science and art of flying.

Panel Facilitators:

Mr. Jim Batterson – Special Assistant on Loan from NASA to the Secretary of Education. BS (Mathematics) and MS (Physics) College of William and Mary. He formerly carried out research in system identification applied to flight test data and served as Head of the Dynamical Systems and Control Branch at NASA Langley Research Center. Most recently he served as Deputy Director for Strategic Development. Mr. Batterson has taught high school physics and mathematics and served on the Newport News (VA) School Board and New Horizons Governors School Board.

Dr. Charlie Sapp – BS (Aeronautical Engineering) U.S. Naval Academy; MS (Aeronautical Engineering); MA (International relations and National Security); MA (Strategic Studies); Ph.D (Organizational Leadership). He previously served as a pilot in the United States Navy, retiring as a Captain. Dr. Sapp has also served on Vice President Gore's government reform task force and as an examiner for the Malcolm Baldridge National Quality Award and the President's Quality Award programs. He is currently a member of the Hampton (VA) City Council.

B

APPENDIX B

Pre-meeting Reading Materials

Introduction and Background

Kentucky Survey of Critical Technologies

Project 2061: Benchmarks for Science Literacy (3 Excerpts)

National Science Education Standards (Excerpts)

A "Critique" of the National Science Education Standards

Leon Lederman on Science Reform

Innovation America

Ford Motor Company PAS Curriculum

Texas Instruments Infinity Project

Project Lead The Way and Technology Literacy

Massachusetts K-12 Engineering SOL

Comparing Some National and International Assessments

A Brief Introduction and Some Background for K-12 Physics, Chemistry, and Engineering Panel Members

Jim Batterson

There were more than 1.2 million children in Virginia K-12 schools in 2005. More than one million (or approximately ninety per-cent) of these students were in public school, an estimated 125,000 were in private schools, and 17,500 were home-schooled. The public school students almost exclusively attend school in their county or city. In Virginia, these counties and cities, when taken together comprise the 134 school divisions in the Commonwealth.[1] There are some wonderful programs of instruction in place and numerous excellent teachers working in schools throughout these 134 school divisions. Children complete some of these programs at some schools with incredible knowledge and skills and proceed to be successful at some of the top colleges in the Nation. Other students complete these courses or very good courses with highly qualified teachers and are successful at a diverse range of colleges, two-year institutions, or in the workplace. However, not all students have access to highly qualified teachers, exposure to specific content, or support infrastructure – particularly in science and mathematics[2] - and many graduates go on to the workplace or further education after high school graduation feeling unprepared, identified by their employers as unprepared, or requiring remedial, not-for-credit courses[3]. Outcomes are uneven within school divisions where, even when technology and infrastructure are evenly distributed, a few schools may have more highly qualified teachers than others.

The United States has no national curriculum. The evolution of education in the United States has left the responsibility for educating the Nation's young to each State (Tenth Amendment to the Constitution of the United States). A brief chronology of education in the United States is drawn from Pulliam and Van Patten's *History of Education in America*:

- 1600's – 1750's: Government involvement in education varies by geography. Northern colonies require primary education first at home then at "schools" to be

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[1] As a reference, there are approximately 50 million K-12 students nationwide attending school in approximately 15,000 school divisions.

[2] In 1992, only twenty-two out of sixty-one high school mathematics teachers had a subject-area degree (defined as 36 semester hours of Calculus or higher coursework) in a review of transcripts of teachers in one large urban Virginia school division. More recent data show that approximately 10% of high school students (grades 9-12) are enrolled in one or more AP (Advanced Placement) courses, 1% are in Governor's Schools, and 0.25% are in IB (International Baccalaureate) Programs. This means that some 90% of Virginia's children rely on the Virginia Standards of Learning (SOL) to assure the quality and appropriateness of their science course content.

[3] Rising to the Challenge: Are High School Graduates Prepared for College Work? A Study of Recent High School Graduates, College Instructors, and Employers. Conducted for Achieve, Inc, by Peter D. Hart Research Associates (February 2005).

established with tax dollars. Southern farm economy and demography focuses more on home-schooling with a few free-schools sponsored by the wealthy. Teachers in schools have minimal education. Teaching confined to reading, arithmetic, writing, and religion (four R's). Only two universities by 1700 (Harvard and William & Mary – both religious as were the next ones, Yale, Princeton).

- 1770's – 1850's: State universities established; "Graded" primary schools established (1820); high schools established (1830); still wide discrepancies between northern cities and agricultural South. Most schools still one room, utilitarian or worse; Establishment of teacher training "normal schools" (1830's). By 1850, 45% of children attended school and half the states had established school systems.

- 1860's – 1910: Establishment of Land Grant colleges for agriculture and engineering (Morrill Act) by Federal government (industrial revolution). High school growth (1890); standardization of curriculum 1910; 400 teacher training (normal) schools by 1900.

- 1910 – 1950's: Establishment of vocational training schools; special education curriculum; development of educational theories and research; national accreditation standards; school year of 172 days with compulsory attendance (1930); GI Bill for continuing education (1944); Vannevar Bush's "The Endless Frontier" emphasizing the critical importance of science to the U.S. economy and National defense (NSF Report 1945)

- 1954 – today: Brown v. Board of Education; Cold War post-Sputnik focus on Science and Mathematics; National Defense Education Act; Elementary and Secondary Education Act (1965 – Title I) and amended to Improving America's Schools (1994), and to No Child Left Behind (2002); Teacher Corps; growth of kindergarten enrollment; much research into child psychology and learning; Department of Education (Cabinet level) established 1979; A Nation at Risk (1980's); National Science Education Standards (1996); Science for All Americans/Benchmarks/Project 2061 (1990's). State Standards of Learning (1990's). Physics First (2000); ubiquitous availability of knowledge on the World Wide Web (2000); Global outsourcing (2000); Computational technology double exponential growth (Moore's Law)

- Today – 2030: ?? Political, Economic, Social, Technology impacts ??

From this synopsis, we see that while education remains the responsibility of the states, there has been increasing responsibility/authority taken on by the Federal Government, particularly with and since the establishment of Land Grant colleges in 1862. Most recently, two well-respected national organizations, the National Research Council of the National Academies of Science and the American Association for the Advancement of

Science have developed documents that lay out *potential* national standards and benchmarks for Science in the Nation's schools K-12[4].

In addition to these two national efforts, the past fifteen years has seen individual states develop their own standards in a number of academic disciplines. Virginia began its standards development under Governor Allen around 1994. The focus of these first standards was school *accountability*. In an effort to assure accountability of all of Virginia's public schools with respect to some common course content, the Virginia Standards of Learning (SOL) were created. These SOL are implemented as *outcome* standards in that the assessments or tests associated with them identify whether the material was *learned* by students (as opposed to simply *taught* by teachers).

To further clarify what the SOL are intended to be and what they are not intended to be, we can look at two excerpts from the Introduction to Virginia's Science SOL:

- "The Science Standards of Learning for Virginia's Public Schools identify academic content for essential components of science curriculum at different grade levels." and;
- "The Standards of Learning are not intended to encompass the entire science curriculum for a given grade level or course or to prescribe how the content should be taught. Teachers are encouraged to go beyond the standards and select instructional strategies and assessment methods appropriate for their students."

While conceived as minimal accountability standards (a floor), the content of the SOL soon became the course outline for many teachers. As fiscal pressure, particularly through the No Child Left Behind (NCLB) Federal legislation, increased for students to pass these state assessments, school administrators put more pressure on teachers to assure that their students would indeed pass. This pressure along with the large breadth of the SOL for some courses, has precluded many teachers from "go(ing) beyond the standards".

The standards are revised every seven years as a part of the formal review process approved by the State Board of Education – science comes up for its next revision in 2010. *The output from these panels will serve to inform that review process.*

So the job of Physics team and Chemistry team is to develop some consensus around the essentials of citizen knowledge in (Physics)/(Chemistry) for the next 25 years. That is, what is the essential Physics or Chemistry knowledge that citizens should have to understand the world around them, to make decisions on political questions that more and more involve understanding of science and technology, to triage and understand the plethora of news and information that is available by the current World Wide Web and by the next generation Internet. The task of the Engineering team is not too much different

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[4] *National Science Education Standards* (National Academy Press, 1996) and *Project 2061: Science for All Americans* and *Benchmarks* (American Association for the Advancement of Science, 1990) – the latter two books are included in your package.

but will be a bit more broadly defined in terms of what Engineering Program would be most appropriate for our students in the 21st century. As we will discuss when our team meets, Engineering is not a part of the traditional curriculum for which there are SOL; it has developed in the CTE (Career and Technical Education) wing of the Department of Education. Thus we cannot look at an SOL content set for Engineering, but we will look at various programs that our teachers have created and some national programs that have been created.

In addition to the current Virginia Standards, the Physics and Chemistry teams will have available to them sets of standards from other states that have been judged as "leaders" in the development of quality standards[5], the International Baccalaureate (IB) standards which represent a consensus of representatives from more than 100 countries around the world, and some "new" thinking (actually a decade old) by Leon Lederman on sequencing and content of science courses.

We will also have for reference the *National Science Education Standards*, the Project 2061 *Science for All Americans* and *Benchmarks,* and the thinking of the American Institute of Physics on an advanced high school Physics course - *Improving Advanced Study of Mathematics and Science in U.S. High Schools: Report of the Content Panel for Physics (2002).* What our team brings to the scene is unique – not claimed to be better or worse just unique - from previous work in three ways:

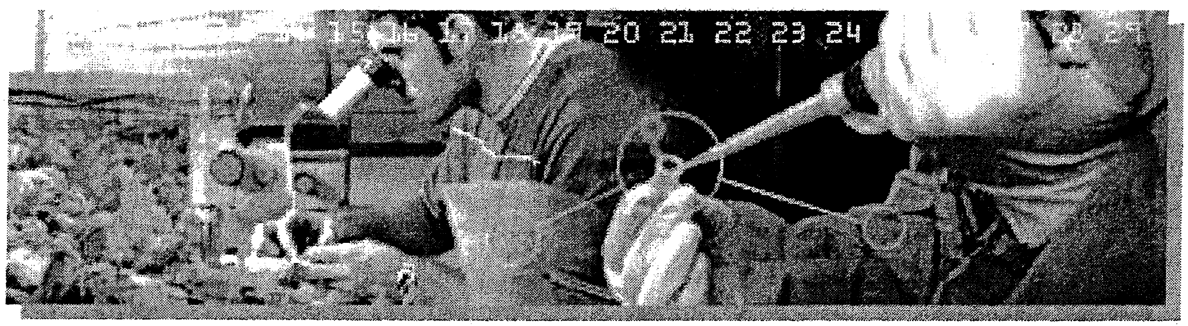
1. We are a team of content-centric practitioners – not education specialists.
2. We have the current range of standards developed and implemented over the past decade as benchmarks – we have the advantage of standing back and evaluating what's been created there.
3. We bring a range of perspective from university *research* through government laboratory *technology and development* to industry *development and applications*.

Finally, a reminder that our panels are NOT defining advanced course content – that work is being done nationally and it focuses on the top 10% of our students. Our focus is on ALL students in laying out a safety net of science (physics/chemistry) content that the remaining 90% of our students need to be economically and politically productive citizens of Virginia in the 21st Century.

On behalf of all the children in the Commonwealth, I thank you for contributing to this unique endeavor.

[5] Paul R. Gross: The State of State SCIENCE Standards. Thomas B. Fordham Institute (2005).

KENTUCKY SURVEY OF CRITICAL TECHNOLOGIES: Highlights



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PREFACE

The economy is being transformed by many exciting new technologies emerging from research labs worldwide - which must be introduced appropriately into learning experiences at various levels throughout the education enterprise. Such a routine infusion of new knowledge will help excite young people to *learn* about some technologies or perhaps their new applications that may not have existed even just a few short years ago. Only by deliberate infusion strategies to keep pace with technological changes will we be able to prepare coming generations of scientific and technologically savvy people for the research labs and start-up companies fueling the knowledge economy.

Kentucky Science and Technology Corporation (KSTC), through the Kentucky Science and Engineering Foundation[1] (KSEF), sponsored this survey of Kentucky science teachers in order to begin a journey alongside our teachers to explore how best to bridge important connections between our schools and the economy, particularly as they relate to keeping pace with critical and emerging technologies. Every day KSTC deals with entrepreneurs, university faculty and educators as they carry out their complementary roles in the knowledge economy. In doing so we began to sense an unintended disconnect among these players, each committed to and deeply engaged in their own work.

We embarked upon this survey, with the assistance of Horizon Research International, to determine if these perceptions were indeed reality - and, if so, to create solid footing on which to extend our work with various groups to develop relevant strategies and processes to help bridge any knowledge gaps on these technologies and others that are sure to emerge for years to come. No one sector or organization can make the fundamental interconnections needed. It will take a crosscutting approach to design dynamic strategies and on-going processes that will assist the information transfer --and age-appropriate translations-- into our schools and learning environments.

This original research involved an on-line survey of Kentucky middle school and high school teachers of science from a diverse, representative set of schools across the State. Our intent was to gauge current levels of understanding of leading edge scientific terms and concepts in five broad categories being targeted by the Commonwealth for investments in tech start-up companies and research efforts. The purpose of the survey was to establish the current levels of awareness, instruction and interest in cutting edge technologies that are reshaping the science and engineering landscape.

The survey was conducted by Horizon Research International under the KSEF human resource development program. Although primarily focused on building Kentucky's world class research capacities, KSEF's complementary education goal is to create and help institute programs for human resource development at schools that ultimately result in a workforce and innovative talent base for creating and applying science and engineering technologies.

We offer these findings in the spirit of thoughtful conversation on the critical and often rapidly changing interconnections between education and economic growth that are increasingly evident now and will continue to emerge for the foreseeable future. We thank Horizon and the many teachers who participated for their willingness to participate in this initial phase of project. It will take many more people from various sectors and regions to engage in an ongoing conversation to strengthen the infusion of critical technologies into the learning enterprise - everyday! Planning is underway to begin developing a cohesive response. We welcome all suggestions for next steps, new strategies and above all your talent to help bring the excitement of discovery from the lab to young learners.

Kentucky Science and Engineering Foundation
Kentucky Science and Technology Corporation

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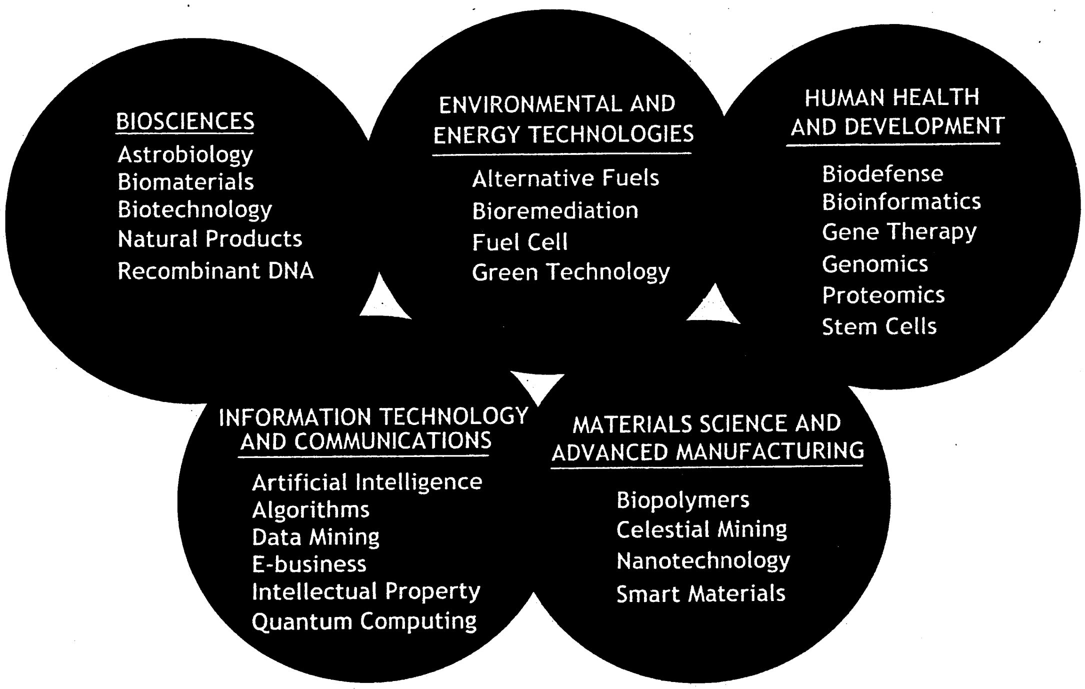
[1] The Kentucky Science and Engineering Foundation is supported by the Commonwealth of Kentucky under a contract between the Council on Postsecondary Education and Kentucky Science and Technology Corporation.

RESEARCH OVERVIEW AND IMPLICATIONS

In 2003, Kentucky Science and Technology Corporation retained Horizon Research International to conduct an on-line survey among science teachers in public middle and high schools across Kentucky. The study was designed to measure the awareness, familiarity, and plans for curriculum integration of 25 scientific and technological concepts[2] that have been identified as among the emerging areas of growth in the New Economy. In February 2004, Horizon completed the survey.



These concepts were concentrated in five scientific and engineering focus areas targeted by Kentucky which included: *Biosciences, Human Health and Development, Environmental and Energy Technologies, Information Technology and Communications, and Materials Science and Advanced Manufacturing*. Concept definitions as they were presented in the survey have been included as an appendix to this report.

[2] Researchers, engineers, educators and business people participated in the selection of the sample of 25 scientific and engineering concepts.

Overview of Findings

Responses gathered from 241 Kentucky teachers[3] highlighted current realities regarding the penetration of these concepts in current curricula. Most notably, the results showed that only 53 percent of middle school teachers were currently teaching any of the concepts to their students. High school teachers, as might be expected, were further along, but there were still one in five who were not teaching any one of the concepts. As a whole, about three out of four science teachers were teaching at least one of the 25 concepts.

Concepts Being Taught Most Often	
Alternative Fuels	42%
Gene Therapy	26%
Recombinant DNA	25%
Natural Products	25%
Stem Cells	24%

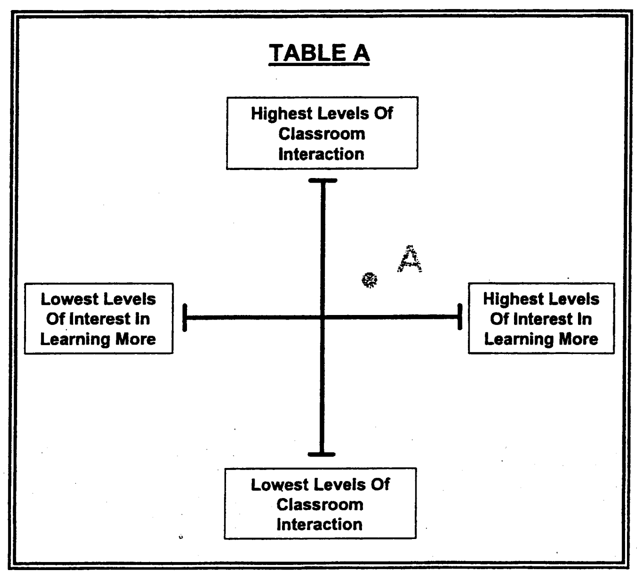
Traction Analysis

Although a discreet series of questions were asked in the survey to gauge awareness and levels of understanding, the response to two specific questions surfaced as the best indicators of not only the current environment, but also where potential may exist for next-step strategies. Those two measures were:

- Which concepts are you currently teaching?
- Which concepts are you interested in learning more about?

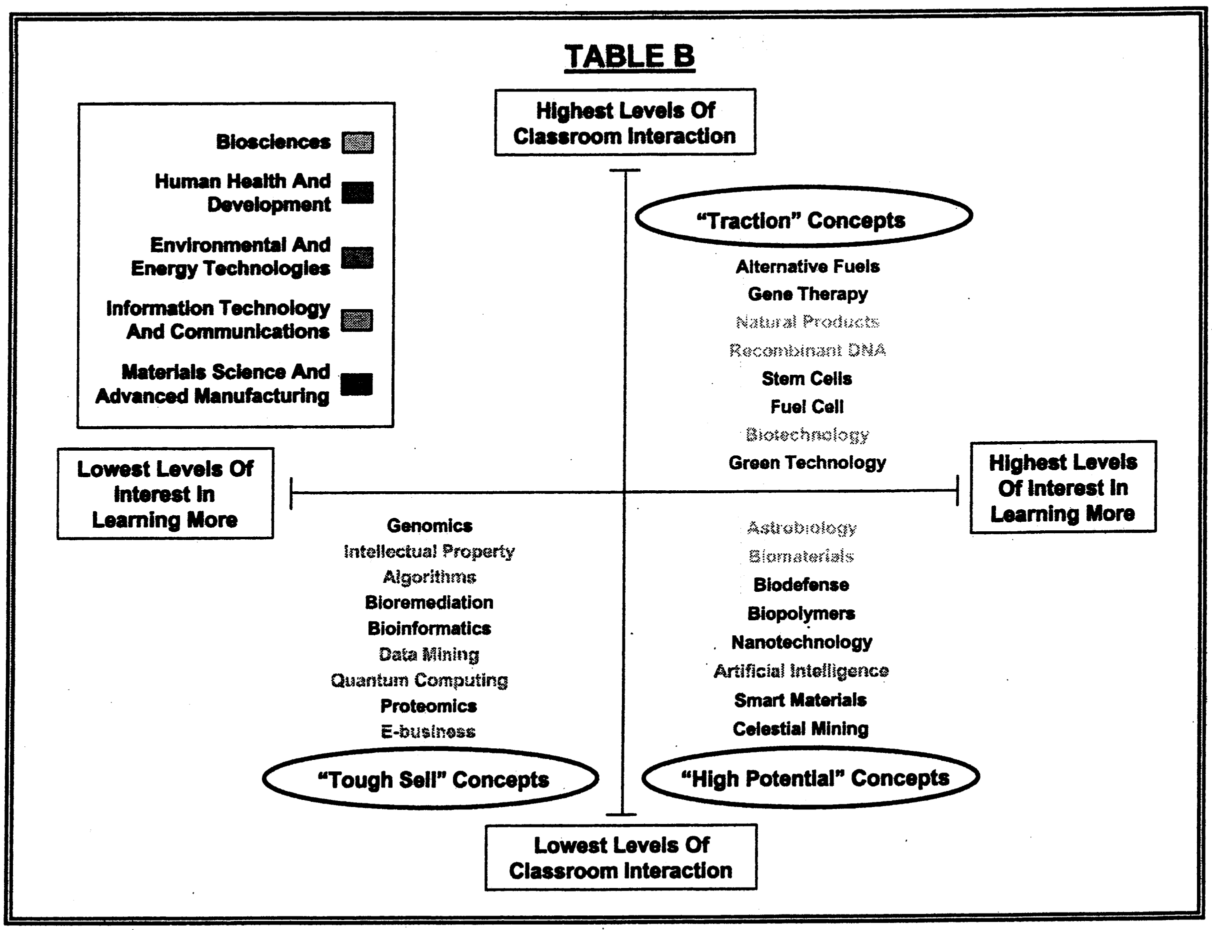
To explore the relationship of these two measures, a quadrant analysis was created (see Table A). The quadrants were defined by plotting the results of two key measures on independent axes.

For example, if a concept was currently being taught by an above average percentage of teachers and an above average percentage of teachers were also interested in learning more about the concept, then the concept would be plotted at point "A" in the upper right quadrant of Table A.



[3] The random sample of science teacher respondents was representative of middle and high schools, urban and rural geographic locations, large and small student enrollments, and economic conditions evidenced by percent of students receiving free and reduced lunches.

By then evaluating each concept in terms of classroom penetration and interest, three distinct categories emerged for classifying the concepts (see Table B).



The categories are explained in further detail on the following pages for consideration in developing possible next step strategies.

When asked about their preference for receiving more information about these emerging concepts and new technologies, the teachers acknowledged that their most preferred method would be "using a Website." "Written materials available by mail" was the second most preferred channel for information distribution.

Teachers read and reference a wide variety of publications. As such, it will be important to disseminate the new information using much broader strategies and not focus exclusively on any one or two particular vehicles.

"Traction" Concepts:

Higher Interest/Several
<u>Currently Teaching</u>

Alternative Fuels
Gene Therapy
Natural Products
Recombinant DNA
Stem Cells
Fuel Cells
Biotechnology
Green Technology

These concepts, relatively speaking, have the highest level of current classroom integration. Teachers are also more interested in learning about these concepts. Apparently these topics are catching on with some teachers and have, in some way, made their way into the classroom already. As a result, teachers are interested in furthering their knowledge base around these concepts so they can continue to expand and integrate their applications in the classroom. These concepts present the best opportunity for immediate success since some teachers have already made the curriculum connection and others have observed or know of their success. As such, teachers have embraced these topics more than others and have demonstrated an interest in taking them to another level.

"High Potential" Concepts:

Higher Interest/Few
<u>Currently Teaching</u>

Astrobiology
Biomaterials
Biodefense
Biopolymers
Nanotechnology
Artificial Intelligence
Smart Materials
Celestial Mining

This category is comprised of concepts that are of some interest, but are not being integrated into the classroom. Teachers are likely to see the immediate value in these concepts and therefore integrate them into their curriculum. However, they do not know enough about the concept specifics to be comfortable in doing so. As a result, they are interested in learning more - probably in the hopes of compiling enough information to help prepare them for teaching the ideas to their students.

"Tough Sell" Concepts:

Low Interest/Few
<u>Currently Teaching</u>

Genomics
Intellectual Property
Algorithms
Bioremediation
Bioinformatics
Data Mining
Quantum Computing
Proteomics
E-business

These concepts are not currently being taught by teachers and do not engender notable levels of interest for future investigation. Teachers probably find it difficult to see how these concepts fit into their current curriculum. They may see the concepts as important but have not made the "connection" that is necessary for classroom integration. These concepts will be the most challenging for teachers and will likely take significant levels of education and demonstrated applications before an attempt will be made to bring the ideas to their students.

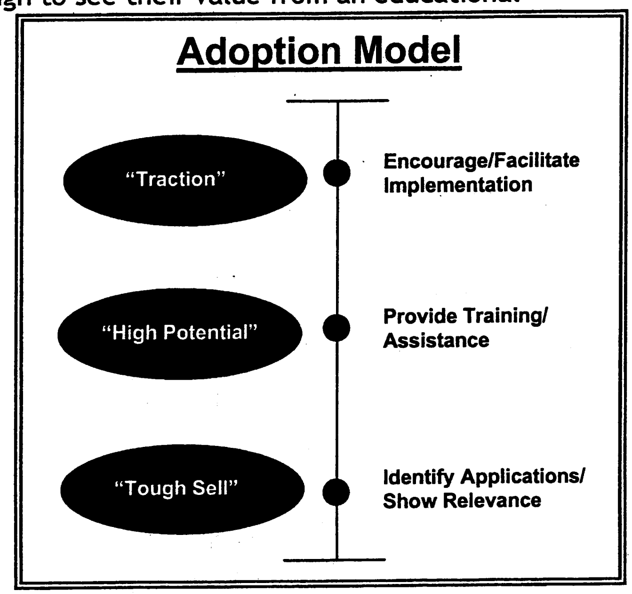
Conclusions and Implications

These 25 concepts were met with very mixed reviews. The survey results indicate "pockets" of concepts that offer opportunities to address the findings in a variety of ways when communicating with the larger body of science educators.

The easiest to integrate into a broader audience will be the "Traction" concepts. Teachers already are infusing them into the classroom and eager for more information. More teachers are likely to be familiar with these concepts; many will understand their basic fundamentals and some will already be teaching the concept. That said, it will be helpful to provide educators with materials and information on how to expand their classroom integration. By providing actionable materials, even lesson plans, Kentucky teachers may more quickly embrace new information and take further action. For those educators who are already discussing the concepts with their students, the materials will provide deeper and richer alternatives for expanding on what they already recognize as important educational fundamentals.

For those who are not currently teaching the concept but might like to do so, these materials would provide them with a medium for integrating the information into their curriculums.

"High Potential" concepts will require a more informative approach. These concepts are relatively familiar to educators, well enough to see their value from an educational standpoint. However, their knowledge is not deep enough yet to engender classroom integration. It will be important to communicate the advanced specifics of these concepts to teachers and help them acquire new knowledge. At this level, it will be important to provide teachers access to the breadth and depth of information they might need for grade-appropriate integration. This could be in the form of text books, white papers, training programs/professional development and/or web sites, etc. Providing them an informational oasis will allow them to increase their own familiarity level first.



"Tough Sell" concepts are likely to meet the most resistance because of the lack of awareness and thus will be difficult for teachers to integrate into the classroom until grade appropriate applications can be made more readily accessible. At present, science teachers have yet to identify with these concepts.

For many teachers, just the term itself might be foreign. In this case an extensive array of materials that identify applications in the modern world and their immediate relevance might prove useful. Only after this is accomplished will a critical mass of teachers become receptive to application materials. This will no doubt be the most challenging of the three approaches.

EXECUTIVE SUMMARY OF FINDINGS

In 2003, Horizon Research International was retained by the Kentucky Science and Technology Corporation to conduct an on-line survey among science teachers in public middle and high schools across Kentucky. The study was designed to measure the awareness, familiarity, and plans for curriculum integration of 25 scientific and technological concepts that have been identified as areas of growth in the Kentucky's "New Economy."

General Summary

The data from 241 interviews displayed results that were as varied as the concepts themselves.

- General name awareness of the concepts ranged from 99% for the more publicly covered concepts such as *Stem Cells* to just 5% for lesser known areas like *Proteomics*.
- Seventy-nine (79) percent of these teachers were familiar with the concept of Alternative Fuels while only 2% had that same familiarity with Proteomics
- There were large disparities between these concepts even when it came to classroom integration. Almost half of the surveyed teachers (42%) were currently teaching some aspect of Alternative Fuels. On the other hand, only 1% of these middle and high school teachers were covering any of the principles of Proteomics in their classrooms.

Even with the wide range of attitudes and behaviors surrounding these concepts, more than two out of every three teachers (69%) were currently teaching at least one of the concepts to their students. However, only about two out of five (41%) were teaching three or more of these concepts.

Consistently noted throughout this data is a significant difference between high school and middle school teachers. Across all the key measures, high school teachers recorded consistently higher ratings than their counterparts. However, this was to be expected given the more advanced nature of high school curriculum compared to that taught in the middle grades.

This gap was the largest when comparing current classroom integration. Where four out of every five high school teachers were currently teaching one or more of these concepts, just over half (53 percent) of middle school teachers were following that same behavior.

Summary By Discipline

While there was wide disparity between these concepts, there were clearly some "disciplines" that, as a whole, were more recognized and integrated than others.

- "Environmental and Energy Technologies" and "Biosciences" were clearly the most popular among the five disciplines. Nearly every teacher had heard of at least one of the concepts associated with these areas and almost half (47 percent and 46 percent respectively) were currently teaching one or more of the associated concepts in their classroom.

- "Materials and Advanced Manufacturing" and "Information Technology and Communications" were on the opposite end of the integration spectrum. While most teachers had heard of at least some of the concepts, less than one out of five were currently teaching any of them.

- Interestingly, almost half of the teachers (45 percent) understood at least one of the "Information Technology and Communications" concepts well enough to teach, yet only 17 percent were currently taking advantage of their knowledge by integrating it into their curriculum.

- "Human Health and Development" was the most varied of the disciplines. This was likely due to the range of concepts it represents. Every teacher had heard of at least one of the discipline's six concepts and two out of three (64 percent) were comfortable enough to integrate one of them in their curriculum. However, only one out of three was currently imparting that knowledge to their students.

Summary Of Concept Awareness

As expected, the more publicized concepts were those with the greatest awareness while the lesser known and more technical concepts fell to the bottom in terms of awareness. This was true of both high school and middle school teachers.

Summary of Concept Familiarity

Familiarity with the concepts mirrored the awareness data. Concepts with the highest levels of awareness were also the most familiar among these teachers.

Also consistent with the awareness findings, high school teachers had significantly higher levels of familiarity with most of these concepts than did middle school teachers.

Summary of Curriculum Integration

Following the established pattern, the concepts with the most familiarity were also those that were understood well enough to be integrated into classroom study.

These same top concepts were also the ones most likely to actually make the transition into the classroom. However, in most cases, only about half of the teachers who were comfortable with the concept were actually teaching it to their students.

Again, the high school teachers were more likely to be currently teaching these concepts than were middle school instructors.

Of further note, consistent across all of these concepts, there existed a gap between comfort and actual integration. This base of teachers felt comfortable enough to integrate the concept's teachings and felt the concepts were grade appropriate, however, they were not integrating them.

RESEARCH BACKGROUND AND METHODOLOGY

Background And Objectives

Horizon Research International was retained by the Kentucky Science And Technology Corporation (KSTC) to measure awareness and knowledge among middle and high school teachers regarding specific concepts related to five areas of new and emerging technologies.

- Biosciences
- Human health and development
- Environmental and energy technologies
- Information technology and communications
- Materials science and advanced manufacturing

The objectives of the study were clearly focused on determining:

- Awareness levels for each concept
- Familiarity, or lack there of, with each concept
- Comfort level with integrating the concepts into the classroom
- Current or future plans for teaching these concepts to students
- Interest in learning more
- Profile of teachers by grade level taught and experience

A total of 25 concepts, selected through an extensive survey of recommendations from scientists, engineers, educators, entrepreneurs and other businesspeople, were tested across these five scientific areas.

Questionnaire Design

A questionnaire was developed by Horizon Research International with consultation from representatives at the Kentucky Science and Technology Corporation.

The final questionnaire was then programmed for Internet-based administration and was hosted on Horizon Research International's secured Internet server.

Sample Design

Several steps were taken to ensure that the interviews completed would be representative of Kentucky's middle and high school teachers as a whole.

A "multi-staged" probability sampling process was used to sort 462 middle and high schools in Kentucky on the criteria below so that schools from all regions, economic situations, and of all sizes would be included in the proper proportion.

- Region (Eastern Kentucky, Western Kentucky, and Central)
- Percent of students receiving free lunch
- Number of enrolled students

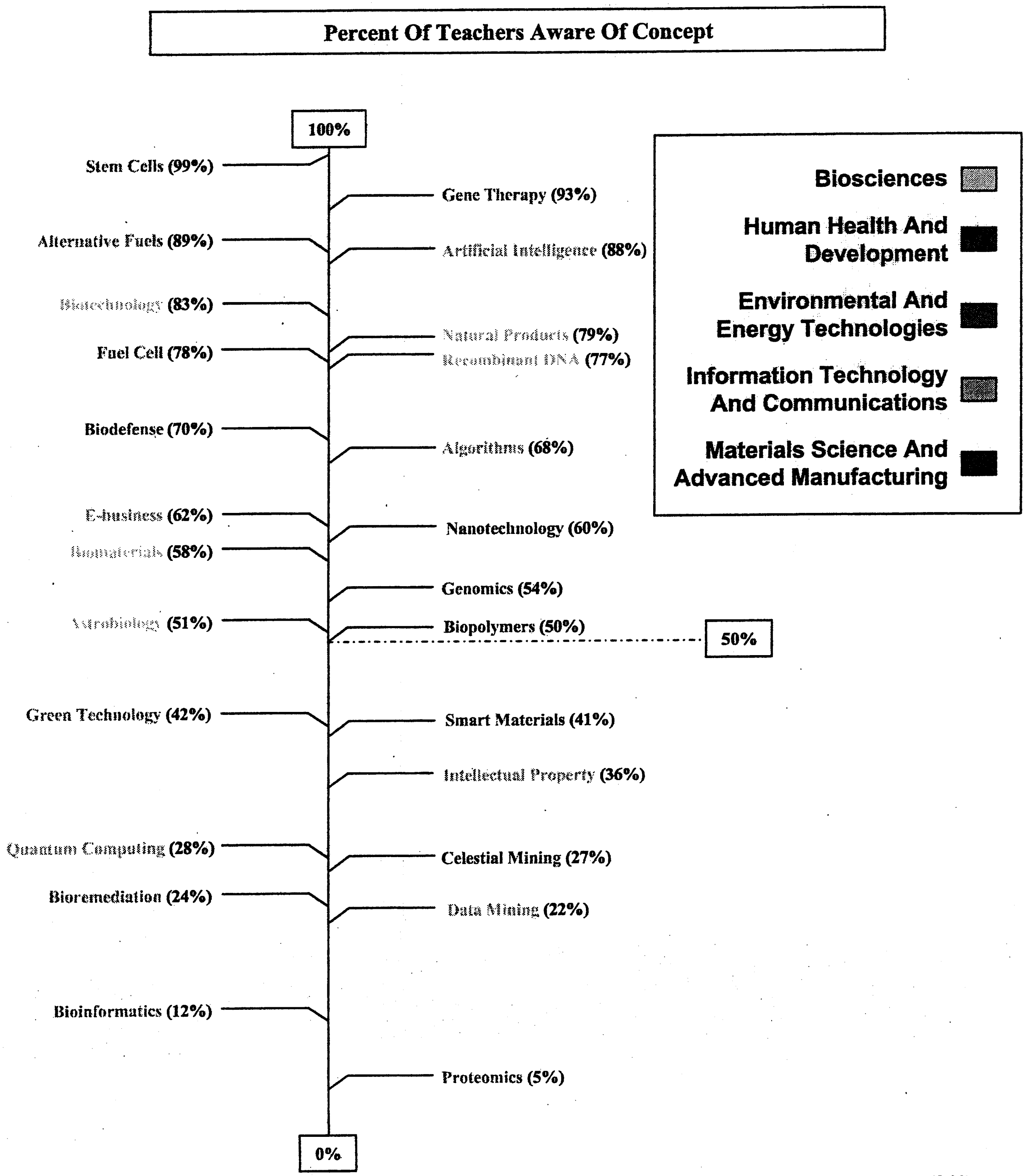
Letters were sent to 120 randomly selected schools. These letters were followed with a phone call from trained interviewers at Horizon Research International. The contact person at the school was asked to provide their email address. However, after a lower than expected response rate, contact was eventually attempted with all 462 middle and high schools.

Horizon Research International then emailed each school contact requesting the email addresses of all science teachers. Those contacts not responding to the initial email request were sent at least two reminder emails requesting the information again. Contacts from 121 schools provided email addresses for their science teachers - a total of 602 teachers. A complete sample disposition has been included in the full report.

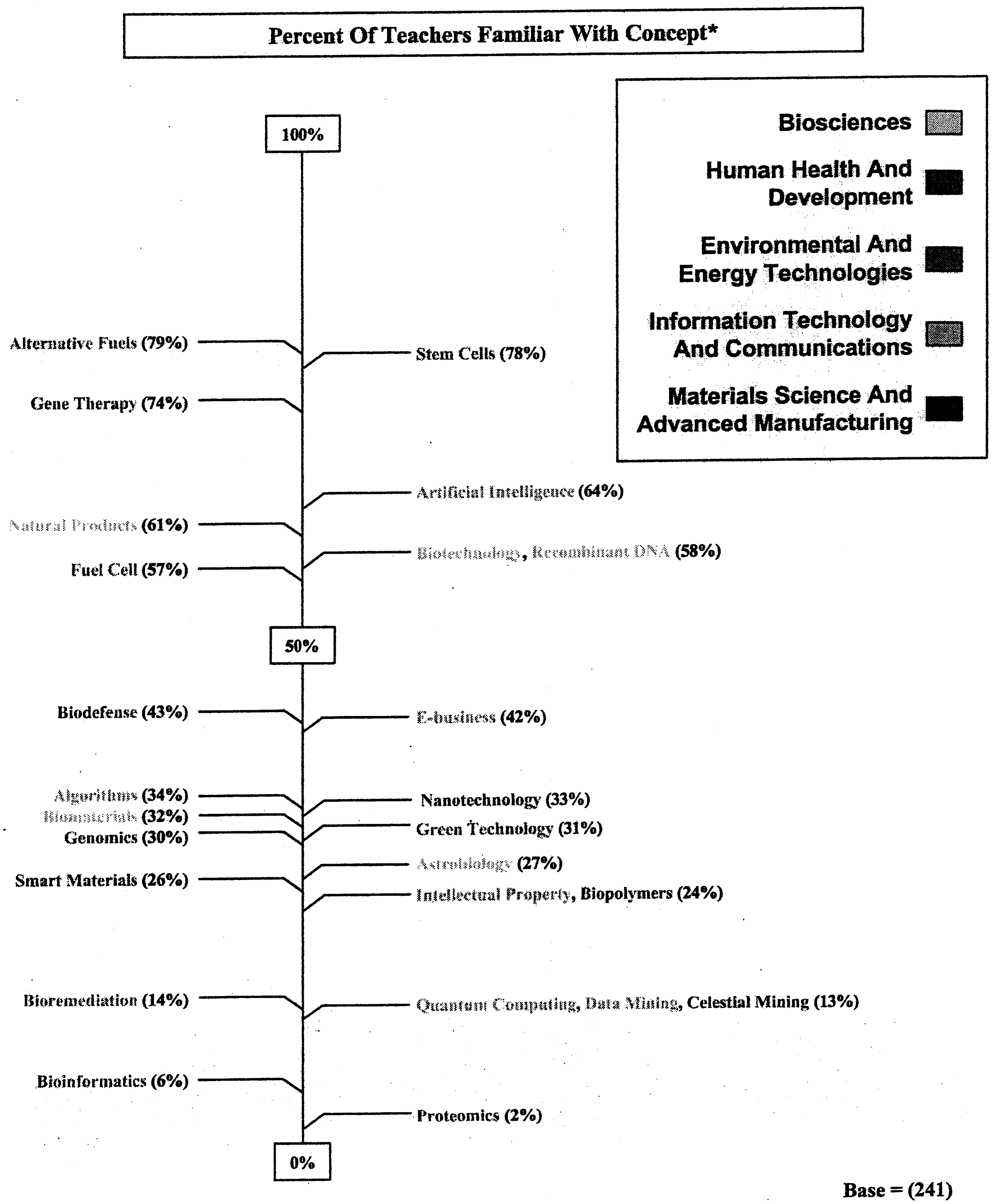
A total of 241 teachers eventually completed the survey. In order to ensure these 241 teachers were representative of all middle and high schools in Kentucky, the data was weighted to the actual proportion of the criteria initially used to stratify the sample - (region, total enrollment, and percent of students on free and reduced lunch).

A sophisticated data tabulation software was then used to tabulate the data and analyze the results.

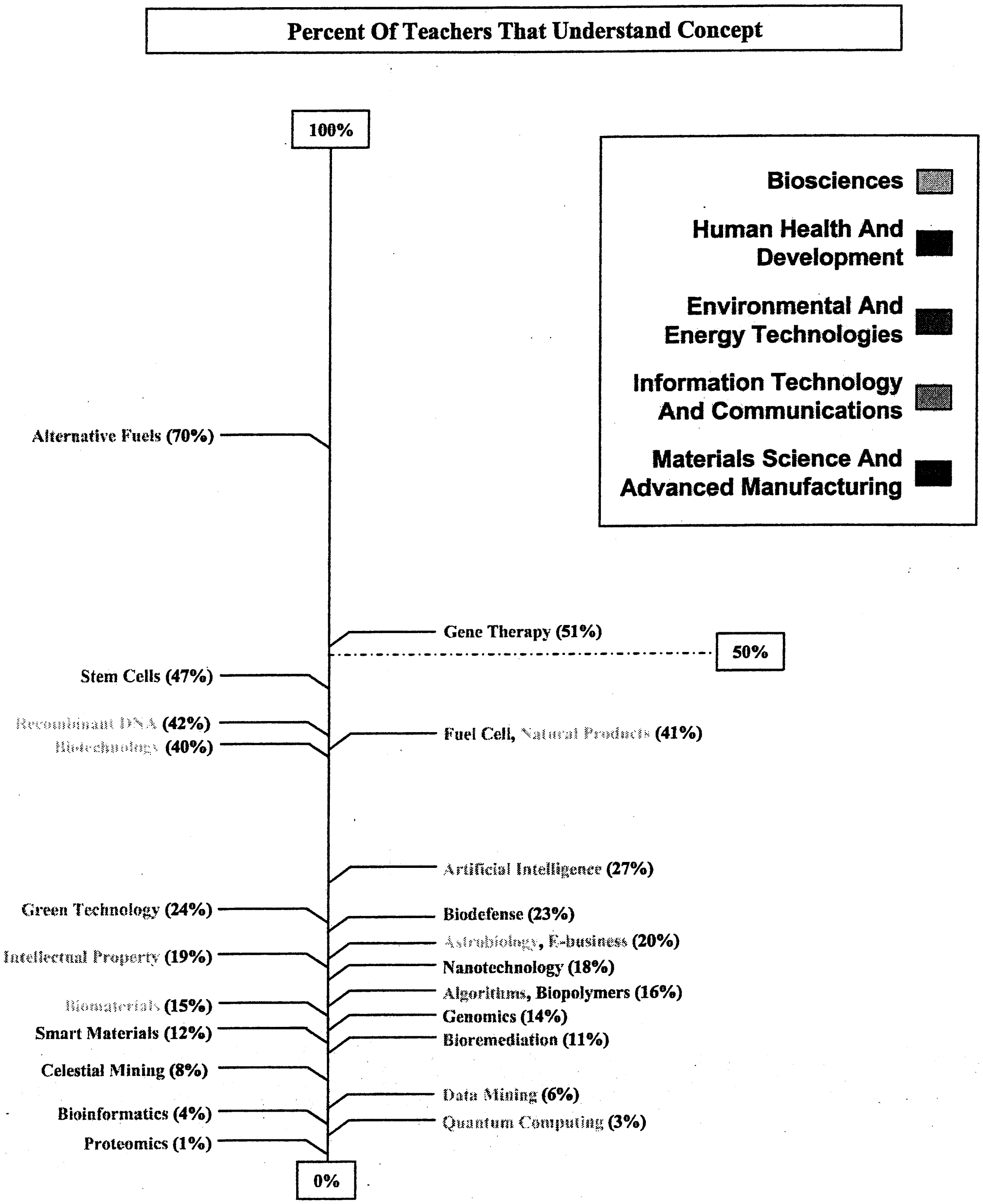
SUMMARY TABLES (TOTAL RESULTS)



Base = (241)

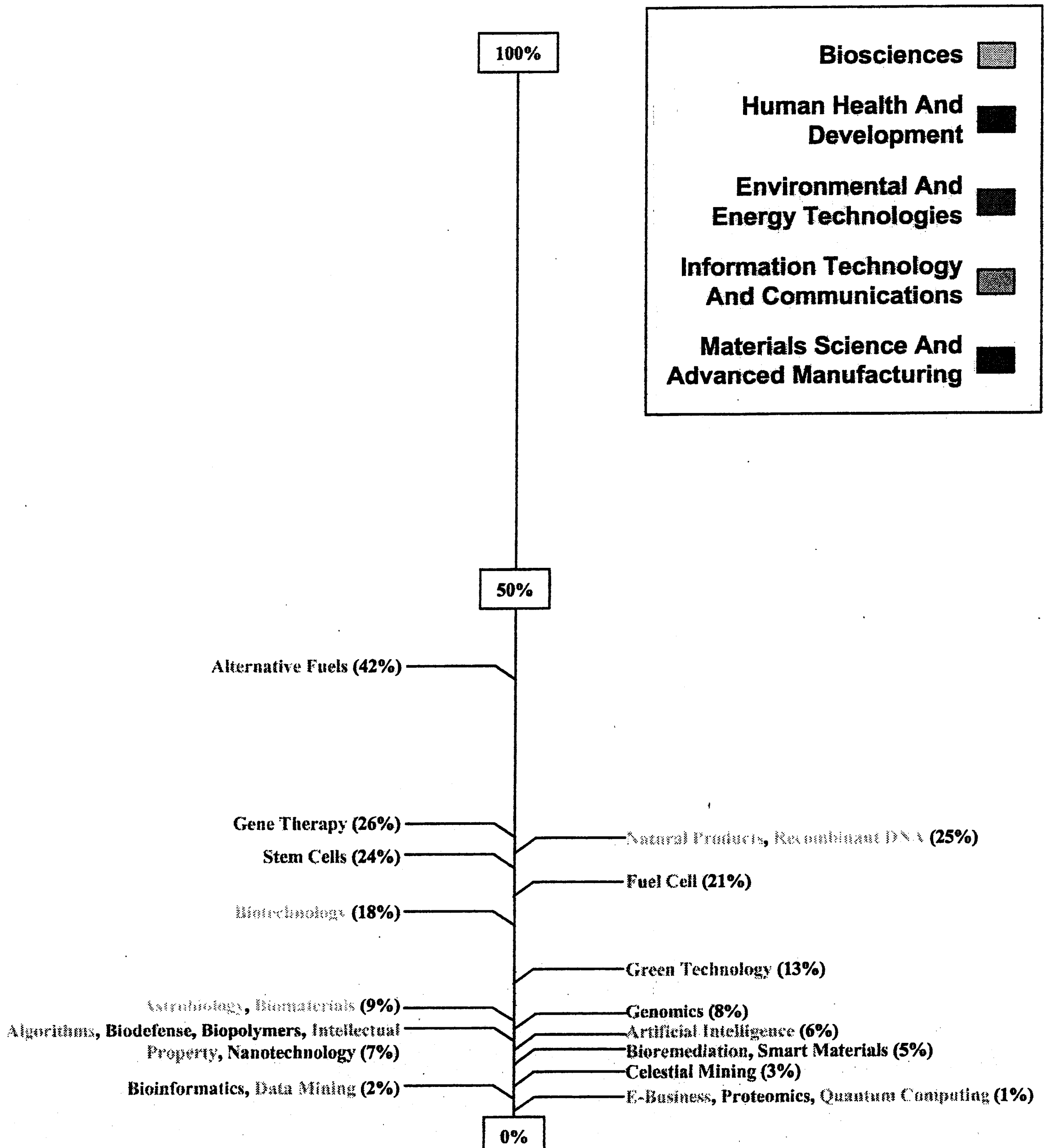


** Summary of "extremely/very/somewhat familiar" with concept.*


Percent Of Teachers That Understand Concept
100%
Biosciences
Human Health And Development
Environmental And Energy Technologies
Information Technology And Communications
Materials Science And Advanced Manufacturing
Alternative Fuels (70%)
Gene Therapy (51%)
50%
Stem Cells (47%)
Recombinant DNA (42%)
Biotechnology (40%)
Fuel Cell, Natural Products (41%)
Artificial Intelligence (27%)
Green Technology (24%)
Biodefense (23%)
Astrobiology, E-business (20%)
Intellectual Property (19%)
Nanotechnology (18%)
Algorithms, Biopolymers (16%)
Biomaterials (15%)
Genomics (14%)
Smart Materials (12%)
Bioremediation (11%)
Celestial Mining (8%)
Data Mining (6%)
Bioinformatics (4%)
Quantum Computing (3%)
Proteomics (1%)
0%

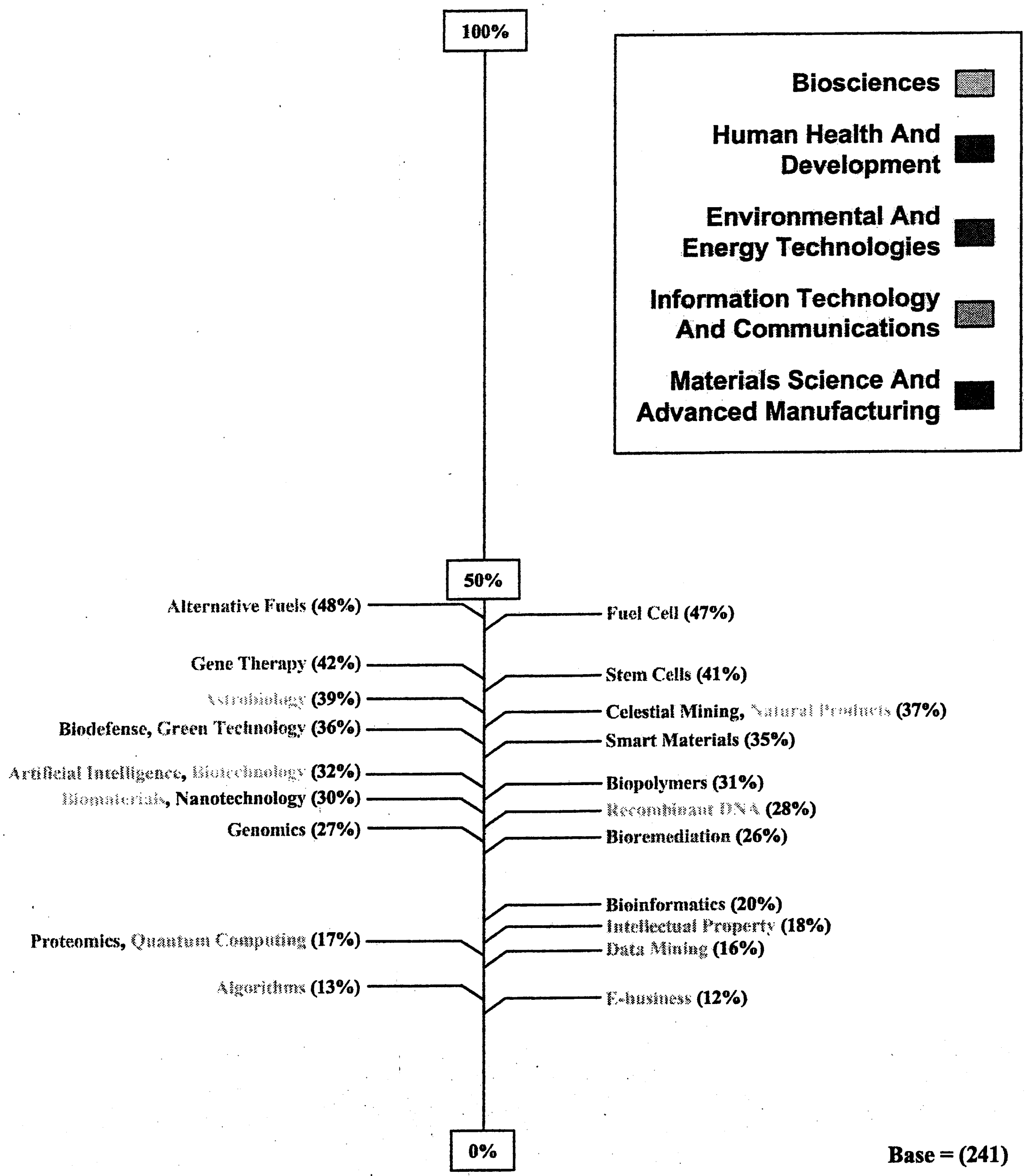
Base = (241)

Percent Of Teachers Currently Teaching Concept



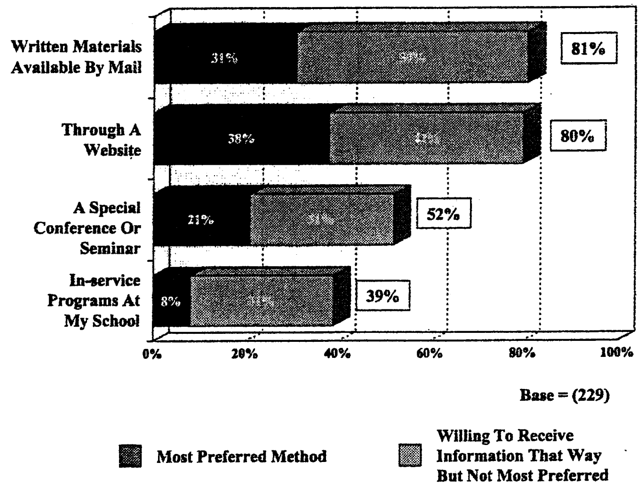
Base = (241)

Percent Of Teachers Who Want To Learn More About Concept



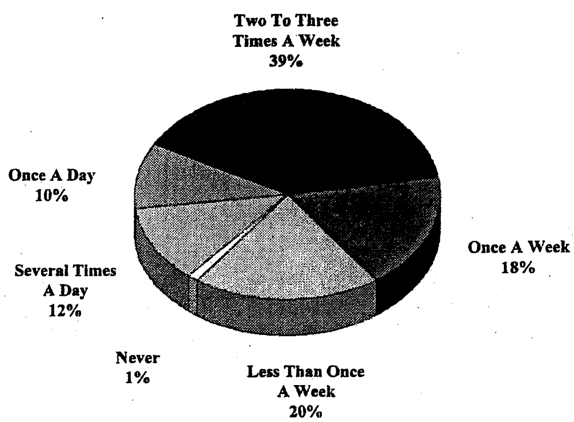
Base = (241)

PREFERRED METHODS OF CONTACT FOR INFORMATION ON EMERGING CONCEPTS AND NEW TECHNOLOGIES TOP RESPONSES*



*Among those who would be interested in learning more about at least one of the concepts.

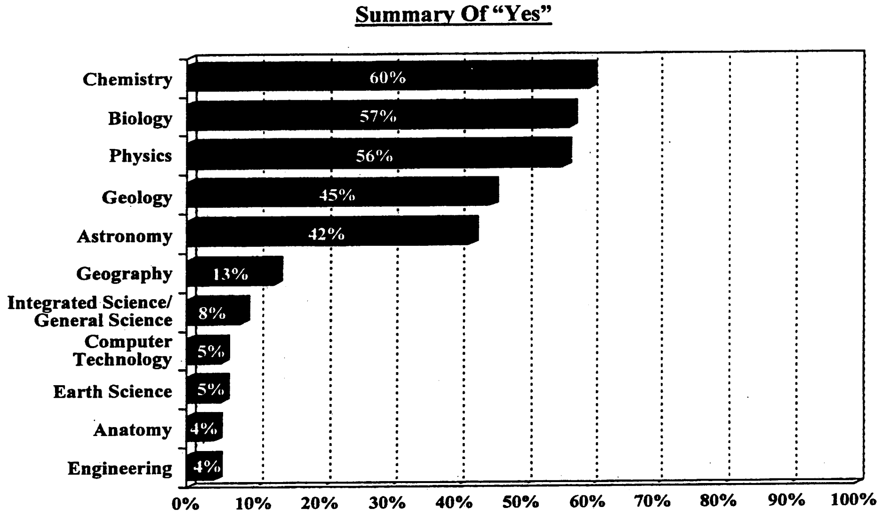
INTERNET USAGE FOR ADDITIONAL INFORMATION ABOUT SUBJECTS BEING TAUGHT



Base = (241)

RESPONDENT PROFILE

SCIENCE SUBJECTS TAUGHT – TOP RESPONSES



Base = (241)

RESPONDENT PROFILE

	Total (%)
GENDER	
Male	31
Female	69
GRADE(S) TAUGHT	
Sixth	14
Seventh	19
Eighth	17
Ninth	37
Tenth	40
Eleventh	44
Twelfth	43
YEARS TEACHING	
Less Than A Year	4
One To Three Years	10
Three To Five Years	11
Five To Ten Years	23
Ten Years Or More	51
Mean =	[10.0]
YEARS TEACHING SCIENCE-BASED CURRICULUM	
Less Than A Year	8
One To Three Years	10
Three To Five Years	16
Five To Ten Years	23
Ten Years Or More	43
Mean =	[9.1 Years]
AVERAGE RANGE OF STUDENTS PER CLASS DURING NORMAL DAY	
Minimum	20 Students
Maximum	29 Students
Base =	(241)

TEACHER SURVEY CONCEPT DEFINITIONS

Biosciences (5)
Astrobiology; Biomaterials; Biotechnology; Natural Products; Recombinant DNA

Human Health & Development (6)
Biodefense; Bioinformatics; Gene Therapy; Genomics; Proteomics; Stem Cells

Environmental & Energy Technologies (4)
Alternative Fuels; Bioremediation; Fuel Cell; Green Technology

Information Technology & Communications (6)
Algorithms; Artificial Intelligence; Data Mining; E-Business; Intellectual Property; Quantum Computing

Materials Science & Advanced Manufacturing (4)
Biopolymers; Celestial Mining; Nanotechnology; Smart Materials

CONCEPT DEFINITIONS

Algorithms: A finite set of step-by-step instructions for problem-solving or computational procedures, especially ones that can be implemented by a computer.

Alternative Fuels: Study of alternative ways to produce energy for both stationary (e.g., power plant) and non-stationary (e.g., automobiles & aircraft) applications. Alternate fuel sources include wind and solar power and hydrogenated biofuels, such as fuel cells. Ethanol can be produced from grains, agricultural wastes and excess crops. The alternatives are promoted for pollution reduction properties and/or to reduce U.S. dependence on the imported oil.

Artificial Intelligence: Computers and hardware that can make intelligent decisions based on sensory feedback.

Astrobiology: The scientific study of life in the universe - its origin, evolution, distribution, and future. This multidisciplinary field brings together the physical and biological sciences to address some of the most fundamental questions of the natural world: How do living systems emerge? How do habitable worlds form and how do they evolve? Does life exist on worlds other than Earth? How could terrestrial life potentially survive and adapt beyond our home planet?

Biodefense: Knowledge and understanding gained through genomics and proteomics leveraged to protect humans and animals against the intentional use of pathogens (bioterrorism) by detecting, identifying and assessing pathogens.

Bioinformatics: Use of computers in biology-related sciences to organize, interpret, and predict biological structure and function. Bioinformatics is usually applied in the context of analyzing DNA sequence data.

Biomaterials: Synthetic or natural materials that can replace or augment tissues, organs or body functions.

Biopolymers: Polymeric material produced from or by biological sources, for example, biodegradable plastics, that are synthesized by living organisms.

Bioremediation: The process by which living organisms act to degrade or transform hazardous organic contaminants.

Biotechnology: The use of micro-organisms, live plant or animal cells or their parts to create new products or to carry out biological processes aimed at genetic improvement for the benefit of people.

Celestial Mining: The search for, excavation and processing of essential elements and materials on extra-terrestrial bodies (planets, asteroids, etc.).

Data Mining: The process of extracting and refining useful knowledge from large databases.

E-Business: The process of doing business with trading partners electronically. This includes electronically processing business transactions, integrating business processes, transferring payments, and delivering services.

Fuel Cell: A device for generating electrical energy directly from chemical energy. It differs from a battery in that the chemicals are not stored in the cell. Rather, they are fed into it as power is needed. In most fuel cells, hydrogen is combined with oxygen

Gene Therapy: Introducing a normal, functional copy of a gene into a cell for the purpose of correcting defective, disease causing genes.

Genomics: The study of an organism's full complement of genes to enable understanding of the genes and their expression using powerful computer technologies.

Green Technology: The ability to do an industrial process with less environmental damage.

Intellectual Property: An invention that provides rights for use to an individual, group of inventors, or to an organization to exclude imitations from the market for a limited time

Nanotechnology: Technology that allows development and use of materials or structures that have a size of less than 200 nanometers. Production of devices on this small of a scale saves space and resources, resulting in improved efficiency and processing speed.

Natural Products: Chemical compounds, naturally produced in plants or by microbial species that are harvested for use in health care and drug development.

Proteomics: The study of the totality of proteins in an organism. Proteins are the building blocks of genes and studying their form and function with the aid of supercomputers complements the scientific advances being made by the mapping of Genomes.

Quantum Computing: A fundamentally new mode of information processing (still in development) that can be performed only by harnessing physical phenomena unique to quantum mechanics (especially quantum interference), with performance, potentially, billions of times faster than today's most powerful supercomputer.

Recombinant DNA: DNA that has been altered by joining genetic material from two different sources to study the expression of a gene.

Smart Materials: Materials that have imbedded sensors and actuators so that they can sense and react to their environment.

Stem Cells: Cells that, given proper growth conditions, can proliferate with almost unlimited potential, maintaining a pool of growing and dividing cells that have the ability to differentiate into a number of different cell types with specific biological functions.

Benchmarks On-Line

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ABOUT BENCHMARKS

The terms and circumstances of human existence can be expected to change radically during the next human life span. Science, mathematics, and technology will be at the center of that change--causing it, shaping it, responding to it. Therefore, they will be essential to the education of today's children for tomorrow's world.

What should the substance and character of such education be?

The purpose of this report is to propose an answer to that question.

That was how *Science for All Americans* (*SFAA*), the first Project 2061 publication, identified itself. Now, four years later, those words serve equally well to introduce *Benchmarks for Science Literacy*, a companion report. *SFAA* answers the question of what constitutes adult science literacy, recommending what all students should know and be able to do in science, mathematics, and technology by the time they graduate from high school. *Benchmarks* specifies how students should progress toward science literacy, recommending what they should know and be able to do by the time they reach certain grade levels. Together, the two publications can help guide reform in science, mathematics, and technology education.

About Project 2061

Project 2061's benchmarks are statements of what all students should know or be able to do in science, mathematics, and technology by the end of grades 2, 5, 8, and 12. The grade demarcations suggest reasonable checkpoints for estimating student progress toward the science literacy goals outlined in *SFAA*. It is important to view the benchmarks in the context of the following Project 2061 premises concerning curriculum reform:

- Project 2061 promotes literacy in science, mathematics, and technology in order to help people live interesting, responsible, and productive lives. In a culture increasingly pervaded by science, mathematics, and technology, science literacy requires understandings and habits of mind that enable citizens to grasp what those enterprises are up to, to make some sense of how the natural and designed worlds work, to think critically and independently, to recognize and weigh alternative explanations of events and design trade-offs, and to deal sensibly with problems that involve evidence, numbers, patterns, logical arguments, and uncertainties.

- Curriculum reform should be shaped by our vision of the *lasting* knowledge and skills we want students to acquire by the time they become adults. This ought to include both a common core of learning--the focus of Project 2061--and learning that addresses the particular needs and interests of individual students.

- If we want students to learn science, mathematics, and technology well, we must radically reduce the sheer amount of material now being covered. The overstuffed curriculum places a premium on the ability to commit terms, algorithms, and generalizations to short-term memory and impedes the acquisition of understanding.

- Goals should be stated so as to reveal the intended character and sophistication of learning to be sought. Although goals for knowing and doing can be described separately, they should be learned together in many different contexts so that they can be used together in life outside of school.

- The common core of learning in science, mathematics, and technology should center on science literacy, not on an understanding of each of the separate disciplines. Moreover, the core studies should include connections among science, mathematics, and technology and between those areas and the arts and humanities and the vocational subjects.

- Common goals do not require uniform curricula, teaching methods, and materials. Project 2061 is developing tools to enable teachers to design learning experiences for students that take into account state and district requirements, student backgrounds and interests, teacher preferences, and the local environment.

- Reform must be comprehensive and long-term, if it is to be significant and lasting. It must center on *all* children, *all* grades, and *all* subjects. In addition, it must deal interactively with all aspects of the system--curriculum, teacher education, the organization of instruction, assessment, materials and technology, policy, and more. All of which takes time.

Characterizing Benchmarks

Benchmarks for Science Literacy is consistent with the above premises, but is sufficiently different in content, purpose, and style from other reform reports to require some clarification.

- ***Benchmarks* is a report from a cross-section of practicing educators**. In 1989, six school-district teams were formed in different parts of the nation to rethink the K-12 curriculum and outline alternative ways of achieving the literacy goals of *SFAA*. Each team, backed by consultants and Project 2061 staff, was made up of 25 teachers and administrators and cut across grade levels and subjects. Working together over four summers and three academic years, the teams developed a common set of benchmarks. Drafts of *Benchmarks* were critiqued in detail by hundreds of elementary-, middle-, and high-school teachers, as well as by administrators, scientists, mathematicians, engineers, historians, and experts on learning and curriculum design. Chapter 13: The Origin of *Benchmarks*, describes the process in greater detail.

- ***Benchmarks* is different from a curriculum, a curriculum framework, a curriculum design, or a plan for a curriculum**. It is a tool to be used by educators in designing a curriculum that makes sense to them and meets the standards for science literacy recommended in SFAA. Moreover, *Benchmarks* does not advocate any particular curriculum design. Far from pressing for one way of organizing instruction, Project 2061 pursues a reform strategy that will lead eventually to greater curriculum diversity than is common today.

- ***Benchmarks* is a compendium of specific science literacy goals that can be organized however one chooses**. As in most reference works, chapter order is unrelated to the relative importance of the benchmarks. Chapter 1 does not set the tone for all those that follow, nor does Chapter 12 culminate all that came before. Indeed, Project 2061 expects that benchmarks from the latter will appear in combination with those from various other chapters in most curriculum units that address science literacy goals. A version of *Benchmarks* on a computer disk will enable users to assemble benchmarks from various chapters into cogent sets.

- ***Benchmarks* specifies thresholds rather than average or advanced performance.** It describes levels of understanding and ability that *all* students are expected to reach on the way to becoming science-literate. A well-designed curriculum will provide students with the help and encouragement they need to meet those standards.

- ***Benchmarks* concentrates on the *common core* of learning that contributes to the science literacy of all students.** It does not spell out all of the science, mathematics, and technology goals that belong in the K-12 curriculum. Most students have interests, abilities, and ambitions that extend beyond the core studies, and some have learning difficulties that must be taken into account.

- ***Benchmarks* avoids technical language used for its own sake**. The number of technical terms that most adults must understand is relatively small. Accordingly, the 12th-grade benchmarks use only those technical terms that ought to be in the vocabulary of science-literate people. The language in the benchmarks for earlier grades is intended to signal the nature and sophistication of understandings to be sought. The Project 2061 analysis of these and other issues is summarized in Chapter 14: Issues and Language.

- ***Benchmarks* sheds only partial light on how to achieve the goals it recommends**. Deliberately. The means for realizing the ends listed in *Benchmarks* will be discussed in other Project 2061 materials. Although *Benchmarks* includes some commentary on aspects of instruction, that commentary is to clarify the meaning and intent of the benchmarks, not to present a systematic and detailed program of instruction.

- ***Benchmarks* is informed by research**. Research on students' understanding and learning bears significantly on the selection and grade placement of the benchmarks. Project 2061 surveyed the relevant research literature in the English language (and some in other languages) in search of solid findings on which to base benchmark decisions. The findings are discussed in Chapter 15: The Research Base.

- ***Benchmarks* is a developing product.** It will undergo periodic updates as more research on learning becomes available and as users of *Benchmarks* report their experiences. One of the important responsibilities of the Project 2061 school-district sites is to suggest revisions of *Benchmarks* based on their analysis of ongoing research and user recommendations.

- ***Benchmarks* is but one of a family of tools being designed by Project 2061.** To help educators bring about fundamental, lasting reform, *Benchmarks* and *SFAA* will be joined by other products. *Designs for Science Literacy* will describe Project 2061 models and curriculum blocks and will outline principles for configuring Project 2061 curricula. *Resources for Science Literacy* will be a continually updated database of outstanding learning and teaching materials suitable for curricula based on Project 2061 principles. *Blueprints for Reform* will recommend changes in the education system needed to make innovative K-12 curriculum reforms possible. A computerized curriculum-design and resource system is being developed to incorporate all of the Project 2061 products and link them interactively to each other and to educational resources. For more on this, see Chapter 16: Beyond *Benchmarks*.

- ***Benchmarks* is a companion for *SFAA*, not a substitute.** *SFAA* presents a vision of science literacy goals for all students to reach by the time they finish the 12th grade, and *Benchmarks* maps out the territory that students will have to traverse to get there. *SFAA* emphasizes cogency and connectedness. *Benchmarks* emphasizes analysis of the *SFAA* story into components and their sequence. In grades 9-12, where building coherence and connections becomes the main task, no list of components would be adequate to represent science literacy. (Indeed, not all of the detailed ideas in *SFAA* are represented in *Benchmarks*.) At the 9-12 level, therefore, reference to *SFAA* is more than ever necessary for a complete picture of science literacy, which the 9-12 *Benchmarks* only approximate. So, when working with *Benchmarks*, be sure to have a copy of *SFAA* at hand.

Using Benchmarks

Benchmarks was prepared as a tool to be used, along with *SFAA*, by everyone engaged in state or local efforts to transform learning in science, mathematics, and technology. The following suggestions for using *Benchmarks* came from Project 2061 team members, consultants, and staff, and from individuals who have seen prepublication draft versions of *Benchmarks*:

- Study groups of teachers, administrators, school board members, parents, interested citizens, and, whenever possible, scientists, engineers, and mathematicians can use *Benchmarks* to explore the concept of science literacy in relation to instruction in the early elementary, upper elementary, middle-, and high-school grades.

- Cross-grade, cross-subject committees of teachers and curriculum specialists can use *Benchmarks* to gauge how well a K-12 curriculum or curriculum framework (state or local) addresses education for science literacy. Such an analysis can also lead to suggestions for making immediate and long-term curriculum and course improvement.

- Developers of instructional materials can use *Benchmarks* to guide the creation of materials to support the work of teachers who are trying to foster science literacy for all students. Similarly, test writers can use *Benchmarks* to develop grade-level materials and techniques for assessing student progress toward science literacy.

- Other reform efforts may find *Benchmarks* useful in supporting their work, just as Project 2061 has relied on so many of them for ideas and information. The federal programs that drew heavily on *SFAA*, such as the Statewide Systemic Initiatives (National Science Foundation), the Eisenhower Science and Mathematics Initiative (Department of Education), and the National Assessment of Educational Progress, have indicated that they intend also to use *Benchmarks*.

- Universities and colleges that prepare elementary- and secondary-school teachers can use *Benchmarks* to supplement *SFAA*. Whereas *SFAA* explores the concept of science literacy in general, *Benchmarks* raises issues closer to the realities of curriculum and instruction.

- Researchers can use *Benchmarks* to identify important topics for investigation. Such topics might include studies on the grade-level placement of benchmarks, the relationship between benchmarks and their precursors, effective ways to group benchmarks into instructional units, how to assess student progress toward science literacy, and how to evaluate learning materials and techniques used in support of the benchmarks.

3. THE NATURE OF TECHNOLOGY

View Research

As long as there have been people, there has been technology. Indeed, the techniques of shaping tools are taken as the chief evidence of the beginning of human culture. On the whole, technology has been a powerful force in the development of civilization, all the more so as its link with science has been forged. Technology-like language, ritual, values, commerce, and the arts-is an intrinsic part of a cultural system and it both shapes and reflects the system's values. In today's world, technology is a complex social enterprise that includes not only research, design, and crafts but also finance, manufacturing, management, labor, marketing, and maintenance.

In the broadest sense, technology extends our abilities to change the world: to cut, shape, or put together materials; to move things from one place to another; to reach farther with our hands, voices, and senses. We use technology to try to change the world to suit us better. The changes may relate to survival needs such as food, shelter, or defense, or they may relate to human aspirations such as knowledge, art, or control. But the results of changing the world are often complicated and unpredictable. They can include unexpected benefits, unexpected costs, and unexpected risks-any of which may fall on different social groups at different times. Anticipating the effects of technology is therefore as important as advancing its capabilities.

Science for All Americans

In the United States, unlike in most developed countries in the world, technology as a subject has largely been ignored in the schools. It is not tied to graduation requirements, has no fixed place in elementary education, is absent altogether in the college preparatory curriculum, and does not constitute part of the content in science courses at any level.

However, that situation is now changing. There is growing awareness that technology works in everyday life to shape the character of civilization. Design projects are becoming more evident in the elementary grades, and the transformation of industrial arts and other subjects into technology education is gaining momentum. And the Science-Technology-Society (STS) emphasis in the curriculum is gaining adherents.

The task ahead is to build technology education into the curriculum, as well as use technology to promote learning, so that all students become well informed about the nature, powers, and limitations of technology. As a human enterprise, technology has its own history and identity, quite apart from those of science and mathematics. In history, it preceded science and only gradually has come to draw on science-knowledge of how the natural world works-to help in controlling what happens in the world. In modern times, technology has become increasingly characterized by the interdependent relationships it has with science and mathematics. The benchmarks that follow suggest how students should develop their understanding of these relationships.

This chapter presents recommendations on what knowledge about the nature of technology is required for scientific literacy and emphasizes ways of thinking about technology that can contribute to using it wisely. Chapter 8: The Designed World presents principles relevant to some of the key technologies of today's world. Chapter 10: Historical Perspectives, includes a discussion of the Industrial Revolution. Chapter 12: Habits of Mind includes some skills relevant to participating in a technological world.

A. Technology and Science Chapter Contents View Research Also See...

Technology is an overworked term. It once meant knowing how to do things-the practical arts or the study of the practical arts. But it has also come to mean innovations such as pencils, television, aspirin, microscopes, etc., that people use for specific purposes, and it refers to human activities such as agriculture or manufacturing and even to processes such as animal breeding or voting or war that change certain aspects of the world. Further, technology sometimes refers to the industrial and military institutions dedicated to producing and using inventions and know-how. In any of these senses, technology has economic, social, ethical, and aesthetic ramifications that depend on where it is used and on people's attitudes toward its use.

Sorting out these issues is likely to occur over many years as students engage in design and technology activities. First, they must use different tools to do different things in science and to solve practical problems. Through design and technology projects, students can engage in problem-solving related to a wide range of real-world contexts. By undertaking design projects, students can encounter technology issues even though they cannot define technology. They should have their attention called to the use of tools and instruments in science and the use of practical knowledge to solve problems before the underlying concepts are understood.

Kindergarten through Grade 2 Chapter Contents

Young children are veteran technology users by the time they enter school. They ride in automobiles, use household utilities, operate wagons and bikes, use garden tools, help with the cooking, operate the television set, and so on. Children are also natural explorers and inventors, and they like to make things. School should give students many opportunities to examine the properties of materials, to use tools, and to design and build things. Activities should focus on problems and needs in and around the school that interest the children and that can be addressed feasibly and safely.

The task in these grades is to begin to channel the students' inventive energy and to increase their purposeful use of tools and-in the process-broaden their understanding of what constitutes a tool (a container, paper and pencil, camera, magnifier, etc.). Design and technology activities can be used to introduce students to measurement tools and techniques in a natural and meaningful manner. For example, five-year-olds have little trouble in designing and making things for their teddy bears built to an appropriate scale. Measurements should deal with magnitudes that are comprehensible to children of this age, which excludes, for example, the circumference of the earth or the diameter of a microbe.

By the end of the 2nd grade, students should know that

- **Tools are used to do things better or more easily and to do some things that could not otherwise be done at all. In technology, tools are used to observe, measure, and make things.**
- **When trying to build something or to get something to work better, it usually helps to follow directions if there are any or to ask someone who has done it before for suggestions.**

Grades 3 through 5 Chapter Contents

These years should build on the previous ones by increasing the sophistication of the design projects that students undertake. This approach entails students' increasing their repertoire of tools and techniques and improving their skills in measurement, calculation, and communication. Activities calling on the use of instruments such as microscopes, telescopes, cameras, and sound recorders to make observations and measurements are especially important for reinforcing the importance of the dependence of science on technology. Just as important, students should develop skill and confidence in using ordinary tools for personal, everyday purposes.

Students should begin now to write about technology, particularly about how technology helps people. Most of the complexities of the social consequences of the use of technology can wait, but students should begin to consider alternative ways of doing something and compare the advantages and disadvantages.

By the end of the 5th grade, students should know that

- **Throughout all of history, people everywhere have invented and used tools. Most tools of today are different from those of the past but many are modifications of very ancient tools.**

- **Technology enables scientists and others to observe things that are too small or too far away to be seen without them and to study the motion of objects that are moving very rapidly or are hardly moving at all**
- **Measuring instruments can be used to gather accurate information for making scientific comparisons of objects and events and for designing and constructing things that will work properly.**
- **Technology extends the ability of people to change the world: to cut, shape, or put together materials; to move things from one place to another; and to reach farther with their hands, voices, senses, and minds. The changes may be for survival needs such as food, shelter, and defense, for communication and transportation, or to gain knowledge and express ideas.**

Grades 6 through 8 Chapter Contents

Students can now develop a broader view of technology and how it is both like and unlike science. They do not easily distinguish between science and technology, seeing both as trying to get things (including experiments) to happen the way one wants them to. There is no need to insist on definitions, but students' attention can be drawn to when they are clearly trying to find something out, clearly trying to make something happen, or doing some of each.

Furthermore, as students begin to think about their own possible occupations, they should be introduced to the range of careers that involve technology and science, including engineering, architecture, and industrial design. Through projects, readings, field trips, and interviews, students can begin to develop a sense of the great variety of occupations related to technology and to science, and what preparation they require.

By the end of the 8th grade, students should know that

- **In earlier times, the accumulated information and techniques of each generation of workers were taught on the job directly to the next generation of workers. Today, the knowledge base for technology can be found as well in libraries of print and electronic resources and is often taught in the classroom.**
- **Technology is essential to science for such purposes as access to outer space and other remote locations, sample collection and treatment, measurement, data collection and storage, computation, and communication of information.**
- **Engineers, architects, and others who engage in design and technology use scientific knowledge to solve practical problems. But they usually have to take human values and limitations into account as well.**

Grades 9 through 12 Chapter Contents

In addition to participating in major design projects to deepen their understanding of technology, students now should be helped to develop a richer sense of the relationships linking technology and science. That can come from reflection on the project experiences and from a study of the history of science and technology. Certain episodes in the history of science illustrate the importance of technology to science and the difficulty of clearly separating science and technology. The Industrial Revolution is especially important in this regard.

By the end of the 12th grade, students should know that

- **Technological problems often create a demand for new scientific knowledge, and new technologies make it possible for scientists to extend their research in new ways or to undertake entirely new lines of research. The very availability of new technology itself often sparks scientific advances.**
- **Mathematics, creativity, logic and originality are all needed to improve technology.**
- **Technology usually affects society more directly than science because it solves practical problems and serves human needs (and may create new problems and needs). In contrast, science affects society mainly by stimulating and satisfying people's curiosity and occasionally by enlarging or challenging their views of what the world is like.**

B. Design and Systems

Chapter Contents | View Research | Also See...

Engineering is the professional field most closely, or at least most deliberately, associated with technology. Engineers solve problems by applying scientific principles to practical ends. They design instruments, machines, structures, and systems to accomplish specified ends, and must do so while taking into account limitations imposed by time, money, law, morality, insufficient information, and more. In short, engineering has largely to do with the design of technological systems.

Perhaps the best way to become familiar with the nature of engineering and design is to do some. By participating in such activities, students should learn how to analyze situations and gather relevant information, define problems, generate and evaluate creative ideas, develop their ideas into tangible solutions, and assess and improve their solutions. To become good problem solvers, students need to develop drawing and modeling skills, along with the ability to record their analyses, suggestions, and results in clear language.

Gradually, as students participate in more sophisticated projects, they will encounter constraints and the need for making trade-offs. The concept of trade-off in technology-and more broadly in all social systems-is so important that teachers should put it into as many problem-solving contexts as possible. Students should be explicit in their own proposals about what is being traded off for what. They should learn to expect the same of others who propose technical, economic, or political solutions to problems.

Feedback should be another main concept learned in the study of technological systems. Students are likely to encounter it often in biology, physiology, politics, games, conversation, and even when operating tools and machines. Students should also learn that technologies always have side effects and that all technological systems can fail. These ideas can be introduced in simple form early and gradually become more prominent in the upper grades.

Just as with trade-off and feedback, these new concepts should be encountered in a variety of contexts. Daily newspapers provide an inexhaustible supply of examples to analyze.

Kindergarten through Grade 2 Chapter Contents

Children should design and make things with simple tools and a variety of materials. They should identify a need or opportunity of interest to them, and then plan, design, make, evaluate, and modify the design with appropriate help. They might need help identifying problems that are both interesting to them and within their capabilities. After they gain experience working through one problem, they may find their next design project easier and feel more confident about trying it.

One design consideration to be introduced right away is constraints. Safety, time, cost, school policy, space, availability of materials, and other realities restrict student projects. Teachers can point out that adults also face constraints when they design things, and that the real challenge, for adults or children, is to devise solutions that give good results in spite of the restrictions. In the early grades, children may be inclined to go with their first design notion with little patience for testing or revision. Where possible, they should be encouraged to improve their ideas, but it is more important that they develop confidence in their ability to think up and carry out design projects. When their projects are complete, students can tell what they like about one another's designs.

By the end of the 2nd grade, students should know that

- **People may not be able to actually make or do everything that they can design.**

Grades 3 through 5 Chapter Contents

Students should become increasingly comfortable with developing designs and analyzing the product: "Does it work?" "Could I make it work better?" "Could I have used better materials?" The more experience students accrue, the less direct guidance they need. They should realize early that cooperative efforts and individual initiative are valuable in spotting and ironing out design glitches. They should begin to enjoy challenges that require them to clarify a problem, generate criteria for an acceptable solution, suggest possible solutions, try one out, and then make adjustments or start over with a newly proposed solution.

As students undertake more extensive design projects, emphasis should be placed on the notion that there usually is not one best design for a product or process, but a variety of alternatives and possibilities. One way to accomplish this goal is to have several groups design and execute solutions to the same problem and then discuss the advantages and disadvantages of each solution. Ideally, the problems should be "real" and engaging for the students.

By the end of the 5th grade, students should know that

- **There is no perfect design. Designs that are best in one respect (safety or ease of use, for example) may be inferior in other ways (cost or appearance). Usually some features must be sacrificed to get others. How such trade-offs are received**

depends upon which features are emphasized and which are down-played.

- **Even a good design may fail. Sometimes steps can be taken ahead of time to reduce the likelihood of failure, but it cannot be entirely eliminated.**
- **The solution to one problem may create other problems.**

Grades 6 through 8 Chapter Contents

An idea to be developed in the middle grades is that complex systems require control mechanisms. The common thermostat for controlling room temperature is known to most students and can serve as a model for all control mechanisms. But students should explore how controls work in various kinds of systems-machines, athletic contests, politics, the human body, learning, etc. At some point, students should try to invent control mechanisms, which need not be mechanical or electrical, that they can actually put into operation.

The concept of side effects can be raised at this time, perhaps by using actual case studies of technologies (antibiotics, automobiles, spray cans, etc.) that turned out to have unexpected side effects. Students should also meet more interesting and challenging constraints as they work on design projects. Also, students should become familiar with many actual examples of how overdesign and redundancy are used to deal with uncertainty.

By the end of the 8th grade, students should know that

- **Design usually requires taking constraints into account. Some constraints, such as gravity or the properties of the materials to be used, are unavoidable. Other constraints, including economic, political, social, ethical, and aesthetic ones, limit choices.**
- **All technologies have effects other than those intended by the design, some of which may have been predictable and some not. In either case, these side effects may turn out to be unacceptable to some of the population and therefore lead to conflict between groups.**
- **Almost all control systems have inputs, outputs, and feedback. The essence of control is comparing information about what is happening to what people want to happen and then making appropriate adjustments. This procedure requires sensing information, processing it, and making changes. In almost all modern machines, microprocessors serve as centers of performance control.**
- **Systems fail because they have faulty or poorly matched parts, are used in ways that exceed what was intended by the design, or were poorly designed to begin with. The most common ways to prevent failure are pretesting parts and procedures, overdesign, and redundancy.**

Grades 9 through 12 Chapter Contents

Adequate time should be spent fleshing out the concepts of resources (tools, materials, energy, information, people, capital, time), systems, control, and impacts introduced in earlier grades. Students should also move to higher levels of critical and creative thinking through progressively more demanding design and technology work. They need practice as individuals and as members of a group in developing and defining ideas using drawings and models.

New concepts to be introduced in high school include risk analysis and technology assessment. Students should become aware that designed systems are subject to failure but that the risk of failure can be reduced by a variety of means: overdesign, redundancy, fail-safe designs, more research ahead of time, more controls, etc. They should also come to recognize that these precautions add costs that may become prohibitive, so that few designs are ideal.

Because no number of precautions can reduce the risk of system failure to zero, comparing the estimated risks of a proposed technology to its alternatives is often necessary. The choice, usually, is not between a high-risk option and a risk-free one, but comes down to making a trade-off among actions, all of which involve some risk.

Students should realize that analyzing risk entails looking at probabilities of events and at how bad the events would be if they were to happen. Through surveys and interviews, students can learn that comparing risks is difficult because people vary greatly in their perception of risk, which tends to be influenced by such matters as whether the risk is gradual or instantaneous (global warming versus plane crashes), how much control people think they have over the risk (cigarette smoking versus being struck by lightning), and how the risk is expressed (the number of people affected versus the proportion affected).

By the end of the 12th grade, students should know that

- **In designing a device or process, thought should be given to how it will be manufactured, operated, maintained, replaced, and disposed of and who will sell, operate, and take care of it. The costs associated with these functions may introduce yet more constraints on the design.**
- **The value of any given technology may be different for different groups of people and at different points in time.**
- **Complex systems have layers of controls. Some controls operate particular parts of the system and some control other controls. Even fully automatic systems require human control at some point.**
- **Risk analysis is used to minimize the likelihood of unwanted side effects of a new technology. The public perception of risk may depend, however, on psychological factors as well as scientific ones.**
- **The more parts and connections a system has, the more ways it can go wrong. Complex systems usually have components to detect, back up, bypass, or compensate for minor failures.**
- **To reduce the chance of system failure, performance testing is often conducted using small-scale models, computer simulations, analogous systems, or just the parts of the system thought to be least reliable.**

C. Issues in Technology

Chapter Contents View Research Also See...

More and more, citizens are called on to decide which technologies to develop, which to use, and how to use them. Part of being prepared for that responsibility is knowing about how technology works, including its alternatives, benefits, risks, and limitations. The long-term interests of society are best served when key issues concerning proposals to introduce or curtail technology are addressed before final decisions are made. Students should learn how to ask important questions about the immediate and long-range impacts that technological innovations and the elimination of existing technologies are likely to have. But intelligent adults disagree about wise use of technology. Schooling should help students learn how to think critically about technology issues, not what to think about them. Teachers can help students acquire informed attitudes on the various technologies and their social, cultural, economic, and ecological consequences. When teachers do express their personal views (to demonstrate that adults can have well-informed opinions), they should also acknowledge alternative views and fairly state the evidence, logic, and values that lead other people to have those views.

Understanding the potential impact of technology may be critical to civilization. Technology is not innately good, bad, or neutral. Typically, its effects are complex, hard to estimate accurately, and likely to have different values for different people at different times. Its effects depend upon human decisions about development and use. Human experience with technology, including the invention of processes and tools, shows that people have some control over their destiny. They can tackle problems by searching for better ways to do things, inventing solutions and taking risks.

Case studies of actual technologies provide an excellent way for students to discuss risk. There is a vast array of topics: the Aswan High Dam, the contraceptive pill, steam engines, pesticides, public-opinion polling, penicillin, standardized parts, refrigeration, nuclear power, fluoridated water, and hundreds more. Teachers and students can assemble case-study material or use commercially developed case studies. Good design projects and case studies can help students to develop insight into experience.

Kindergarten through Grade 2 Chapter Contents

Design projects give students interesting opportunities to solve problems, use tools well, measure things carefully, make reasonable estimations, calculate accurately, and communicate clearly. And projects also let students ponder the effects their inventions might have. For example, if a group of the children in a class decides to build a large shallow tank to create an ocean habitat, the whole class should discuss what happens if the tank leaks, whether this project interferes with other projects or classroom activities, whether there are other ways to learn about ocean habitats, and so forth. More generally, young children can begin to learn about the effects that people have on their surroundings.

Students at this level are old enough to see that solving some problems may lead to other problems, but the social impact matters should not be pressed too hard now. That might overemphasize constraints and take much of the fun out of doing simple projects by requiring too much analysis.

By the end of the 2nd grade, students should know that

- **People, alone or in groups, are always inventing new ways to solve problems and get work done. The tools and ways of doing things that people have invented**

affect all aspects of life.

- **When a group of people wants to build something or try something new, they should try to figure out ahead of time how it might affect other people.**

Grades 3 through 5 Chapter Contents

Students can become interested in comparing present technology with that of earlier times, as well as the technology in their everyday lives with that of other places in the world. They can imagine what life would be like without certain technology, as well as what new technology the future might hold. Reading about other civilizations or earlier times than their own will illustrate the central role that different technologies play. Students may get involved in current campaigns related to technology-saving energy, recycling materials, reducing litter, and the like. Waste disposal may be a particularly comprehensible and helpful topic in directing their attention to the side effects of technology.

By the end of the 5th grade, students should know that

- **Technology has been part of life on the earth since the advent of the human species. Like language, ritual, commerce, and the arts, technology is an intrinsic part of human culture, and it both shapes society and is shaped by it. The technology available to people greatly influences what their lives are like.**
- **Any invention is likely to lead to other inventions. Once an invention exists, people are likely to think up ways of using it that were never imagined at first.**
- **Transportation, communications, nutrition, sanitation, health care, entertainment, and other technologies give large numbers of people today the goods and services that once were luxuries enjoyed only by the wealthy. These benefits are not equally available to everyone.**
- **Scientific laws, engineering principles, properties of materials, and construction techniques must be taken into account in designing engineering solutions to problems. Other factors, such as cost, safety, appearance, environmental impact, and what will happen if the solution fails also must be considered.**
- **Technologies often have drawbacks as well as benefits. A technology that helps some people or organisms may hurt others-either deliberately (as weapons can) or inadvertently (as pesticides can). When harm occurs or seems likely, choices have to be made or new solutions found.**
- **Because of their ability to invent tools and processes, people have an enormous effect on the lives of other living things.**

Grades 6 through 8 Chapter Contents

To enrich their understanding of how technology has shaped how people live now, students should examine what life was like under different technological circumstances in the past. They should become aware that significant changes occurred in the lives of people when technology provided more and better food, control of sewage, heat and light for homes, and rapid transportation. Studying the past should engender respect for the inventions and constructions of earlier civilizations and cultures.

Both historical and literary approaches ought to be used to imagine what the future will bring and to reflect on people's somewhat limited ability to predict the future. Science fiction and novels set in future times suggest changes in human life that might occur because of yet uninvented technology. Stories selected for this purpose should raise many different issues regarding the impact of technology, and students should probe beneath the plot to analyze those issues. Student groups can formulate and compare their own scenarios for some future time-say, when they are adults.

By the end of the 8th grade, students should know that

- **The human ability to shape the future comes from a capacity for generating knowledge and developing new technologies-and for communicating ideas to others.**
- **Technology cannot always provide successful solutions for problems or fulfill every human need.**
- **Throughout history, people have carried out impressive technological feats, some of which would be hard to duplicate today even with modern tools. The purposes served by these achievements have sometimes been practical, sometimes ceremonial.**
- **Technology has strongly influenced the course of history and continues to do so. It is largely responsible for the great revolutions in agriculture, manufacturing, sanitation and medicine, warfare, transportation, information processing, and communications that have radically changed how people live.**
- **New technologies increase some risks and decrease others. Some of the same technologies that have improved the length and quality of life for many people have also brought new risks.**
- **Rarely are technology issues simple and one-sided. Relevant facts alone, even when known and available, usually do not settle matters entirely in favor of one side or another. That is because the contending groups may have different values and priorities. They may stand to gain or lose in different degrees, or may make very different predictions about what the future consequences of the proposed action will be.**
- **Societies influence what aspects of technology are developed and how these are used. People control technology (as well as science) and are responsible for its effects.**

Grades 9 through 12 Chapter Contents

As suggested earlier, the real-world work of students as supplemented by case studies probably provides the most effective way to examine issues related to how society responds to the promise or threat of technological change-whether by adopting new technologies or curtailing the use of existing ones. What must be avoided by teachers is turning the case studies into occasions for promoting a particular point of view. People tend to hold very strong opinions on the use of technologies, and not only of nuclear reactors and genetic engineering. The teacher's job is not to provide students with the "right" answers about technology but to see to it that students know what questions to ask.

Students can also add detail to their awareness of the effects of the human presence on life. For instance, they should be able to cite several examples of how the introduction of foreign species has changed an ecosystem. Out of this should come an awareness that people can make some decisions about what life on earth will survive and a sense of responsibility about exercising power. Students also should learn that people cannot shape every aspect of life to their own liking.

For example, most Americans recognize that technology has provided new goods and services, but not that industrialization of agriculture, by eliminating the need for children to work in the fields, made it possible for them to attend school, thereby increasing the general educational level of the population. These kinds of social impacts should be studied as well as those that affect human health and the environment.

By the end of the 12th grade, students should know that

- **Social and economic forces strongly influence which technologies will be developed and used. Which will prevail is affected by many factors, such as personal values, consumer acceptance, patent laws, the availability of risk capital, the federal budget, local and national regulations, media attention, economic competition, and tax incentives.**
- **Technological knowledge is not always as freely shared as scientific knowledge unrelated to technology. Some scientists and engineers are comfortable working in situations in which some secrecy is required, but others prefer not to do so. It is generally regarded as a matter of individual choice and ethics, not one of professional ethics.**
- **In deciding on proposals to introduce new technologies or to curtail existing ones, some key questions arise concerning alternatives, risks, costs, and benefits. What alternative ways are there to achieve the same ends, and how do the alternatives compare to the plan being put forward? Who benefits and who suffers? What are the financial and social costs, do they change over time, and who bears them? What are the risks associated with using (or not using) the new technology, how serious are they, and who is in jeopardy? What human, material, and energy resources will be needed to build, install, operate, maintain, and replace the new technology, and where will they come from? How will the new technology and its waste products be disposed of and at what costs?**
- **The human species has a major impact on other species in many ways: reducing the amount of the earth's surface available to those other species, interfering with their food sources, changing the temperature and chemical composition of their habitats, introducing foreign species into their ecosystems, and altering organisms directly through selective breeding and genetic engineering.**
- **Human inventiveness has brought new risks as well as improvements to human existence.**

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8. THE DESIGNED WORLD

View Research

The world we live in has been shaped in many important ways by human action. We have created technological options to prevent, eliminate, or lessen threats to life and the environment and to fulfill social needs. We have dammed rivers and cleared forests, made new materials and machines, covered vast areas with cities and highways, and decided-sometimes willy-nilly-the fate of many other living things.

In a sense, then, many parts of our world are designed-shaped and controlled, largely through the use of technology-in light of what we take our interests to be. We have brought the earth to a point where our future well-being will depend heavily on how we develop and use and restrict technology. In turn, that will *depend heavily on how well we understand the workings of technology and the social, cultural, economic, and ecological systems within which we live.*

Science for All Americans

Here the focus is on particular technological systems, such as agriculture and manufacturing, and the benchmarks indicate what particular engineering, scientific, social, and historical understandings students should gain. In the companion Chapter 3: The Nature of Technology, the benchmarks deal with general principles of technology and engineering, with the relationships between technology and science, and with the effects of technology on society.

The sections in this chapter are not intended to cover all major areas of technology. Other areas-such as the technology of warfare, transportation, or architecture- might also have been included. The areas covered here should supply an ample sampling of major ideas to serve as a basis for understanding various key technologies of today-and those that will come tomorrow. For many of the ideas in this chapter, students will need a background understanding of the physical setting and the living environment, for which benchmarks are given in Chapter 4: The Physical Setting and Chapter 5: The Living Environment.

The content should not be taught solely in the technology curriculum. The responsibility needs to be shared by science, mathematics, social studies, and history. Some of the instruction can be didactic but much of it should be done through student projects. Technology projects should be part of the curriculum from the earliest grades, gradually becoming longer and more complex. Most projects should be done by small student groups with teachers acting as advisers. Classroom visits by people involved in technology-related fields-such as architecture, transportation, and textiles-may help to acquaint students with occupational opportunities in technology.

A. Agriculture Chapter Contents Also See...

A majority of people never see food or fiber before those products get to retail stores, and primary-school children may have only vague ideas about where their foods and fabrics come from. So the first steps in teaching children about agriculture are to acquaint them with basics: what grows where, what is required to grow and harvest it, how it gets to the stores, and how modern-day U.S. agriculture compares with agriculture in other places and other times. Such comparisons prepare students to consider how agriculture can be improved, what resources are needed, and the consequences for society and the environment.

For most students, media resources about agricultural production in the United States and elsewhere may have to supplement firsthand experiences. Projects to trace locally available food and fiber back to their origins are helpful in providing at least some personal experience. As students become better able to handle complexity, they can undertake projects that require planting, fertilizing, selecting desirable features, and adjusting the amount of light, water, and warmth.

Projects for older students can involve the preservation of food and fiber, requirements for good nutrition, comparing energy efficiency of different products, and long-term changes in water, soil, and forest resources. They should expand their sense of what agriculture is to include the planting and harvesting of materials for use as fibers and fuel and for building shelters. When students are able to grasp the interdependent elements of the agricultural system, including fuel, roads, communications, weather, and prices, they may assess what disasters do to an agricultural system and possible ways of recovering or even reducing their likelihood.

Kindergarten through Grade 2 Chapter Contents

The basic experiences for primary-school children include seeing plants grow from seeds they have planted, eating the edible portions of the mature plants, and noticing what plants and other things animals eat. Comparisons can be made to see what happens if some plants don't get water or light, but carefully controlled experiments should be delayed until later, when students will know better how to conduct scientific investigations. Some of the earliest stories to be read to and by small children can tell about life on the farm and what happens to food between the farm and the store.

By the end of the 2nd grade, students should know that

- **Most food comes from farms either directly as crops or as the animals that eat the crops. To grow well, plants need enough warmth, light, and water. Crops also must be protected from weeds and pests that can harm them.**
- **Part of a crop may be lost to pests or spoilage.**
- **A crop that is fine when harvested may spoil before it gets to consumers.**
- **Machines improve what people get from crops by helping in planting and harvesting, in keeping food fresh by packaging and cooling, and in moving it long distances from where it is grown to where people live.**

Grades 3 through 5 Chapter Contents

Students should enhance their earlier experiences by following plants through the production of new seeds and offspring. They can design experiments to see the effects of water, light, and fertilizer, although their experiments should involve only one variable at a time.

They should study what crops are found in different environments, including oceans, and trace the paths that various foods and fibers take as they move from growers to consumers. Storage, transportation, preservation, processing, and packaging should be considered. Where possible, students should visit markets, farms, grain elevators, and processing plants and examine trucks, trains, cargo planes, and as many other parts of the "technological food chain" as possible.

To appreciate the rigors of agriculture, students should learn about life in earlier times and the great effort that went into planting, nurturing, harvesting, and using crops. It is important that they know some of the hazards that food encounters from the time it is a seed until it reaches the kitchen. Food preservation and sanitation can be explored in early grades, but explanation of spoilage as the result of microorganisms should wait until 6th through 8th grades.

By the end of the 5th grade, students should know that:

- **Some plant varieties and animal breeds have more desirable characteristics than others, but some may be more difficult or costly to grow. The kinds of crops that can grow in an area depend on the climate and soil. Irrigation and fertilizers can help crops grow in places where there is too little water or the soil is poor.**
- **The damage to crops caused by rodents, weeds, and insects can be reduced by using poisons, but their use may harm other plants or animals as well, and pests tend to develop resistance to poisons.**
- **Heating, salting, smoking, drying, cooling, and airtight packaging are ways to slow down the spoiling of food by microscopic organisms. These methods make it possible for food to be stored for long intervals before being used.**
- **Modern technology has increased the efficiency of agriculture so that fewer people are needed to work on farms than ever before.**
- **Places too cold or dry to grow certain crops can obtain food from places with more suitable climates. Much of the food eaten by Americans comes from other parts of the country and other places in the world.**

Grades 6 through 8 Chapter Contents

In middle school, students can examine how changes in climate, fashion, or ecosystems affect agriculture. The news media, even in the cities, often report how well particular crops are doing in response to weather, pestilence, market demand, federal policies, and the like. Students' discussions of such current events can lead them to raise technological, scientific, economic, and political questions for further study.

Students should continue to be engaged in gardening and experimentation. As an addition to traditional seeds-in-soil activities, hydroponics is an inexpensive and relatively rapid way to help students understand modern agriculture because it allows them to monitor and control many of the variables that contribute to plant growth and development. Students at this level also study geography and the early history of the human species, including the transformation from hunting and gathering to farming. This agricultural revolution provides a dramatic instance of social change made possible by technological advances and, conversely, of technological advance promoted by social change.

By the end of the 8th grade, students should know that

- **Early in human history, there was an agricultural revolution in which people changed from hunting and gathering to farming. This allowed changes in the division of labor between men and women and between children and adults, and the development of new patterns of government.**
- **People control the characteristics of plants and animals they raise by selective breeding and by preserving varieties of seeds (old and new) to use if growing**

conditions change.

- **In agriculture, as in all technologies, there are always trade-offs to be made. Getting food from many different places makes people less dependent on weather in any one place, yet more dependent on transportation and communication among far-flung markets. Specializing in one crop may risk disaster if changes in weather or increases in pest populations wipe out that crop. Also, the soil may be exhausted of some nutrients, which can be replenished by rotating the right crops.**
- **Many people work to bring food, fiber, and fuel to US markets. With improved technology, only a small fraction of workers in the United States actually plant and harvest the products that people use. Most workers are engaged in processing, packaging, transporting, and selling what is produced.**

Grades 9 through 12 Chapter Contents

Students' understanding of agricultural technology can increasingly draw upon their understanding of underlying science concerning the interaction of living things with their environments in ecosystems, the inheritance of traits, mutations, and natural selection. Their growing familiarity with systems concepts should be exploited in agricultural contexts to study the interactions among production, preservation, transportation, communications, government regulations, subsidies, and world markets. Social side-effects and tradeoffs of agricultural strategies should be discussed in both local and world contexts.

By the end of the 12th grade, students should know that

- **New varieties of farm plants and animals have been engineered by manipulating their genetic instructions to produce new characteristics.**
- **Government sometimes intervenes in matching agricultural supply to demand in an attempt to ensure a stable, high-quality, and inexpensive food supply. Regulations are often also designed to protect farmers from abrupt changes in farming conditions and from competition by farmers in other countries.**
- **Agricultural technology requires tradeoffs between increased production and environmental harm and between efficient production and social values. In the past century, agricultural technology led to a huge shift of population from farms to cities and a great change in how people live and work.**

B. Materials and Manufacturing Chapter Contents Also See...

Most children like to make things. Over the school years, students should study and manipulate (shape, cut, drill, pound, bake, soak, radiate, join, grind, etc.) many different kinds of materials, from mud, clay, and paper to chemical reagents, alloys, and plastics. In doing so, they learn about the physical and chemical properties of materials as well as about manufacturing. In their building activities, students should progress from using simple tools (scissors, paste, string, rulers) to standard hand tools and cooking utensils to sensitive measuring instruments and power tools.

Students should also move from designing and making simple objects to designing, assembling, and operating a manufacturing system. The importance of planning, coordination, and control should become as evident as the importance of selecting the most appropriate materials and processes. Also evident will be the need for financing, sales, and follow-up (including maintenance, repair, and handling complaints).

Historical, social, cultural, and scientific perspectives, involving readings and films to focus class discussion and student papers, can help to fill in the picture of materials and manufacturing as essential components of human society.

Kindergarten through Grade 2 Chapter Contents

Young children should have many experiences in working with different kinds of materials, identifying and composing their properties and figuring out their suitability for different purposes. (The Three Little Pigs is a familiar introduction to the world of materials for very young children.). It is not too early for children to begin to wonder what happens to something after it has been thrown away. They can monitor the amount of waste that people produce or take part in community recycling projects.

By the end of the 2nd grade, students should know that:

- **Some kinds of materials are better than others for making any particular thing. Materials that are better in some ways (such as stronger or cheaper) may be worse in other ways (heavier or harder to cut).**
- **Several steps are usually involved in making things.**
- **Tools are used to help make things, and some things cannot be made at all without tools. Each kind of tool has a special purpose.**
- **Some materials can be used over again.**

Grades 3 through 5 Chapter Contents

Many interesting activities enable children to experience how people process materials. Cooking can help young people develop concepts about the effects of combining various ingredients and treating mixtures to change their properties. Weaving cloth and straw, shaping metal and plastic, cutting wood, and stamping leather can help students discover the properties of various materials and experience how people transform materials into useful objects.

Teachers can channel students' inclination to make things into assembly activities that benefit from teamwork and go beyond producing a single product. Students can develop and use a series of simple workstations to make sandwiches or fold paper into objects. Students should consider how to improve product uniformity, quantity, and quality and reduce the costs of manufacturing products.

By the end of the 5th grade, students should know that:

- **Naturally occurring materials such as wood, clay, cotton, and animal skins may be processed or combined with other materials to change their properties.**
- **Through science and technology, a wide variety of materials that do not appear in nature at all have become available, ranging from steel to nylon to liquid crystals.**
- **Discarded products contribute to the problem of waste disposal. Sometimes it is possible to use the materials in them to make new products, but materials differ widely in the ease with which they can be recycled.**
- **Through mass production, the time required to make a product and its cost can be greatly reduced. Although many things are still made by hand in some parts of the world, almost everything in the most technologically developed countries is now produced using automatic machines. Even automatic machines require human supervision.**

Grades 6 through 8 Chapter Contents

Recycling activities take on added value when students learn about a material's origins and history. Students at this level can trace the production cycle of common materials such as paper, lumber, rubber, steel, aluminum, glass, petroleum, and plastics. Their investigation should begin with the natural formation of raw materials and examine the techniques employed to gather these raw materials, process them into workable materials, transform them into industrial and consumer products, and dispose of the products when they are no longer useful. Students should identify points in the production and disposal cycle where used materials can be collected, sorted, and reprocessed into usable materials. Once students have a sense of the whole cycle, they can understand how recycling can conserve energy and natural resources. Students can reflect on the influences that their own consumption choices can have on what products are made and how they are packaged. (Later, they can find out that sometimes recycling may use more energy and other resources than it saves.)

It is appropriate in the middle grades for students to undertake one or more manufacturing initiatives of some magnitude and complexity. At this level, students should address the challenges of conducting efficiency studies, designing production tooling, engineering a production facility, maintaining quality-control standards, and marketing their final product. The emphasis at this level should be on efficiency by maximizing production while minimizing losses (for example, of time, material, energy, and effort).

By the end of the 8th grade, students should know that

- **The choice of materials for a job depends on their properties and on how they interact with other materials. Similarly, the usefulness of some manufactured parts of an object depends on how well they fit together with the other parts.**
- **Manufacturing usually involves a series of steps, such as designing a product, obtaining and preparing raw materials, processing the materials mechanically or chemically, and assembling, testing, inspecting, and packaging. The sequence of**

these steps is also often important.

- **Modern technology reduces manufacturing costs, produces more uniform products, and creates new synthetic materials that can help reduce the depletion of some natural resources.**
- **Automation, including the use of robots, has changed the nature of work in most fields, including manufacturing. As a result, high-skill, high-knowledge jobs in engineering, computer programming, quality control, supervision, and maintenance are replacing many routine, manual-labor jobs. Workers therefore need better learning skills and flexibility to take on new and rapidly changing jobs.**

Grades 9 through 12 Chapter Contents

The study and design of materials involves several disciplines and issues. An effort should be made to explore how scientific knowledge fuels technological advances and how technology creates new scientific knowledge. Chemistry, physics, biology, and geology provide many clear examples of this interactive relationship between science and technology. As students understand better how atoms are configured in molecules and crystals (and less-well-defined arrangements), they can begin to see the connections to large-scale properties of materials. This understanding leads naturally to laboratory tests that measure a material's physical properties (such as tensile strength, hardness, and absorbency). Such tests can be included in problems that require students to select and process materials to give the optimum compromise between properties available and properties needed. Students should see some automated production process firsthand, if possible, or at least they should see some media presentations of several automated processes.

To develop an understanding of how modern manufacturing works, students need to study and experience the role of automation in freeing people from tasks that are typically "dull, dirty, or dangerous." Students should have opportunities to manipulate and program automated devices such as tabletop robots. Students generally have a lot of misconceptions and negative attitudes about industrial robots, often based on television and movie depictions of robots. Without concrete experience, they tend to think robots are intelligent and evil machines that take jobs away from people. After a little experience playing with an industrial robot, they often report that robots are very stupid machines that are dependent on people for all the brain work and can perform only the very simplest tasks.

By the end of the 12th grade, students should know that

- **Manufacturing processes have been changed by improved tools and techniques based on more thorough scientific understanding, increases in the forces that can be applied and the temperatures that can be reached, and the availability of electronic controls that make operations occur more rapidly and consistently.**
- **Waste management includes considerations of quantity, safety, degradability, and cost. It requires social and technological innovations, because waste-disposal problems are political and economic as well as technical.**
- **Scientific research identifies new materials and new uses of known materials.**

- **Increased knowledge of the molecular structure of materials helps in the design and synthesis of new materials for special purposes.**

C. Energy Sources and Use

Chapter Contents Also See...

Here the focus is on what practical knowledge students should have about energy, for which benchmarks are presented in Chapter 4: The Physical Setting and Chapter 5: The Living Environment. Students will use the term energy long before they have much of an idea of what energy is. In the elementary grades, students can simply associate energy with getting things done and with heat. Students should have experience in using a variety of energy-transforming devices and considering what their inputs and outputs are. Understanding of the science and technology of energy can grow together and lead to a better grasp of this elusive term. It also can lead to understandings needed to inform decisions about energy use.

Kindergarten through Grade 2

Chapter Contents

Young children tend to associate the term energy with moving around a lot. They are likely to know sources of energy by what they are used for-electricity gives people lights or cooks their food, the sun melts snow or makes some calculators work, and moving air makes a pinwheel turn and helps some boats move. But young children probably don't see heat and light as forms of energy and need not be asked to. The emphasis should be on familiarizing them with a wide variety of phenomena that result from moving water, wind, burning fuel, or connecting to batteries and wall sockets.

By the end of the 2nd grade, students should know that

- **People can save money by turning off machines when they are not using them.**
- **People burn fuels such as wood, oil, coal, or natural gas, or use electricity to cook their food and warm their houses.**

Grades 3 through 5

Chapter Contents

The emphasis here is on energy sources. Students should have many opportunities to observe and talk about what the sun's energy is used for. They can see moving water as an energy source for "running" mills but its conversion to electricity should probably wait until they have some familiarity with the relation between electricity and magnetism.

Students may be intrigued with the story of fossil fuels, particularly if it is linked to the era of the dinosaurs. Some students may wonder why the plants that died so long ago didn't just turn into soil the way the plants in their garden do; wondering like this should be encouraged. Just realizing that fossil fuels formed under very special conditions can help students to appreciate that these fuels are not easily replaced.

For the more easily observed sources of energy, students can start to consider inputs and outputs; what it takes for something to work and what all the effects are.

By the end of the 5th grade, students should know that

- **Moving air and water can be used to run machines.**
- **The sun is the main source of energy for people and they use it in various ways. The energy in fossil fuels such as oil and coal comes from the sun indirectly, because the fuels come from plants that grew long ago.**
- **Some energy sources cost less than others and some cause less pollution than others.**
- **People try to conserve energy in order to slow down the depletion of energy resources and/or to save money.**

Grades 6 through 8 Chapter Contents

The emphasis here is on energy transformation. Students at this level usually respond enthusiastically to design challenges in which teams of students are called upon to create energy-conversion systems using readily available mechanical, electrical, and electronic devices. Ingenuity, simplicity, and complexity can all be rewarded but only for those teams that also can describe correctly the science of what is happening as energy goes through its transformation(s) in their machines.

At this level, students enjoy making and testing simple energy-conversion devices such as tabletop wind generators and model solar collectors. During the testing process, students can monitor the energy-conversion process by making input versus output comparisons. The data they gather can inspire hypotheses that subsequently inspire modifications. These modifications might include altering the pitch of a wind turbine's blades to increase their speed or adding reflector panels to a solar collector to increase the amount of radiant energy entering the device. Such modifications can result in a higher output voltage in the case of the wind generator or a greater temperature gain in the case of the solar collector.

Such tinkering experiences typically create a genuine desire and readiness on the part of students to understand the laws of nature that can help them explain why their devices behave the way they do. Alternative and appropriate energy-utilization systems are typically easy to understand because they are relatively simple. Because of the simplicity of such systems, almost all students can experience some degree of success in designing, building, and testing a model alternative-energy device.

By the end of the 8th grade, students should know that

- **Energy can change from one form to another, although in the process some energy is always converted to heat. Some systems transform energy with less loss of heat than others.**
- **Different ways of obtaining, transforming, and distributing energy have different environmental consequences.**
- **In many instances, manufacturing and other technological activities are performed at a site close to an energy source. Some forms of energy are**

transported easily, others are not.

- **Electrical energy can be produced from a variety of energy sources and can be transformed into almost any other form of energy. Moreover, electricity is used to distribute energy quickly and conveniently to distant locations.**
- **Energy from the sun (and the wind and water energy derived from it) is available indefinitely. Because the flow of energy is weak and variable, very large collection systems are needed. Other sources don't renew or renew only slowly.**
- **Different parts of the world have different amounts and kinds of energy resources to use and use them for different purposes.**

Grades 9 through 12 Chapter Contents

Students can compare industrial and nonindustrial societies by their standards of living and energy consumption. They can examine the consequences of the world's dependence on fossil fuels, explore a wide range of alternative energy resources and technologies, and consider tradeoffs in each. They might evaluate such matters as the use of high-quality energy resources such as natural gas for such applications as heating homes. They can even propose policies for conserving and managing energy resources.

By the end of the 12th grade, students should know that

- **A central factor in technological change has been how hot a fire could be made. The discovery of new fuels, the design of better ovens and furnaces, and the forced delivery of air or pure oxygen have progressively increased the available temperature. Lasers are a new tool for focusing radiation energy with great intensity and control.**
- **At present, all fuels have advantages and disadvantages so that society must consider the tradeoffs among them.**
- **Nuclear reactions release energy without the combustion products of burning fuels, but the radioactivity of fuels and by-products poses other risks, which may last for thousands of years.**
- **Industrialization brings an increased demand for and use of energy. Such usage contributes to the high standard of living in the industrially developing nations but also leads to more rapid depletion of the earth's energy resources and to environmental risks associated with the use of fossil and nuclear fuels.**
- **Decisions to slow the depletion of energy sources through efficient technology can be made at many levels, from personal to national, and they always involve tradeoffs of economic costs and social values.**

D. Communication Chapter Contents Also See...

Communication is the transfer of information and some means of ensuring that what is sent is also received. Technology increases the ways in which information can be communicated, the speed of transmission, and the total volume that can be handled at any one time. The spread of communication technologies brings social change, affects people's attitudes toward others, and influences behavior.

Nearly everyone is interested in audio and television systems, radar, and communications satellites, yet they need also to realize that earlier communication technologies, such as writing and moveable type, revolutionized civilization. And before that, the development of spoken language, coupled with mobility, was an important step forward in communication technology.

People are a part of every communications system, in both its design and operation. Many students see the communications industry as important for entertainment and job prospects. Students can move from being users of various communication devices to understanding general communications principles and appreciating opportunities and problems that come with these technologies.

Kindergarten through Grade 2 Chapter Contents

Even before children master the alphabet, they know that various shapes, symbols, and colors have special meanings in society (for example, red means danger, a red octagon means stop, green means go, arrows show direction, a circle with a slash means no). Young children are fascinated by various forms of giving messages, including sign language, road signs, recycling symbols, and company logos, and they should have opportunities to invent forms of their own. Their symbols can be used in classroom routines, illustrating the need to have common meanings for signs, symbols, and gestures. They should learn that writing things down and drawing pictures can help them tell their ideas to others accurately. (Second-graders need not be burdened yet with "communicating information"-they can tell and hear and send and get messages.). Students can discuss what the best ways are to convey different kinds of messages-not to decide on right answers, of course, but to start thinking about advantages and disadvantages.

By the end of the 2nd grade, students should know that

- **Information can be sent and received in many different ways. Some allow answering back and some do not. Each way has advantages and disadvantages.**
- **Devices can be used to send and receive messages quickly and clearly.**

Grades 3 through 5 Chapter Contents

Students can start to study the internal workings of major communications systems, including those of the past. For example, they can study how the parts of the world are connected by telephone lines (many of which can be traced from a building to telephone poles and from telephone poles to the local switching office). Students can learn how telephone numbers are codes for activating switches and how these switches make a series of connections that link one location to another.

Students at this level delight in using secret codes. Their own experiences and stories about the use of codes can lead to reflections about the requirements for code use. By trying to break secret codes made by classmates, students can develop skills in finding patterns and using logic. Also, students are generally eager to use a variety of communication devices. They should gain experience using computers, audiotapes, and videotapes-as well as writing and drawing implements-to communicate information to classmates and students elsewhere.

By the end of the 5th grade, students should know that

- **People have always tried to communicate with one another. Signed and spoken language was one of the first inventions. Early forms of recording messages used markings on materials such as wood or stone.**
- **Communication involves coding and decoding information. In any language, both the sender and the receiver have to know the same code, which means that secret codes can be used to keep communication private.**
- **People have invented devices, such as paper and ink, engraved plastic disks, and magnetic tapes, for recording information. These devices enable great amounts of information to be stored and retrieved-and be sent to one or many other people or places.**
- **Communication technologies make it possible to send and receive information more and more reliably, quickly, and cheaply over long distances.**

Grades 6 through 8

Chapter Contents

At this level, students can understand communication systems as a series of black boxes linked together to connect people in one location with people in another location. They can recognize that each black box in the chain accepts an input signal, processes that signal, and produces and sends a new signal. Consequently, a microphone is a black box that converts sound into electricity, an amplifier is a black box that uses a weak signal and produces a stronger signal, and a speaker converts electricity into sound. Building on their experiences with electricity, students can understand how these devices need to be connected together with wire to work. Students need to experiment with simple devices such as microphones, speakers, and amplifiers before they can think about more sophisticated devices such as video cameras, cathode-ray tubes, stereo systems, and satellites.

By the end of the 8th grade, students should know that

- **Errors can occur in coding, transmitting, or decoding information, and some means of checking for accuracy is needed. Repeating the message is a frequently used method.**
- **Information can be carried by many media, including sound, light, and objects. In this century, the ability to code information as electric currents in wires, electromagnetic waves in space, and light in glass fibers has made communication millions of times faster than is possible by mail or sound.**

Grades 9 through 12

Chapter Contents

Students need to experience firsthand how technology helps people communicate more information to more people in less time, with greater accuracy, and fewer misunderstandings. They can begin to understand how some common communication devices transform patterns of sound or light into patterns of electricity and transmit electrical patterns across a variety of linkages and how receivers process incoming signals and convert patterns of electricity back into patterns of sound and light.

By the end of the 12th grade, students should know that

- **Almost any information can be transformed into electrical signals. A weak electrical signal can be used to shape a stronger one, which can control other signals of light, sound, mechanical devices, or radio waves.**
- **The quality of communication is determined by the strength of the signal in relation to the noise that tends to obscure it. Communication errors can be reduced by boosting and focusing signals, shielding the signal from internal and external noise, and repeating information, but all of these increase costs. Digital coding of information (using only 1's and 0's) makes possible more reliable transmission of information.**
- **As technologies that provide privacy in communication improve, so do those for invading privacy.**

E. Information Processing Chapter Contents Also See...

Technology has played an important role in collecting, storing, retrieving, and dealing with information as well as in transmitting it. Through experience and discussion, students should learn that writing on paper, making drawings, taking pictures with a camera, talking into a tape recorder, and entering letters and numbers into a computer are all ways of capturing and saving information. The invention of writing, moveable type, tables of data, diagrams, mathematical formulas, and filing systems have all increased the amount of information that people can handle. Large amounts of information are needed to operate modern societies, and generating, processing, and transferring information are among the most common occupations in modern countries. Students should all become comfortable using computers to manipulate information and have some idea of the processes involved. They should also explore the social consequences of increased access to information and of the fact that some people or groups have greater access than others.

Kindergarten through Grade 2 Chapter Contents

Children are often required to keep folders, notebooks, journals, and/or portfolios to organize and store their work so it can be reviewed at a later date-the essence of an information storage and retrieval system. The children can help design and use simple strategies for storing and retrieving information that is recorded in the form of words and pictures on physical media (for example, audio and video cassette tapes, paper, and photographs). Using things such as personal folders, pockets mounted on the wall, and plastic file boxes located in workstations, students can learn that things need to have places where they can be stored-and if they are stored well, they are easier to find later. Things containing the same type of information can be assigned a special color or name that make it easier to store them correctly and find them later. These experiences can provide students with the foundation they will need to address more sophisticated information-management problems in the future.

By the end of the 2nd grade, students should know that

- **There are different ways to store things so they can be easily found later.**
- **Letters and numbers can be used to put things in a useful order.**

Grades 3 through 5 Chapter Contents

Children should have the opportunity to use and investigate a range of information-handling devices such as electronic mail, audio and video recorders, and reference books. They should gather, organize, and present information in several ways, using reference books, paper files, and computers.

Students are now beginning to encounter challenging information-processing problems in their school work. These problems have one or more appropriate procedures (software) for processing data, and these procedures often can be performed more efficiently with the aid of technology (hardware). Students should be encouraged to identify the data presented in the problem, develop a procedure for processing the data, implement the procedure with the aid of technology, and evaluate the reasonableness of their results. As students encounter more sophisticated problems with more complicated data sets, the procedures and tools that they use should also become more sophisticated. Eventually, students should be gathering data, processing information, and presenting the results of their data-analysis activities.

By the end of the 5th grade, students should know that

- **Computers are controlled partly by how they are wired and partly by special instructions called programs that are entered into a computer's memory. Some programs stay permanently in the machine but most are coded on disks and transferred into and out of the computer to suit the user.**
- **Computers can be programmed to store, retrieve, and perform operations on information. These operations include mathematical calculations, word processing, diagram drawing, and the modeling of complex events.**
- **Mistakes can occur when people enter programs or data into a computer. Computers themselves can make errors in information processing because of defects in their hardware or software.**

Grades 6 through 8 Chapter Contents

Students should use simple electronic devices for sensing, making logical decisions, counting, and storing information. It is important to put programming in perspective. Only a tiny percentage of computer users need to know how to program computers. However, working out a simple program of only a few steps can help students see the importance of logical thinking and increase their understanding of how a computer works. Programming a computer also helps students realize that all the capabilities that computers have come from human intelligence.

By the end of the 8th grade, students should know that

- **Most computers use digital codes containing only two symbols, 0 and 1, to perform all operations. Continuous signals must be transformed into digital codes before they can be processed by a computer.**
- **What use can be made of a large collection of information depends upon how it is organized. One of the values of computers is that they are able, on command, to reorganize information in a variety of ways, thereby enabling people to make more and better uses of the collection.**
- **Computer control of mechanical systems can be much quicker than human control. In situations where events happen faster than people can react, there is little choice but to rely on computers. Most complex systems still require human oversight, however, to make certain kinds of judgments about the readiness of the parts of the system (including the computers) and the system as a whole to operate properly, to react to unexpected failures, and to evaluate how well the system is serving its intended purposes.**
- **An increasing number of people work at jobs that involve processing or distributing information. Because computers can do these tasks faster and more reliably, they have become standard tools both in the workplace and at home.**

Grades 9 through 12 Chapter Contents

Students should use information devices to collect and analyze data from experiments, to simulate a variety of biological and physical phenomena, to access and organize information from databases, and to use programmable systems to control electric and mechanical devices. They should also have experience using computer models. This level is a good time to think about organisms as systems in which information is shared in genes in a code that can be interpreted by biochemical processes.

By the end of the 12th grade, students should know that

- **Computer modeling explores the logical consequences of a set of instructions and a set of data. The instructions and data input of a computer model try to represent the real world so the computer can show what would actually happen. In this way, computers assist people in making decisions by simulating the consequences of different possible decisions.**
- **Redundancy can reduce errors in storing or processing information but increases costs.**
- **Miniaturization of information-processing hardware can increase processing speed and portability, reduce energy use, and lower cost. Miniaturization is made possible through higher-purity materials and more precise fabrication**

technology.

F. Health Technology Chapter Contents Also See...

Good health practices should be taught for their own sake and to provide students with an understanding of the relationship between health technology and the health of the population. Learning starts with the health of each student and the means of protecting it, then gradually moves to explanations of how the body works, what causes diseases, how they are transmitted, and how the body protects itself from disease. Along the way, students learn about the role of technology in health maintenance.

It is important not to exaggerate the importance of glamorous technologies such as dialysis machines, life-support systems, and organ-transplant surgery, because ordinary public health measures have contributed more to improving the human condition and life span. Students should learn of the advances in health and human life expectancy that have resulted from inoculations, modern waste-disposal systems, sanitary food handling, refrigeration, antibiotics, medical imaging, and other technologies now considered commonplace. Individuals and society continue to deal with difficult issues in making decisions about the use of modern medical technologies. Some of these issues are technical, some are ethical. Some of the issues, such as the worldwide population explosion, are consequences of the success of technology.

Kindergarten through Grade 2 Chapter Contents

Young children know that germs can make them sick, even though they may not know exactly what germs are. Of course, good health habits should be taught and encouraged: knowing when it's important to wash their hands, being careful about what goes into their mouths, not sneezing and coughing on others, and avoiding contact with someone who is contagiously sick. Children also know that shots and oral vaccines can help prevent certain diseases and that, if they do get sick, medicines can sometimes help them get better. This knowledge can be built upon to help students realize that science and technology contribute to good health.

By the end of the 2nd grade, students should know that

- **Vaccinations and other scientific treatments protect people from getting certain diseases, and different kinds of medicines may help those who do become sick to recover.**

Grades 3 through 5 Chapter Contents

Students can collect information on their own health with simple devices, such as a watch, a thermometer, and a stethoscope, and they can begin to get a sense of how such information varies. Students can even undertake projects such as designing aids for the disabled. If children visit a hospital, they can see examples of how computers and monitoring instruments are important in various aspects of health care.

By the end of the 5th grade, students should know that

- **There are normal ranges for body measurements-including temperature, heart rate, and what is in the blood and urine-that help to tell when people are well. Tools, such as thermometers and x-ray machines, provide us clues about what is happening inside the body.**
- **Technology has made it possible to repair and sometimes replace some body parts.**

Grades 6 through 8 Chapter Contents

Teachers can capitalize on students' interest in their changing bodies by having them monitor and assess their basic vital signs and other health-related characteristics. Using simple tools such as electronic blood-pressure devices, digital thermometers, stethoscopes, biofeedback monitors, and cardiovascular-fitness software, students can monitor their own health. The data they gather can be analyzed to show how healthy people are different.

The history of medicine and public health contains numerous accounts likely to fascinate many middle-school students. Students usually know about the marvels of modern treatments but not preventions such as sewer systems. Because the health of populations depends more on public health measures than on treatment, an effort should be made to interest students in prevention, vaccination, and other public health measures.

By the end of the 8th grade, students should know that

- **Sanitation measures such as the use of sewers, landfills, quarantines, and safe food handling are important in controlling the spread of organisms that cause disease. Improving sanitation to prevent disease has contributed more to saving human life than any advance in medical treatment.**
- **The ability to measure the level of substances in body fluids has made it possible for physicians to make comparisons with normal levels, make very sophisticated diagnoses, and monitor the effects of the treatments they prescribe.**
- **It is becoming increasingly possible to manufacture chemical substances such as insulin and hormones that are normally found in the body. They can be used by individuals whose own bodies cannot produce the amounts required for good health.**

Grades 9 through 12 Chapter Contents

Students can understand some of the science that underlies the technology, such as genetics and molecular chemistry, which make possible genetic engineering and chemical synthesis of drugs, or radioactivity and the behavior of waves in materials, which make possible various imaging techniques. Students can routinely use information technology to store, retrieve, and analyze physiological and health information. They should also examine and discuss issues of life support and access to affordable health care.

Collection of data on their own vital signs can include response to exercise and schedule changes and be done carefully and often enough to show bodily cycles in temperature and heart rate as well as individual differences in findings that can be compared for a large group.

By the end of the 12th grade, students should know that

- **Owing to the large amount of information that computers can process, they are playing an increasingly larger role in medicine. They are used to analyze data and to keep track of diagnostic information about individuals and statistical information on the distribution and spread of various maladies in populations.**
- **Almost all body substances and functions have daily or longer cycles. These cycles often need to be taken into account in interpreting normal ranges for body measurements, detecting disease, and planning treatment of illness. Computers aid in detecting, analyzing, and monitoring these cycles.**
- **Knowledge of genetics is opening whole new fields of health care. In diagnosis, mapping of genetic instructions in cells makes it possible to detect defective genes that may lead to poor health. In treatment, substances from genetically engineered organisms may reduce the cost and side effects of replacing missing body chemicals.**
- **Inoculations use weakened germs (or parts of them) to stimulate the body's immune system to react. This reaction prepares the body to fight subsequent invasions by actual germs of that type. Some inoculations last for life.**
- **Knowledge of molecular structure and interactions aids in synthesizing new drugs and predicting their effects.**
- **The diagnosis and treatment of mental disorders are improving but not as rapidly as for physical health. Techniques for detecting and diagnosing these disorders include observation of behavior, in-depth interviews, and measurements of body chemistry. Treatments range from discussing problems to affecting the brain directly with chemicals, electric shock, or surgery.**
- **Biotechnology has contributed to health improvement in many ways, but its cost and application have led to a variety of controversial social and ethical issues.**

National Science Education Standards: An Overview

In a world filled with the products of scientific inquiry, scientific literacy has become a necessity for everyone. Everyone needs to use scientific information to make choices that arise every day. Everyone needs to be able to engage intelligently in public discourse and debate about important issues that involve science and technology. And everyone deserves to share in the excitement and personal fulfillment that can come from understanding and learning about the natural world. ▮ Scientific literacy also is of increasing importance in the workplace. More and more jobs demand advanced skills, requiring that people be able to learn, reason, think creatively, make decisions, and solve problems. An understanding of science and the processes of science contributes in an essential way to these skills. Other countries are investing heavily to create scientifically and technically literate work forces. To keep pace in global markets, the United States needs to have an equally capable citizenry.

The *National Science Education Standards* present a vision of a scientifically literate populace. They outline what students need to know, understand, and be able to do to be scientifically literate at different grade levels. They describe an educational system in which all students demonstrate high levels of performance, in which teachers are empowered to make the decisions essential for effective learning, in which interlocking communities of teachers and students are focused on learning science, and in which supportive educational programs and systems nurture achievement. The *Standards* point toward a future that is challenging but attainable—which is why they are written in the present tense.

The intent of the *Standards* can be expressed in a single phrase: Science standards for all students. The phrase embodies both excellence and equity. The *Standards* apply to all students, regardless of age, gender, cultural or ethnic background, disabilities, aspirations, or interest and motivation in science. Different students will achieve understanding in different ways, and different students will achieve different degrees of depth and breadth of understanding depending on interest, ability, and context. But all students can develop the knowledge and skills described in the *Standards*, even as some students go well beyond these levels.

By emphasizing both excellence and equity, the *Standards* also highlight the need to give students the opportunity to learn science. Students cannot achieve high levels of performance without access to skilled professional teachers, adequate classroom time, a rich array of learning materials, accommodating work spaces, and the resources of the communities surrounding their schools. Responsibility for providing this support falls on all those involved with the science education system.

Implementing the *Standards* will require major changes in much of this country's science education. The *Standards* rest on the premise that science is an active process. Learning science is something that students do, not something that is done to them. "Hands-on" activities, while essential, are not enough. Students must have "minds-on" experiences as well.

The *Standards* call for more than "science as process," in which students learn such skills as observing, inferring, and experimenting. Inquiry is central to science learning. When engaging in inquiry, students describe objects and events, ask questions, construct explanations, test those explanations against current scientific knowledge, and communicate their ideas to others. They identify their assumptions, use critical and logical thinking, and consider alternative explanations. In this way, students actively develop their understanding of science by combining scientific knowledge with reasoning and thinking skills.

The importance of inquiry does not imply that all teachers should pursue a single approach to teaching science. Just as inquiry has many different facets, so teachers need to use many different strategies to develop the understandings and abilities described in the *Standards*.

Nor should the *Standards* be seen as requiring a specific curriculum. A curriculum is the way content is organized and presented in the classroom. The content embodied in the *Standards* can be organized and presented with many different emphases and perspectives in many different curricula.

Instead, the *Standards* provide criteria that people at the local, state, and national levels can use to judge whether particular actions will serve the vision of a scientifically literate society. They bring coordination, consistency, and coherence to the improvement of science education. If people take risks in the name of improving science education, they know they will be supported by policies and procedures throughout the system. By moving the practices of extraordinary teachers and administrators to the forefront of science education, the *Standards* take science education beyond the constraints of the present and toward a shared vision of the future.

Hundreds of people cooperated in developing the *Standards*, including teachers, school administrators, parents, curriculum developers, college faculty and administrators, scientists, engineers, and government officials. These individuals drew heavily upon earlier reform efforts, research into teaching and learning, accounts of exemplary practice, and their own personal experience and insights. In turn, thousands of people reviewed various drafts of the standards. That open, iterative process produced a broad consensus about the elements of science education needed to permit all students to achieve excellence.

Continuing dialogues between those who set and implement standards at the national, state, and local levels will ensure that the *Standards* evolve to meet the needs of students, educators, and society at large. The *National Science Education Standards* should be seen as a dynamic understanding that is always open to review and revision.

Organization of the *Standards*

After an introductory chapter and a chapter giving broad principles and definitions of terms, the *National Science Education Standards* are presented in six chapters:

- **Standards for science teaching (Chapter 3).**
- **Standards for professional development for teachers of science (Chapter 4).**
- **Standards for assessment in science education (Chapter 5).**
- **Standards for science content (Chapter 6).**
- **Standards for science education programs (Chapter 7).**
- **Standards for science education systems (Chapter 8).**

For the vision of science education described in the *Standards* to be attained, the standards contained in all six chapters need to be implemented. But the *Standards* document has been designed so that different people can read the standards in different ways. Teachers, for example, might want to read the teaching, content, and program standards before turning to the professional development, assessment, and systems standards. Policy makers might want to read the system and program standards first, while faculty of higher education might want to read the professional development and teaching standards first, before turning to the remaining standards.

Science Teaching Standards

The science teaching standards describe what teachers of science at all grade levels should know and be able to do. They are divided into six areas:

- **The planning of inquiry-based science programs.**
- **The actions taken to guide and facilitate student learning.**
- **The assessments made of teaching and student learning.**
- **The development of environments that enable students to learn science.**
- **The creation of communities of science learners.**
- **The planning and development of the school science program.**

Effective teaching is at the heart of science education, which is why the science teaching standards are presented first. Good teachers of science create environments in which they and their students work together as active learners. They have continually expanding theoretical and practical knowledge about science, learning, and science teaching. They use assessments of students and of their own teaching to plan and conduct their teaching. They build strong, sustained relationships with students that are grounded in their knowledge of students' similarities and differences. And they are active as members of science-learning communities.

In each of these areas, teachers need support from the rest of the educational system if they are to achieve the objectives embodied in the *Standards.* Schools, districts, local communities, and states need to provide teachers with the necessary resources—including time, appropriate numbers of students per teacher, materials, and schedules. For teachers to design and implement new ways of teaching and learning science, the practices, policies, and overall culture of most schools must change. Such reforms cannot be accomplished on a piecemeal or ad hoc basis.

Considerations of equity are critical in the science teaching standards. All students are capable of full participation and of making meaningful contributions in science classes. The diversity of students' needs, experiences, and backgrounds requires that teachers and schools support varied, high-quality opportunities for all students to learn science.

Professional Development Standards

The professional development standards present a vision for the development of professional knowledge and skill among teachers. They focus on four areas:

- **The learning of science content through inquiry.**
- **The integration of knowledge about science with knowledge about learning, pedagogy, and students.**
- **The development of the understanding and ability for lifelong learning.**

- **The coherence and integration of professional development programs.**

As envisioned by the standards, teachers partake in development experiences appropriate to their status as professionals. Beginning with preservice experiences and continuing as an integral part of teachers' professional practice, teachers have opportunities to work with master educators and reflect on teaching practice. They learn how students with diverse interests, abilities, and experiences make sense of scientific ideas and what a teacher does to support and guide all students. They study and engage in research on science teaching and learning, regularly sharing with colleagues what they have learned. They become students of the discipline of teaching.

Reforming science education requires substantive changes in how science is taught, which requires equally substantive change in professional development practices at all levels. Prospective and practicing teachers need opportunities to become both sources of their own growth and supporters of the growth of others. They should be provided with opportunities to develop theoretical and practical understanding and ability, not just technical proficiencies. Professional development activities need to be clearly and appropriately connected to teachers' work in the context of the school. In this way, teachers gain the knowledge, understanding, and ability to implement the *Standards*.

Assessment Standards

The assessment standards provide criteria against which to judge the quality of assessment practices. They cover five areas:

- **The consistency of assessments with the decisions they are designed to inform.**
- **The assessment of both achievement and opportunity to learn science.**
- **The match between the technical quality of the data collected and the consequences of the actions taken on the basis of those data.**
- **The fairness of assessment practices.**
- **The soundness of inferences made from assessments about student achievement and opportunity to learn.**

In the vision described by the *Standards*, assessments are the primary feedback mechanism in the science education system. They provide students with feedback on how well they are meeting expectations, teachers with feedback on how well their students are learning, school districts with feedback on the effectiveness of their teachers and programs, and policy makers with feedback on how well policies are working. This feedback in turn stimulates changes in policy, guides the professional development of teachers, and encourages students to improve their understanding of science.

Ideas about assessments have undergone important changes in recent years. In the new view, assessment and learning are two sides of the same coin. Assessments provide an operational definition of standards, in that they define in measurable terms what teachers should teach and students should learn. When students engage in assessments, they should learn from those assessments.

Furthermore, assessments have become more sophisticated and varied as they have focused on higher-order skills. Rather than simply checking whether students have memorized certain items of information, new assessments probe for students understanding, reasoning, and use of that knowledge—the skills that are developed through inquiry. A particular challenge to teachers is to communicate to parents and policy makers the advantages of new assessment methods.

Assessments can be done in many different ways. Besides conventional paper and pencil tests, assessments might include performances, portfolios, interviews, investigative reports, or written essays. They need to be developmentally appropriate, set in contexts familiar to students, and as free from bias as possible. At the district, state, and national levels, assessments need to involve teachers in their design and administration, have well-thought-out goals, and reach representative groups to avoid sampling bias.

Assessments also need to measure the opportunity of students to learn science. Such assessments might measure teachers' professional knowledge, the time available to teach science, and the resources available to students. Although difficult, such evaluations are a critical part of the *Standards.*

Science Content Standards

The science content standards outline what students should know, understand, and be able to do in the natural sciences over the course of K-12 education. They are divided into eight categories:

- **Unifying concepts and processes in science.**
- **Science as inquiry.**
- **Physical science.**
- **Life science.**
- **Earth and space science.**
- **Science and technology.**
- **Science in personal and social perspective.**
- **History and nature of science.**

The first category is presented for all grade levels, because the understandings and abilities associated with these concepts need to be developed throughout a student's educational experiences. The other seven categories are clustered for grade levels K-4, 5-8, and 9-12.

Each content standard states that as a result of activities provided for all students in those grade levels, the content of the standard is to be understood or certain abilities are to be developed. The standards refer to broad areas of content, such as objects in the sky, the interdependence of organisms, or the nature of scientific knowledge. Following each standard is a discussion of how students can learn that material, but these discussions are illustrative, not proscriptive. Similarly, the discussion of each standard concludes with a guide to the fundamental ideas that underlie that standard, but these ideas are designed to be illustrative of the standard, not part of the standard itself.

Because each content standard subsumes the knowledge and skills of other standards, they are designed to be used as a whole. Although material can be added to the content standards, using only a subset of the standards will leave gaps in the scientific literacy expected of students.

Science Education Program Standards

The science education program standards describe the conditions necessary for quality school science programs. They focus on six areas:

- **The consistency of the science program with the other standards and across grade levels.**
- **The inclusion of all content standards in a variety of curricula that are developmentally appropriate, interesting, relevant to student's lives, organized around inquiry, and connected with other school subjects.**
- **The coordination of the science program with mathematics education.**
- **The provision of appropriate and sufficient resources to all students.**
- **The provision of equitable opportunities for all students to learn the standards.**
- **The development of communities that encourage, support, and sustain teachers.**

Program standards deal with issues at the school and district level that relate to opportunities for students to learn and opportunities for teachers to teach science. The first three standards address individuals and groups responsible for the design, development, selection, and adaptation of science programs—including teachers, curriculum directors, administrators, publishers, and school committees. The last three standards describe the conditions necessary if science programs are to provide appropriate opportunities for all students to learn science.

Each school and district must translate the *National Science Education Standards* into a program that reflects local contexts and policies. The program standards discuss the planning and actions needed to provide comprehensive and coordinated experiences for all students across all grade levels. This can be done in many ways, because the *Standards* do not dictate the order, organization, or framework for science programs.

Science Education System Standards

The science education system standards consist of criteria for judging the performance of the overall science education system. They consider seven areas:

- **The congruency of policies that influence science education with the teaching, professional development, assessment, content, and program standards.**
- **The coordination of science education policies within and across agencies, institutions, and organizations.**
- **The continuity of science education policies over time.**
- **The provision of resources to support science education policies.**
- **The equity embodied in science education policies.**
- **The possible unanticipated effects of policies on science education.**
- **The responsibility of individuals to achieve the new vision of science education portrayed in the standards.**

Schools are part of hierarchical systems that include school districts, state school systems, and the national education system. Schools also are part of communities that contain organizations that influence science education, including colleges and universities, nature centers, parks and museums, businesses, laboratories, community organizations, and various media.

Although the school is the central institution for public education, all parts of the extended system have a responsibility for improving science literacy. For example, functions generally decided at the state (but sometimes at the local) level include the content of the school science curriculum, the characteristics of the science program, the nature of science teaching, and assessment practices. These policies need to be consistent with the vision of science education described in the *Standards* for the vision as a whole to be realized.

Today, different parts of the education system often work at cross purposes, resulting in waste and conflict. Only when most individuals and organizations share a common vision can we expect true excellence in science education to be achieved.

Toward the Future

Implementing the *National Science Education Standards* is a large and significant process that will extend over many years. But through the combined and continued support of all Americans, it can be achieved. Change will occur locally, and differences in individuals, schools, and communities will produce different pathways to reform, different rates of progress, and different final emphases. Nevertheless, with the common vision of the *Standards*, we can expect deliberate movement over time, leading to reform that is pervasive and permanent.

No one group can implement the *Standards*. The challenge extends to everyone within the education system, including teachers, administrators, science teacher educators, curriculum designers, assessment specialists, local school boards, state departments of education, and the federal government. It also extends to all those outside the system who have an influence on science education, including students, parents, scientists, engineers, businesspeople, taxpayers, legislators, and other public officials. All of these individuals have unique and complementary roles to play in improving the education that we provide to our children.

Efforts to achieve the vision of science education set forth in the *Standards* will be time-consuming, expensive, and sometimes uncomfortable. They also will be exhilarating and deeply rewarding. Above all, the great potential benefit to students requires that we act now. There is no more important task before us as a nation.

PHYSICAL SCIENCE, LIFE SCIENCE, AND EARTH AND SPACE SCIENCE STANDARDS

The standards for physical science, life science, and earth and space science describe the subject matter of science using three widely accepted divisions of the domain of science. Science subject matter focuses on the science facts, concepts, principles, theories, and models that are important for all students to know, understand, and use. Tables 6.2, 6.3, and 6.4 are the standards for physical science, life science, and earth and space science, respectively.

SCIENCE AND TECHNOLOGY STANDARDS

The science and technology standards in Table 6.5 establish connections between the natural and designed worlds and provide students with opportunities to develop decision-making abilities. They are not standards for technology education; rather, these standards emphasize abilities associated with the process of design and fundamental understandings about the enterprise of science and its various linkages with technology.

As a complement to the abilities developed in the science as inquiry standards,

TABLE 6.2. PHYSICAL SCIENCE STANDARDS

LEVELS K-4	LEVELS 5-8	LEVELS 9-12
Properties of objects and materials	Properties and changes of properties in matter	Structure of atoms
Position and motion of objects	Motions and forces	Structure and properties of matter
Light, heat, electricity, and magnetism	Transfer of energy	Chemical reactions
		Motions and forces
		Conservation of energy and increase in disorder
		Interactions of energy and matter

TABLE 6.3. LIFE SCIENCE STANDARDS

LEVELS K-4	LEVELS 5-8	LEVELS 9-12
Characteristics of organisms	Structure and function in living systems	The cell
Life cycles of organisms	Reproduction and heredity	Molecular basis of heredity
Organisms and environments	Regulation and behavior	Biological evolution
	Populations and ecosystems	Interdependence of organisms
	Diversity and adaptations of organisms	Matter, energy, and organization in living systems
		Behavior of organisms

these standards call for students to develop abilities to identify and state a problem, design a solution—including a cost and risk-and-benefit analysis—implement a solution, and evaluate the solution.

Science as inquiry is parallel to technology as design. Both standards emphasize student development of abilities and understanding. Connections to other domains, such as mathematics, are clarified in Chapter 7, *Program Standards*.

SCIENCE IN PERSONAL AND SOCIAL PERSPECTIVES STANDARDS

An important purpose of science education is to give students a means to understand and act on personal and social issues. The science in personal and social perspectives standards help students develop decision-making skills. Understandings associated with the concepts in Table 6.6 give students a foundation on which to base decisions they will face as citizens.

HISTORY AND NATURE OF SCIENCE STANDARDS

In learning science, students need to understand that science reflects its history and is an ongoing, changing enterprise. The standards for the history and nature of science recommend the use of history in school science programs to clarify different aspects of scientific inquiry, the human aspects of science, and the role that science has played in the development of various cultures. Table 6.7 provides an overview of this standard.

TABLE 6.4. EARTH AND SPACE SCIENCE STANDARDS

LEVELS K-4	LEVELS 5-8	LEVELS 9-12
Properties of earth materials	Structure of the earth system	Energy in the earth system
Objects in the sky	Earth's history	Geochemical cycles
Changes in earth and sky	Earth in the solar system	Origin and evolution of the earth system
		Origin and evolution of the universe

TABLE 6.5. SCIENCE AND TECHNOLOGY STANDARDS

LEVELS K-4	LEVELS 5-8	LEVELS 9-12
Abilities to distinguish between natural objects and objects made by humans	Abilities of technological design	Abilities of technological design
Abilities of technological design	Understanding about science and technology	Understanding about science and technology
Understanding about science and technology		

Science and Technology

CONTENT STANDARD E:

As a result of activities in grades K-4, all students should develop

- **Abilities of technological design**
- **Understanding about science and technology**
- **Abilities to distinguish between natural objects and objects made by humans**

DEVELOPING STUDENT ABILITIES AND UNDERSTANDING

The science and technology standards connect students to the designed world, offer them experience in making models of useful things, and introduce them to laws of nature through their understanding of how technological objects and systems work.

This standard emphasizes developing the ability to design a solution to a problem and understanding the relationship of science and technology and the way people are involved in both. This standard helps establish design as the technological parallel to inquiry in science. Like the science as inquiry standard, this standard begins the understanding of the design process, as well as the ability to solve simple design problems.

Children in grades K-4 understand and can carry out design activities earlier than they can inquiry activities, but they cannot easily tell the difference between the two, nor is it important whether they can. In grades K-4, children should have a variety of educational experiences that involve science and technology, sometimes in the same activity and other times separately. When the activities are informal and open, such as building a balance and comparing the weight of objects on it, it is difficult to separate inquiry from technological design. At other times, the distinction might be clear to adults but not to children.

Children's abilities in technological problem solving can be developed by firsthand experience in tackling tasks with a technological purpose. They also can study technological products and systems in their world—zippers, coat hooks, can openers, bridges, and automobiles. Children can engage in projects that are appropriately challenging for their developmental level—ones in which they must design a way to fasten, move, or communicate. They can study existing products to determine function and try to identify problems solved, materials used, and how well a product does what it is supposed to do. An old technological device, such as an apple peeler, can be used as a mystery object for students to investigate and figure out what it does, how it helps people, and what problems it might solve and cause. Such activities provide excellent opportunities to direct attention to specific technology—the tools and instruments used in science.

Suitable tasks for children at this age should have clearly defined purposes and be related with the other content standards. Tasks should be conducted within immediately familiar contexts of the home and school. They should be straightforward; there should be only one or two well-defined ways to solve the problem, and there should be a single, well-defined criterion for success. Any construction of objects should

Weather Instruments

Titles in this example emphasize some important components of the assessment process. Superficially, this assessment task is a simple matching task, but the teacher's professional judgment is still key. For example, is the term "wind gauge" most appropriate or should the more technical term "anemometer" be used? The teacher needs to decide if the use of either term places some students at a disadvantage. Teacher planning includes collecting pictures of weather instruments and ensuring that all students have equal opportunity to study them. A teacher who uses this assessment task recognizes that all assessments have strengths and weaknesses; this task is appropriate for one purpose, and other modes of assessment are appropriate for other purposes. This assessment task presupposes that students have developed some understanding of weather, technology, changing patterns in the environment, and the roles science and technology have in society. The teacher examines the patterns in the responses to evaluate the individual student responses.

[This example highlights some elements of Teaching Standards A, C, and D; Assessment Standards A, B, and D; and K-4 Content Standards D, E, and F.]

SCIENCE CONTENT: The K-4 content standard for earth science is supported by the fundamental concept that weather can be described in measurable quantities.

ASSESSMENT ACTIVITY: Students match pictures of instruments used to measure weather conditions with the condition the instrument measures.

ASSESSMENT TYPE: Individual, short-answer responses to matching item format.

DATA: Students' responses.

ASSESSMENT PURPOSE: When used in conjunction with other data, this assessment activity provides information to be used in assigning a grade.

CONTEXT: This assessment activity is appropriate at the end of a unit on the weather in grades 3 or 4.

ASSESSMENT EXERCISE:

Match pictures of the following weather instruments with the weather condition they measure:

1. Thermometers of various types, including liquid-expansion thermometers, metal-expansion thermometers and digital-electronic thermometers—used to measure temperature.
2. Barometers of various types, including aneroid and mercury types—used to measure air pressure.
3. Weather vanes—used to measure wind direction.
4. Wind gauges of various sorts—instruments to measure windspeed or velocity.
5. Hygrometers of various sorts—to measure moisture in the air.
6. Rain gauges of various sorts—used to measure depth of precipitation.

EVALUATING STUDENT PERFORMANCE:

EXEMPLARY PERFORMANCE: Student matches all instruments with their use.

AVERAGE PERFORMANCE: Student matches familiar forms of measuring instruments with their uses. A student might mistakenly say that the thermometer measures heat or might not understand the concepts of air pressure or humidity. Students at this age cannot be expected to develop sophisticated understanding of the concepts of air pressure, humidity, heat, temperature, speed, or velocity.

require developmentally appropriate manipulative skills used in elementary school and should not require time-consuming preparation and assembly.

Over the course of grades K-4, student investigations and design problems should incorporate more than one material and several contexts in science and technology. A suitable collection of tasks might include making a device to shade eyes from the sun, making yogurt and discussing how it is made, comparing two types of string to see which is best for lifting different objects, exploring how small potted plants can be made to grow as quickly as possible, designing a simple system to hold two objects together, testing the strength of different materials, using simple tools, testing different designs, and constructing a simple structure. It is important also to include design problems that require application of ideas, use of communications, and implementation of procedures—for instance, improving hall traffic at lunch and cleaning the classroom after scientific investigations.

Experiences should be complemented by study of familiar and simple objects through which students can develop observation and analysis skills. By comparing one or two obvious properties, such as cost and strength of two types of adhesive tape, for example, students can develop the abilities to judge a product's worth against its ability to solve a problem. During the K-4 years, an appropriate balance of products could come from the categories of clothing, food, and common domestic and school hardware.

A sequence of five stages—stating the problem, designing an approach, implementing a solution, evaluating the solution, and communicating the problem, design, and solution—provides a framework for planning and for specifying learning outcomes. However, not every activity will involve all of those stages, nor must any particular sequence of stages be followed. For example, some activities might begin by identifying a need and progressing through the stages; other activities might involve only evaluating existing products.

GUIDE TO THE CONTENT STANDARD

Fundamental abilities and concepts that underlie this standard include

ABILITIES OF TECHNOLOGICAL DESIGN

IDENTIFY A SIMPLE PROBLEM. In problem identification, children should develop the ability to explain a problem in their own words and identify a specific task and solution related to the problem.

See Content Standard A (grades K-4)

PROPOSE A SOLUTION. Students should make proposals to build something or get something to work better; they should be able to describe and communicate their ideas. Students should recognize that designing a solution might have constraints, such as cost, materials, time, space, or safety.

IMPLEMENTING PROPOSED SOLUTIONS. Children should develop abilities to work individually and collaboratively and to use suitable tools, techniques, and quantitative measurements when appropriate. Students should demonstrate the ability to balance simple constraints in problem solving.

EVALUATE A PRODUCT OR DESIGN. Students should evaluate their own results or solutions to problems, as well as those of other children, by considering how well a product or design met the challenge to solve a problem. When possible, students should use measurements and include constraints and other criteria in their evaluations. They should modify designs based on the results of evaluations.

COMMUNICATE A PROBLEM, DESIGN, AND SOLUTION. Student abilities should include oral, written, and pictorial communication of the design process and product. The communication might be show and tell, group discussions, short written reports, or pictures, depending on the students' abilities and the design project.

UNDERSTANDING ABOUT SCIENCE AND TECHNOLOGY

- People have always had questions about their world. Science is one way of answering questions and explaining the natural world.
- People have always had problems and invented tools and techniques (ways of doing something) to solve problems. Trying to determine the effects of solutions helps people avoid some new problems.
- Scientists and engineers often work in teams with different individuals doing different things that contribute to the results. This understanding focuses primarily on teams working together and secondarily, on the combination of scientist and engineer teams.
- Women and men of all ages, backgrounds, and groups engage in a variety of scientific and technological work.
- Tools help scientists make better observations, measurements, and equipment for investigations. They help scientists see, measure, and do things that they could not otherwise see, measure, and do.

ABILITIES TO DISTINGUISH BETWEEN NATURAL OBJECTS AND OBJECTS MADE BY HUMANS

- Some objects occur in nature; others have been designed and made by people to solve human problems and enhance the quality of life.
- Objects can be categorized into two groups, natural and designed.

Science in Personal and Social Perspectives

CONTENT STANDARD F:
As a result of activities in grades K-4, all students should develop understanding of

- **Personal health**
- **Characteristics and changes in populations**
- **Types of resources**
- **Changes in environments**
- **Science and technology in local challenges**

DEVELOPING STUDENT UNDERSTANDING

Students in elementary school should have a variety of experiences that provide initial understandings for various science-related personal and societal challenges. Central ideas related to health, populations, resources, and environments provide the foundations for students' eventual under-

- Gravity is the force that keeps planets in orbit around the sun and governs the rest of the motion in the solar system. Gravity alone holds us to the earth's surface and explains the phenomena of the tides.
- The sun is the major source of energy for phenomena on the earth's surface, such as growth of plants, winds, ocean currents, and the water cycle. Seasons result from variations in the amount of the sun's energy hitting the surface, due to the tilt of the earth's rotation on its axis and the length of the day.

Science and Technology

CONTENT STANDARD E:
As a result of activities in grades 5-8, all students should develop

- **Abilities of technological design**
- **Understandings about science and technology**

DEVELOPING STUDENT ABILITIES AND UNDERSTANDING

Students in grades 5-8 can begin to differentiate between science and technology, although the distinction is not easy to make early in this level. One basis for understanding the similarities, differences, and relationships between science and technology should be experiences with design and problem solving in which students can further develop some of the abilities introduced in grades K-4. The understanding of technology can be developed by tasks in which students have to design something and also by studying technological products and systems.

In the middle-school years, students' work with scientific investigations can be complemented by activities in which the purpose is to meet a human need, solve a human problem, or develop a product rather than to explore ideas about the natural world. The tasks chosen should involve the use of science concepts already familiar to students or should motivate them to learn new concepts needed to use or understand the technology. Students should also, through the experience of trying to meet a need in the best possible way, begin to appreciate that technological design and problem solving involve many other factors besides the scientific issues.

In the middle-school years, students' work with scientific investigations can be complemented by activities that are meant to meet a human need, solve a human problem, or develop a product...

Suitable design tasks for students at these grades should be well-defined, so that the purposes of the tasks are not confusing. Tasks should be based on contexts that are immediately familiar in the homes, school, and immediate community of the students. The activities should be straightforward with only a few well-defined ways to solve the problems involved. The criteria for success and the constraints for design should be limited. Only one or two science ideas should be involved in any particular task. Any construction involved should be readily

The Egg Drop

This rich example includes both a description of teaching and an assessment task. Mr. S. has students engage in a full design activity, designing and testing a container that can prevent an egg from breaking when dropped. The technology activity was preceded by a science unit on force and motion so that students were able to use their understanding of science in the design process. He has carefully considered commercially prepared versions of this activity but modified them to create one based on his experiences and the needs of the students. He has considered the safety of the students. The use of the videotape of former students not only provides a local context for the activity, but provides students with ideas about the designs that work and do not work. After the enjoyable day, Mr. S. requires students to reflect on what they have learned and apply it to a new, but similar problem.

[This example highlights some elements of all of the Teaching Standards; Assessment Standard A; 5-8 Content Standards B and E; Program Standard D; and System Standard D.]

As Mr. S. reviewed his syllabus for the year, he saw the next unit and smiled. On Monday they would begin the "Egg Drop"—the students, working in teams, would design a container for an uncooked egg. The time was right. During the period between the winter break and the new semester, the students had focused on the similarities and differences between science and technology. At the beginning of the second semester the students had completed activities and engaged in discussions until they demonstrated an adequate understanding of force, motion, gravity and acceleration. Now it was time to bring the knowledge of science principles to a design problem. The problem was to design a container that could be dropped from the second floor balcony without breaking the egg.

Some variation of the egg drop activity was found in just about every middle school science book that Mr. S. had ever seen. But over the years he had come to know what worked and what didn't, where to anticipate the students would have difficulties, and just how to phrase questions and challenges the students could respond to without being overwhelmed. He had developed some aspects of the unit that were special to him and to the students in Belle Vue Middle School. He knew when he introduced the idea that at least one student would have a tale to tell about dropping a carton of eggs when carrying groceries home from the store or when removing the carton from the refrigerator. While dropping eggs from the balcony was not part of the every day experience of the students, dropping things and having them break was.

On Monday, he would set the challenge, the constraints, and the schedule. They would begin with a whole class review of what the students knew about force, acceleration, and gravity and the design principles. He would have someone write these on a chart that they could hang on the wall during the unit. Next they would identify things they had seen fall gently without breaking and about the size, shape, material, and construction of these items. Finally he would tell the students the constraints: teams would be made up of three students each; materials would be limited to the "stuff" available on the work table; teams would have to show him a sketch before they began building their container; they would have to conduct at least two trials with their container—one with a plastic egg and one with a hard-cooked egg. For years, he had collected odds and ends—string and plastic, paper towel rolls end egg cartons, Styrofoam peanuts, cotton and other packing material. In the world outside of school, limited availability of materials was a real constraint. He was grateful that he taught in Florida where he could open the door and watch the students outside as they climbed to the second floor balcony to conduct their trial runs. He knew that if he taught up North, where they would have to do this activity from the gym balcony, he would have to plan differently as the class would have to move to and from the gym.

On Tuesday, he would have a few raw eggs for each class. He would have several students try to crush them by exerting force with their hands. He would need lab aprons, goggles, and plastic gloves for that. Then he would show the egg drop video. After the first few years, he learned to videotape the class on the day of the egg drop. He had edited a short video of some of the more spectacular egg drops—both successful and unsuccessful. The students enjoyed watching older brothers and sisters, and famous and infamous students. The students would then get into their groups and discuss the features of the containers in which the eggs broke and those in which the eggs did not break. He would challenge them to consider how they might improve the successful egg drop containers. Toward the end of the period, each group would have someone report to the class one thing the group had learned from the video and discussion.

Wednesday would be an intense day as students argued and sketched, sketched and argued, had plans approved, collected materials, bartered with other teams for materials, and tried to build a prototype of their container.

Thursday they would begin class with a discussion of why they needed to build a prototype and why they needed to do some trial runs with plastic and hard cooked eggs. He would ask them the advantages and disadvantages of using the plastic and hard cooked eggs in the trial runs. This would give them an opportunity to consider cost and the characteristics of models. There would be time in class to work and some groups would be ready to begin the field trials. He would need a supply of trash bags to use as drop cloths.

Friday's class would begin by reminding the students that the assessment for the egg drop would not be whether the egg broke, but rather how they would be able to share what they considered as they tried to solve the problem of designing a container for an egg so that the egg would drop 15 feet and not break. He would also remind them that the egg drop was scheduled for Wednesday, ready or not.

Monday would be an uninterrupted work day. On Tuesday they would by work in their groups to determine what would be needed to make their egg drop event a success. In his plans Mr. S. noted that he would need a setup team that would cover the ground below the balcony with trash bags. A clean up crew, again wearing plastic gloves, would gather the bags and get them into the disposal. He anticipated that they would want two class mates to have stopwatches to measure the time it took for the egg to drop. The students would want to determine where the egg should be held for the start of the egg drop. There were always heated arguments about whether the starting line was from the arm of the dropper or from some point on the container. They would need someone to call "Drop!"

Wednesday would be the day of the egg drop. Thursday, the class would begin by meeting in their small groups to discuss what worked, what didn't, why, and what they would do differently if they were to do the egg drop design experiment again. Then they would discuss these same ideas as a whole class.

Friday, the students would fill the board with characteristics of good design procedures. Then they would write and sketch in their notebooks these characteristics and what each had learned from the egg drop activity. He knew from experience that the egg drop would be an engaging activity.

The "header titles" emphasize some important components of the assessment process.

SCIENCE CONTENT: The Content Standards for Science and Technology for students in Grades 5-8 call for them to understand and be able to solve a problem by using design principles. These include the ability to design a product; evaluate technological products; and communicate the process of technological design.

ASSESSMENT ACTIVITY: Following the egg drop activity, students each prepare a report on one thing they propose in order to improve their team's container and how they would test the effectiveness of their improvement.

ASSESSMENT TYPE: Individual. embedded in teaching.

ASSESSMENT PURPOSE: The teacher will use the information to assess student understanding of the process of design and for assigning a grade.

DATA: A report, written, sketched, or both, in which students describe an improvement to the container, the anticipated gains and losses from the improvement, and how they would propose to test the new container.

CONTEXT: The egg drop activity allows students the opportunity to bring scientific principles and creativity to a problem, while developing the skills of technology and having a good time. However, the excitement of the activity can overshadow the intended outcome of developing understanding and abilities of technological design. This assessment activity provides the opportunity for students to reflect on what they have experienced and articulate what they have come to understand. The activity comes after the design of an original container, the testing of that container, a class discussion on what worked and why, what didn't work and why, what they would do differently next time, and an opportunity to make notes in a personal journal for science class.

EVALUATING STUDENT PERFORMANCE: Student progress in understanding and doing design can be evaluated by comparing the student responses in the reports with the list generated by previous classes. The astute teacher will have made sure that the list included constraints such as cost, time, materials, and trade-offs. Criteria for a quality report might also include how well the student has differentiated between the design and its evaluation. The teacher might also consider the clarity of expression, as well as alternate ways used to present the information, such as drawings.

accomplished by the students and should not involve lengthy learning of new physical skills or time-consuming preparation and assembly operations.

During the middle-school years, the design tasks should cover a range of needs, materials, and aspects of science. Suitable experiences could include making electrical circuits for a warning device, designing a meal to meet nutritional criteria, choosing a material to combine strength with insulation, selecting plants for an area of a school, or designing a system to move dishes in a restaurant or in a production line.

Such work should be complemented by the study of technology in the students' everyday world. This could be achieved by investigating simple, familiar objects through which students can develop powers of observation and analysis—for example, by comparing the various characteristics of competing consumer products, including cost, convenience, durability, and suitability for different modes of use. Regardless of the product used, students need to understand the science behind it. There should be a balance over the years, with the products studied coming from the areas of clothing, food, structures, and simple mechanical and electrical devices. The inclusion of some non-product-oriented problems is important to help students understand that technological solutions include the design of systems and can involve communication, ideas, and rules.

The principles of design for grades 5-8 do not change from grades K-4. But the complexity of the problems addressed and the extended ways the principles are applied do change.

GUIDE TO THE CONTENT STANDARD

Fundamental abilities and concepts that underlie this standard include

ABILITIES OF TECHNOLOGICAL DESIGN

See Content Standard A (grades 5-8)

IDENTIFY APPROPRIATE PROBLEMS FOR TECHNOLOGICAL DESIGN. Students should develop their abilities by identifying a specified need, considering its various aspects, and talking to different potential users or beneficiaries. They should appreciate that for some needs, the cultural backgrounds and beliefs of different groups can affect the criteria for a suitable product.

DESIGN A SOLUTION OR PRODUCT. Students should make and compare different proposals in the light of the criteria they have selected. They must consider constraints—such as cost, time, trade-offs, and materials needed—and communicate ideas with drawings and simple models.

IMPLEMENT A PROPOSED DESIGN. Students should organize materials and other resources, plan their work, make good use of group collaboration where appropriate, choose suitable tools and techniques, and work with appropriate measurement methods to ensure adequate accuracy.

EVALUATE COMPLETED TECHNOLOGICAL DESIGNS OR PRODUCTS. Students should use criteria relevant to the original purpose or need, consider a variety of factors that might affect acceptability and suitability for intended users or beneficiaries, and develop measures of quality with respect to such criteria and factors; they should also suggest improvements and, for their own products, try proposed modifications.

See Teaching Standard B

COMMUNICATE THE PROCESS OF TECHNOLOGICAL DESIGN. Students should review and describe any completed piece of work and identify the stages of problem identification, solution design, implementation, and evaluation.

UNDERSTANDINGS ABOUT SCIENCE AND TECHNOLOGY

See Content Standards A, F, & G (grades 5-8)

- Scientific inquiry and technological design have similarities and differences. Scientists propose explanations for questions about the natural world, and engineers propose solutions relating to human problems, needs, and aspirations. Technological solutions are temporary; technologies exist within nature and so they cannot contravene physical or biological principles; technological solutions have side effects; and technologies cost, carry risks, and provide benefits.
- Many different people in different cultures have made and continue to make contributions to science and technology.
- Science and technology are reciprocal. Science helps drive technology, as it addresses questions that demand more sophisticated instruments and provides principles for better instrumentation and technique. Technology is essential to science, because it provides instruments and techniques that enable observations of objects and phenomena that are otherwise unobservable due to factors such as quantity, distance, location, size, and speed. Technology also provides tools for investigations, inquiry, and analysis.
- Perfectly designed solutions do not exist. All technological solutions have trade-offs, such as safety, cost, efficiency, and appearance. Engineers often build in back-up systems to provide safety. Risk is part of living in a highly technological world. Reducing risk often results in new technology.
- Technological designs have constraints. Some constraints are unavoidable, for example, properties of materials, or effects of weather and friction; other constraints limit choices in the design, for example, environmental protection, human safety, and aesthetics.
- Technological solutions have intended benefits and unintended consequences. Some consequences can be predicted, others cannot.

Science in Personal and Social Perspectives

CONTENT STANDARD F:
As a result of activities in grades 5-8, all students should develop understanding of

- **Personal health**
- **Populations, resources, and environments**
- **Natural hazards**
- **Risks and benefits**
- **Science and technology in society**

the earth system. We can observe some changes such as earthquakes and volcanic eruptions on a human time scale, but many processes such as mountain building and plate movements take place over hundreds of millions of years.

- Evidence for one-celled forms of life—the bacteria—extends back more than 3.5 billion years. The evolution of life caused dramatic changes in the composition of the earth's atmosphere, which did not originally contain oxygen.

THE ORIGIN AND EVOLUTION OF THE UNIVERSE

See Content Standard A (grades 9-12)

- The origin of the universe remains one of the greatest questions in science. The "big bang" theory places the origin between 10 and 20 billion years ago, when the universe began in a hot dense state; according to this theory, the universe has been expanding ever since.
- Early in the history of the universe, matter, primarily the light atoms hydrogen and helium, clumped together by gravitational attraction to form countless trillions of stars. Billions of galaxies, each of which is a gravitationally bound cluster of billions of stars, now form most of the visible mass in the universe.
- Stars produce energy from nuclear reactions, primarily the fusion of hydrogen to form helium. These and other processes in stars have led to the formation of all the other elements.

Science and Technology

CONTENT STANDARD E:

As a result of activities in grades 9-12, all students should develop

- **Abilities of technological design**
- **Understandings about science and technology**

DEVELOPING STUDENT ABILITIES AND UNDERSTANDING

This standard has two equally important parts—developing students' abilities of technological design and developing students' understanding about science and technology. Although these are science education standards, the relationship between science and technology is so close that any presentation of science without developing an understanding of technology would portray an inaccurate picture of science.

In the course of solving any problem where students try to meet certain criteria within constraints, they will find that the ideas and methods of science that they know, or can learn, can be powerful aids. Students also find that they need to call on other sources of knowledge and skill, such as cost, risk, and benefit analysis, and aspects of critical thinking and creativity. Learning experiences associated with this standard should include examples of technological achievement in which science has played a part and examples where technological advances contributed directly to scientific progress.

Students can understand and use the design model outlined in this standard. Students respond positively to the concrete, practical, outcome orientation of design problems before they are able to engage in the abstract, theoretical nature of many scientific inquiries. In general, high school students do not distinguish between the roles of science and technology. Helping them do so is implied by this standard. This lack of distinction between science and technology is further confused by students' positive perceptions of science, as when they associate it with medical research and use the common phrase "scientific progress." However, their association of technology is often with environmental problems and another common phrase, "technological problems." With regard to the connection between science and technology, students as well as many adults and teachers of science indicate a belief that science influences technology. This belief is captured by the common and only partially accurate definition "technology is applied science." Few students understand that technology influences science. Unraveling these misconceptions of science and technology and developing accurate concepts of the role, place, limits, possibilities and relationships of science and technology is the challenge of this standard.

The choice of design tasks and related learning activities is an important and difficult part of addressing this standard. In choosing technological learning activities, teachers of science will have to bear in mind some important issues. For example, whether to involve students in a full or partial design problem; or whether to engage them in meeting a need through technology or in studying the technological work of others. Another issue is how to select a task that brings out the various ways in which science and technology interact, providing a basis for reflection on the nature of technology while learning the science concepts involved.

In grades 9-12, design tasks should explore a range of contexts including both those immediately familiar in the homes, school, and community of the students and those from wider regional, national, or global contexts. The tasks should promote different ways to tackle the problems so that different design solutions can be implemented by different students. Successful completion of design problems requires that the students meet criteria while addressing conflicting constraints. Where constructions are involved, these might draw on technical skills and understandings developed within the science program, technical and craft skills developed in other school work, or require developing new skills.

Over the high school years, the tasks should cover a range of needs, of materials, and of different aspects of science. For example, a suitable design problem could include assembling electronic components to control a sequence of operations or analyzing the features of different athletic shoes to see the criteria and constraints imposed by the sport, human anatomy, and materials. Some tasks should involve science ideas drawn from more than one field of science. These can be complex, for example, a machine that incorporates both mechanical and electrical control systems.

Although some experiences in science and technology will emphasize solving problems and meeting needs by focusing on products, experience also should include problems about system design, cost, risk, benefit, and very importantly, tradeoffs.

Because this study of technology occurs within science courses, the number of these activities must be limited. Details specified in this standard are criteria to ensure quality and balance in a small number of tasks and are not meant to require a large number of such activities. Many abilities and understandings of this standard can be developed as part of activities designed for other content standards.

GUIDE TO THE CONTENT STANDARD

Fundamental abilities and concepts that underlie this standard include

ABILITIES OF TECHNOLOGICAL DESIGN

See Content Standard A (grades 9-12)

IDENTIFY A PROBLEM OR DESIGN AN OPPORTUNITY. Students should be able to identify new problems or needs and to change and improve current technological designs.

PROPOSE DESIGNS AND CHOOSE BETWEEN ALTERNATIVE SOLUTIONS. Students should demonstrate thoughtful planning for a piece of technology or technique. Students should be introduced to the roles of models and simulations in these processes.

IMPLEMENT A PROPOSED SOLUTION. A variety of skills can be needed in proposing a solution depending on the type of technology that is involved. The construction of artifacts can require the skills of cutting, shaping, treating, and joining common materials—such as wood, metal, plastics, and textiles. Solutions can also be implemented using computer software.

EVALUATE THE SOLUTION AND ITS CONSEQUENCES. Students should test any solution against the needs and criteria it was designed to meet. At this stage, new criteria not originally considered may be reviewed.

See Teaching Standard B

COMMUNICATE THE PROBLEM, PROCESS, AND SOLUTION. Students should present their results to students, teachers, and others in a variety of ways, such as orally, in writing, and in other forms—including models, diagrams, and demonstrations.

UNDERSTANDINGS ABOUT SCIENCE AND TECHNOLOGY

- Scientists in different disciplines ask different questions, use different methods of investigation, and accept different types of evidence to support their explanations. Many scientific investigations require the contributions of individuals from different disciplines, including engineering. New disciplines of science, such as geophysics and biochemistry often emerge at the interface of two older disciplines.
- Science often advances with the introduction of new technologies. Solving technological problems often results in new scientific knowledge. New technologies often extend the current levels of scientific understanding and introduce new areas of research.
- Creativity, imagination, and a good knowledge base are all required in the work of science and engineering.
- Science and technology are pursued for different purposes. Scientific inquiry is driven by the desire to understand the natural world, and technological design is driven by the need to meet human needs and solve human problems. Technology, by its nature, has a more direct effect on society than science because its purpose is to solve human problems, help humans

adapt, and fulfill human aspirations. Technological solutions may create new problems. Science, by its nature, answers questions that may or may not directly influence humans. Sometimes scientific advances challenge people's beliefs and practical explanations concerning various aspects of the world.

- Technological knowledge is often not made public because of patents and the financial potential of the idea or invention. Scientific knowledge is made public through presentations at professional meetings and publications in scientific journals.

Science in Personal and Social Perspectives

CONTENT STANDARD F:
As a result of activities in grades 9-12, all students should develop understanding of

- **Personal and community health**
- **Population growth**
- **Natural resources**
- **Environmental quality**
- **Natural and human-induced hazards**
- **Science and technology in local, national, and global challenges**

DEVELOPING STUDENT UNDERSTANDING

The organizing principles for this standard do not identify specific personal and societal challenges, rather they form a set of conceptual organizers, fundamental understandings, and implied actions for most contemporary issues. The organizing principles apply to local as well as global phenomena and represent challenges that occur on scales that vary from quite short—for example, natural hazards—to very long—for example, the potential result of global changes.

By grades 9-12, many students have a fairly sound understanding of the overall functioning of some human systems, such as the digestive, respiratory, and circulatory systems. They might not have a clear understanding of others, such as the human nervous, endocrine, and immune systems. Therefore, students may have difficulty with specific mechanisms and processes related to health issues.

The organizing principles apply to local as well as global phenomena.

Most high school students have a concept of populations of organisms, but they have a poorly developed understanding of the relationships among populations within a community and connections between populations and other ideas such as competition for resources. Few students understand and apply the idea of interdependence when considering interactions among populations, environments, and resources. If, for example, students are asked about the size of populations and why some populations would be larger, they often simply describe rather than reason about interdependence or energy flow.

Students may exhibit a general idea of cycling matter in ecosystems, but they may center on short chains of the cyclical process

Testimony of Stan Metzenberg, Ph.D.

Assistant Professor of Biology
California State University Northridge

Before the United States House of Representatives Committee on Science, Subcommittee on Basic Research July 23, 1998

I am very pleased and honored to have this opportunity to speak to you today, about the effects of the educational reform movement on science education in this country.

My name is Stan Metzenberg, and I'm an Assistant Professor of Biology at California State University Northridge. The university is located in the San Fernando Valley, and draws its student population from the greater Los Angeles area. We have a state mandate to accept the top third of graduating high school seniors, but within that population of entering freshmen we find that two thirds are in need of immediate remedial education in mathematics or English. I have the dubious distinction of being at a second-tier institution that is taking in some of the worst-prepared students in California; a state that has nearly the worst-prepared students in the United States; a nation that has nearly the worst-prepared students in the world.

Despite the lack of college-preparedness of our typical freshman, California State University Northridge is successful in providing students with an exceptional education. I am also a laboratory scientist, as well as an educator, and my students and I conduct NIH-supported research in molecular parasitology. Thanks to the largesse of the NIH and the NSF, many non-Ph.D.-granting institutions are similarly able to bring undergraduate students into the laboratory to conduct basic research.

I became interested in K-12 education, in part because of the appalling lack of college-preparedness of students graduating from the Los Angeles Unified School District. For the past six months, I have served as a consultant to a California Commission developing academic content standards in science. Dr. Glenn T. Seaborg is Chair of the Science Committee for the Academic Standards Commission, and has a long and distinguished career as both a scientist and advocate for improving K-12 education.

While assisting the Commission in the preparation of the California Science Standards, I became immersed in The National Science Education Standards, and the AAAS Benchmarks for Science Literacy. These two documents are of extraordinary importance to your hearings today, as they serve as the philosophical basis or *cornerstone* for the NSF Systemic Initiatives.

The message I bring to you today is that the NSF has chosen the wrong path in endorsing these documents. They have set a standard of achievement for students that is shockingly low, and federal funding is helping to create an entire generation of scientific illiterates. The often quoted adage *Less is More* brings little comfort. As any thinking person knows, and as the facts demonstrate, less is not more

-- it's less!

It is often said erroneously, that the AAAS Benchmarks and National Science Education Standards represent the widespread consensus of scientists and educators as to what all high school graduates need, to achieve reasonable literacy in science. In fact, there is not consensus. Although there are some well-meaning scientists who stand behind these documents, the documents were primarily written by education specialists rather than scientists, and the sentiment of most scientists has been one of indifference rather than consensus. Given that only about a fifth of our research grant applications are funded, there should be no surprise that scientists only grudgingly commit time to activities outside of the lab.

In addition to this misleading use of the word *consensus*, it is also said with some frequency that the National Science Education Standards and AAAS Benchmarks are based on scholarly research on how students learn, and what is developmentally appropriate for all students to learn at a given age. In the National Science Education Standards (p. 110) for example, it is stated that there exists *an obligation to develop content standards that appropriately represent the developmental and learning abilities of students*. The prevailing philosophy among education specialists is that a teacher does harm to students by introducing material that is not developmentally appropriate. I have undertaken a study of the literature cited in the AAAS Benchmarks to ask what is the research on learning abilities of students, and is it applicable to our students?

What I have found is quite disturbing. The National Science Education Standards and AAAS Benchmarks are based on the flimsiest excuse for research that I have ever encountered. Fewer than half of the papers covering student learning in physical, earth, and life sciences are in peer-reviewed publications. In fact quite a few of the references are to unpublished talks that were presented at education meetings. This is certainly the lowest form of review, since you and I can't read what was said or even know if the audience clapped politely after the speaker had finished. There are numerous instances where the AAAS Benchmarks misstate the methodology or findings in a paper, claiming that the study was performed on high school students for example, when the paper indicates it was performed on college students.

Most of the peer-reviewed research was not done in the United States at all, but rather in countries such as England, Australia, Germany, and Israel. The AAAS Benchmarks and National Science Education Standards make a tremendous leap of faith in assuming that children in different countries have similar learning stages. Many of the cited papers represent studies conducted on small numbers of students, on the order of 30 to 100, who in many cases were not chosen randomly from an age cohort. It is often the case that the very conclusions of the paper hinge on the responses of a dozen or fewer students, who had not even received formal instruction in the material upon which they were being questioned. It is a sobering thought that educational policy in the United States could be influenced by a few 7-year olds growing up in another country, but this is in fact what has happened.

I will cite three specific example from the AAAS Benchmarks research base, reflecting either a poor research methodology, a possible lack of scientific understanding on the part of the educational researcher, or a significant anti-science bias. There are in total, only forty-three peer-reviewed papers cited in the physical, earth and life sciences sections of the AAAS Benchmarks, and I have managed to obtain and read about thirty-five of them. The three papers I will cite are fairly typical examples.

Childrens' understanding of inherited traits.

In discussing childrens' understanding of inherited traits, the following statements are presented in the two national standards documents:

> *...students might hold some naive thoughts about inheritance, including the belief that traits are inherited from only one parent...* NSES p. 128
>
> *Some students believe that traits are inherited from only one of the parents...It may not be until the end of the 5th grade that some students can use arguments based on chance to predict the outcome of inherited characteristics from observing those characteristics in the parents* AAAS Benchmarks p. 341

What is the research that would support such a statement? The cited paper by Kargbo et al. (Journal of Biological Education 14:138-146) reports on the results of half-hour interviews with 32 Canadian students, with ages ranging from 7 to 13. Twelve of the subjects were under the age of ten, and it's astonishing that such a small group could serve as the basis for the aforementioned statement in the AAAS Benchmarks, on the cognitive limitations of students before the end of 5th grade.

Students were asked the following question (Ibid. Table 4, p. 142): *If a white male dog and a black female dog have six puppies, what colour would the puppies be?* First of all, geneticists know that this is a question that is impossible to answer with the information provided. The students nonetheless gamely answer, guessing that the puppies would be black or some combination of black and white. None of the younger students guessed that the puppies would be all white, which may indicate that they thought the black pigment in the mothers' coat would overcome in some way the absence of pigment in the father's coat. It's a good guess.

The next question in the interview was *Which one of the parent dogs do you think will give more colour to the puppies?* Most young students said the mother dog, remembering perhaps that the father dog was white and had no color. The authors concluded from these interviews that it was clear *...that a large number of the children thought the mother would contribute more to the genetic make-up of the offspring than the father.* (Ibid. p. 142). This is obviously not a fair conclusion, given the context: the students were presented with a black mother dog and white father dog and asked which would contribute more color.

This is an example of poor research design. I wish I could say it was unusual, but in fact this type of error is present in nearly every cited paper. What is most harmful in this example is the statement in the Benchmarks about what children cannot understand before the end of the 5th grade. Learning follows from instruction, after all. The fact that children have misconceptions prior to instruction should not be surprising, nor should it prevent us from attempting to teach them the concepts. The Benchmarks and National Science Standards are full of unscholarly admonishments about what children cannot learn at an early age. By thoughtlessly building national policy around research of this type, we have tremendously underestimated our children's capacity to learn.

Childrens' understanding of cooling objects.

My second example, on childrens' understanding of cooling objects, illustrates a case where the students being interviewed appear to know more about the science than they are being given credit for. Kesidou and Duit (Journal of research on science teaching 30:85-106) conducted interviews with 34 German students in Grade 10, who had previously received four years of physics instruction. The students were asked questions based on a scenario having to do with the cooling of a hot piece of metal. The authors express concern at one point, that:

> *Some students appeared to be unaware that every cooling process requires an interaction partner. It appears that they held the idea that bodies may cool spontaneously without other (colder) bodies being involved.* (Ibid. p. 97)

In reading the background of the German students, it's no wonder that they thought bodies could cool spontaneously -- they learned about heat radiation in the 7th grade. As I'm sure you all know, hot objects can become cooler by emitting infra-red radiation, and do not need to interact with other objects to do so. This error is repeated in the AAAS Benchmarks, which state:

> *Middle- and high-school students do not always explain heat-exchange phenomena as interactions. For example, students often think objects cool down or release heat spontaneously - that is, without being in contact with a cooler object.* (AAAS Benchmarks p. 337)

The paper by Kesidou and Duit has been favorably cited in a recent letter (see appendix) from Bruce Alberts, President of the National Academy of Sciences. Dr. Alberts is an outstanding scientist, but he may be unaware that this paper contains an egregious error. I am compelled to ask why, for all the millions of dollars that have been spent, our students are being so poorly served by these national standards documents? I wish I could say that this was the only example of a paper in which the authors make a mistake about the science. Unfortunately it is a common finding.

Childrens' perceptions of the shape of the Earth.

My final example of citations in the AAAS Benchmarks is representative of a school of thought called post-modernism, in which what is generally called scientific fact is taken to be merely a *belief system*. In the first printing in 1992 of a National Research Council document discussing the intellectual foundations of the National Science Standards, it was stated that the standards would reflect the *postmodernist view of science* that *questions the objectivity of observations and the truth of scientific knowledge.* The National Science Education Standards themselves, state a vision that there should be less emphasis on *knowing scientific facts and information*, less emphasis on *activities that demonstrate and verify science content*, and less emphasis on *getting an answer* (NSES p. 113).

In the cited paper, Vosniadou and Brewer (Cognitive psychology 24: 535-585) report the mental models children hold of shape of the Earth. These authors conducted interviews on 60 students between the ages of 6 and 11, and evaluated artwork they drew of the Earth situated in space. Their rubric for scoring these childrens' drawings was complicated. If for example a child drew the Earth as a circle surrounded by stars in space, that was taken to be a indication that the Earth was a sphere. If the stars appear on only one side of the Earth, it was assumed that the student believed the Earth is flat. What is even more appalling than the research methodology, is the language used by the authors:

> *The purpose of the present study was to further investigate the nature of children's intuitive knowledge about the shape of the earth and to understand how this knowledge changes as children are exposed to the culturally accepted information that the earth is a sphere* (Ibid. p. 541)

The authors repeat this peculiar phrase *the culturally accepted information that the earth is a sphere*, or something similar to it, a total of four times in the paper. It is not clear from these statements whether the authors are themselves willing to commit to the proposition that the Earth is not flat. I would merely ask: How is it possible that the AAAS, the National Academy of Sciences, and the National Science Foundation have spent so many hundreds of millions of dollars to increase the influence of this type of thought in our schools?

The vision of the national standards documents is that scientific facts have little value, and children should not learn them, and after all, cannot learn them. Depriving students of a content-rich education in science will not give them standing in the global economy.

A California Commission has recently taken a different course, in developing content-rich academic standards in science for the K-12 schools. A copy of these standards have been included with my written testimony. Although many documents were consulted during the writing of these standards, including the AAAS Benchmarks and National Science Education Standards, one of the primary considerations was the content knowledge expectations placed on students in other countries.

I have included in my written testimony, the 1997 Indian Certificate of Secondary Education Examination. There are several reasons for assessing our own expectations of student achievement against those of India. Their syllabus distinguishes the content knowledge that all secondary students are to learn, which is indicated in italics, from the more advanced content knowledge expected of college-bound science majors. Since much of the thrust of our own national science standards documents is to define literacy for all students, this is an important distinction.

It is clear from this syllabus that India expects significant content knowledge from all of its students. In the 9th year of schooling (Class IX) for example, all students learn about friction and lubrication, pressure in a liquid at rest, and the effect of pressure on the boiling point of a liquid (appendix p. 64). They learn about the expansion of solids, liquids and gases, and paths of heat conduction, convection and radiation (appendix p. 65). The A-level students learn much more still (see non-italicized text).

Despite the problems of grinding poverty and multiple languages, India is training students to such a high level that they are rapidly becoming a world leader in the fields of information technology. We have also seen evidence in the past few months that their nuclear physicists learned a few things in school. As the late Albert Shanker, President of the American Federation of Teachers remarked (in Making Standards Count: The case for student incentives. American Federation of Teachers, 1994): *...when you talk about world class standards, there is a world out there.*

So what are the systemic initiatives doing to help prepare our students for the global economy? I've copied three exercises from a 9th grade textbook (<u>Issues, Evidence and You</u>, LAB-AIDS, Inc.) being promulgated in the LA schools by the LA Urban Systemic Initiative, and have included them with my written testimony. The first activity in the book has students sipping samples of water from cups, with the challenge to attempt to reach a group consensus on which sample in the taste test might have come from bottled water. An example taken from the middle of the book has students mixing hot and cold water, and predicting the outcome (if you guessed warm water, then you must have studied in advance!). The last activity in the book has students read a short passage about the history of Easter Island, and answer questions such as *What does this parable tell us about our own relationship to our environment?* Though these might be good exercises in the third or fourth grade, the content-knowledge expectations are shockingly low for a student in high school.

The educational reform movement in this country has caused us to lose our grounding and focus on what is good practice in science education. In September of last year, the House Committee on Science heard testimony from the President of the Technical Education Research Center on inquiry-based learning for the 21st century. Among the exemplary curricula presented by this individual was an example called *The Pringle's Challenge*, in which students create a mailing container that is both lightweight and strong, and *use that container to mail one Pringle's potato chip to a partner school without breaking the chip. When* *the package arrives, the receiving school determines whether the chip is intact, measures the weight and volume of the package, and gives the package an overall score based on these three variables.* Our poor showing in the 12th grade TIMSS study should come as no surprise. While our students were mailing potato chips to each other, students in other countries were hitting the science books and learning something.

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Note: See also Follow-Up Questions for Dr. Stan Metzenberg

PHYSICS TODAY online

Reference Frame

Revolution in Science Education: Put Physics First!

Leon Lederman

A time traveler from the year 1899 would be continually amazed by our advanced technology--our cars and airplanes, our skyscraper cities, our TV, radio, computers, and communication abilities. Probably the traveler would be most shaken by our science, from astronomy to zoology. The only place in which this visitor would be comfortably at home is in most of our high schools.

Amazing things are really beginning to happen in the reform of high-school science education, but one needs increased efforts to build momentum. In a previous column (Physics Today, April 1995, page 11*), I noted with mock amazement that students were still taking biology (or earth science) in ninth grade, with 50% going on to a year of chemistry and maybe 20% taking a third year, the dreaded physics, as juniors or seniors.

Since then, a group centered at Fermilab's education section under Marjorie Bardeen has held two intensive workshops, bringing together scientists and teachers with an important sprinkling of Washington-based movers and shakers, who serve as an informal advisory committee, which I chair. These include Bruce Alberts of the National Academy of Sciences (NAS), Rodger Bybee of Biological Sciences Curriculum Studies, George Nelson of Project 2061 of the American Association for the Advancement of Science (AAAS), Shirley Malcom of AAAS, and Gerald Wheeler of the National Science Teachers Association. Out of these workshops came an outline or framework for a three-year science curriculum designed for all students, in which the subject order is reversed: 9th grade, physics; 10th grade, chemistry; and 11th grade, biology. We insisted that the standards propagated by NAS and AAAS required a minimum of three years of science and that the order does matter. The recently released National Research Council report, *Physics in a New Era*,[1] puts it beautifully: "Because all essential biological mechanisms ultimately depend on physical interactions between molecules, physics lies at the heart of the most profound insights into biology."

Of course one can say the same about the need to master basic physics concepts to understand such crucial topics as chemical structures, atomic binding, the gas laws, or that battle flag of chemistry, the periodic table of the elements. And again, as any reader of *The Double Helix* knows, a knowledge of a lot of chemistry is required to begin a study of modern molecular-based biology.[2]

The rational order

We know of more than a hundred schools around the country, about 60% of them private, that have switched the sequence to the rational order. Some have been teaching "physics first" for more than ten years.

Since 1995, I have been thinking deeply about the huge task of writing a new curriculum that would bind the three years into a coherent, core science curriculum for all students. The fail-safe, default curriculum would start with conceptual physics, using the math that was being taught in eigth and ninth grades. Starting with phenomena in the real world around the student, the course would progress through standard, important physics topics, emphasizing those that would be most helpful for future applications to chemistry and biology. I believe the course must conclude with a month on atoms, their structure, and how they bind to form molecules. Here is where the physics year ends and chemistry begins. Repetition is encouraged; the boundaries between the disciplines are lowered so that the transition is seamless.

Physics topics would be repeatedly used in chemistry so that students continue to deepen their understanding through applications. The same thing would happen in the transition from chemistry to biology. Chemistry (and physics) concepts are continually reviewed, embellished, and used. Laboratory work must be inquiry dominated (the opposite of cookbook labs) and designed to illuminate concepts. (See the article in this issue by Ramon Lopez and Theodore Schultz, page 44.)

Since a new curriculum only gets done once in a hundred years or so, let's get it as right as we can. Science majors will surely go on to advanced placement (AP) courses and other elective science courses, so here we are mostly concerned with future citizens. (This set includes a lot of scientists!)

Both science and nonscience students could, and I believe should, be required to take a fourth year of science. I strongly recommend that the fourth year be devoted to Earth science for its integration of disciplines, its intrinsic importance, and its daily applicability. Other possibilities are astronomy, environmental science, computer and computational science, and AP versions of physics, chemistry, and biology.

The three-year sequence must include a lot of process in addition to content. How does science work? How did we discover some of these things? Why is science such a universal culture? How do the traits of skepticism, curiosity, openness to new ideas, and the joy of discovering the beauty of nature affect the process of science? Long after all the formulas, Latin words, and theories are forgotten, the process will be remembered. The goal of teachers using the new curriculum would be to produce high-school graduates who will be comfortable with a scientific way of thinking.

Mathematics must be brought in to this curriculum revolution early because math phobia is a near fatal disease unless the student is inoculated at a young age. Math phobia contributes strongly to the separation of entering ninth graders into the classes of "ready" and "not ready." Seamlessness is essential so that middle-school (and younger) students are prepared, by attitude as well as skills, for the new high-school experience. Obviously, the kindergarten through eighth-grade teachers must be included in our long-term revolution.

Another feature of our 21st-century school is teacher conferences. Not annually but weekly. The math and science teachers must work together in collegial professional development so that the connections of the disciplines are emphasized and the coherent elements emerge. Imagine if the math and physics teachers can design the strategy of the week so that Monday's math is used in Tuesday's physics! I give this activity a costly five hours per week (it's only money). Here are other profound connections: How does history influence science, physics influence philosophy, chemistry influence architecture, neuroscience influence linguistics, music, and mathematics? We must eventually include the teachers of social studies and humanities. I'm not sure what to do with economics.

If we want this reform to last well beyond the first few decades of the 21st century, we must try to anticipate dramatic, mind-numbing changes in science, technology, and human knowledge. The connections we now see may be guidelines for future reorganizations of our knowledge and ways of thinking.

Some of these connections should be part of the core curriculum; others can appear in science, technology, and society-type courses. The arguments and debates in these teacher conferences will be worth the price of admission, but they must have useful and convincing outcomes. High schools will be true communities of learners. (Imagine a roll of drums here.)

So we have continuous professional development, the barriers between the sciences and between science and math are removed, but we maintain respect for the disciplines. The 21st-century graduates, all of them, can connect subjects all over the intellectual map. The highest form of literacy.

For this and any serious reform of science education we need to improve the recruitment, training, retention, and evolution of our teacher workforce. A broad knowledge of science is an essential part of the rational ordering. If our leaders--presidents, governors, congressmen--are serious, the federal government can surely support a revolutionary change in our educational system.

From my list of more than 100 schools that are doing physics first, I have learned that, since there is no curriculum, the schools have innovated. They use books like Paul Hewitt's *Conceptual Physics* (HarperCollins, 1993) or Arthur Eisenkraft's *Active Physics* (six volumes, It's About Time Inc, 1998), which are great books but not designed as a prerequisite for chemistry and biology. So the teachers add, embellish, and improvise. The anecdotal reports from many, if not all, of these schools indicate that after an awkward transition from biology-chemistry-physics to the rational order, it is the way to go. Enrollment in elective science and AP science courses explodes and young women take AP physics! The anecdotal information is heartwarming but must be followed up with hard data. Of course, the schools must manage the teacher assignments to handle the influx of students taking ninth-grade physics. I am in touch with numerous schools that are considering the switch but are concerned about the serious teacher shortage problem.

Connections to other fields

To my knowledge, none of the pioneer schools has gone back. Our optimism has recently been greatly rewarded. In the past few months, the school districts of Cambridge, Massachusetts, and San Diego, California, have opted for all incoming students to take physics in ninth grade, followed by a year of chemistry, then biology. This is a huge domino! San Diego is the sixth largest school system in the nation; Cambridge has a small system but an impressive parent body. So we see some real action.

I have a vision, still a bit cloudy, of a real revolution in high-school science inevitably extending to the entire curriculum. We need to upgrade the economic and social status of teachers so that our best students will want to teach. And we need to help make seamless transitions from middle school to high school to college.

Resistance to change is awesome. Change will be expensive, but since education has been declared essential to national defense,[3] money is no obstacle. Our colleagues who teach physics in high schools must bear the crucial responsibility of making physics--no, science--palatable, important to the lives of their students, exciting to a large new population who may well be the least prepared and the most fearful. My experience is that physics teachers don't like to "do" freshmen. They also worry about those well-prepared freshmen that may be turned off by a too simple, relatively nonmathematical exposure to physics. Any ninth grade physics can't be worse than ninth grade biology! Well prepared freshmen can be offered honors and AP physics if they qualify.

Some critics are concerned that ninth-grade physics may not be suitable for college preparation. Fortunately, college preparation is not a law of nature but a decision made by college admissions officers or the Educational Testing Service or some educational bureaucrats. They must be brought into the discussion so that the students are tested for grasp of concepts, grasp of connections, and grasp of the process of science, in addition to a reasonable skill at problem solving. As we make progress in a real curriculum, the application of physics to chemistry and biology will produce a higher level of sophistication that should gladden the hearts (if any) of the college admissions people. Finally, as Algebra I becomes increasingly part of the armaments of the ninth grader, the course for this grade level can evolve, as it has to, to prepare students for chemistry. Other problems proliferate: Some education experts say physics is too abstract for ninth graders. You can add to this list.

Again I plead with my colleagues to help out. The vision is full of difficulties and may even be wrong in some details. I have read about variations, such as including a new clumping of grades 7, 8, 9, and 10 into middle high school and 11, 12, 13, and 14 into lower college, which would encourage (require?) two years of college for all students. The future scientists will not be injured. We all know students who can solve physics problems but have no grasp of concepts. Attention to *all* the students will surely expose an occasional genius who had never been subjected to a logical sequence. We must all market the new strategy. So go visit your nearest high school; make sure our time traveler from 1899 will be rapturously uncomfortable there.

(Now imagine eight bars of *Thus Spake Zarathustra*. Thank you.)

I would like to thank Ted Schultz of APS, Colleen Megowan, a physics first teacher, and Judy Parrish of Arizona State University for helpful comments.

References

1. NRC Report: Physics in a New Era, Overview, 2001.
2. See also my article in the spring 2001 newsletter of the American Physical Society Forum on Education.

3. US Commission on National Security for the 21st Century, http://www.nssg.gov.

Physics Today Reference
September 2001, page 44

Leon Lederman *is a resident scholar at Illinois Math and Science Academy and Pritzker Professor of Science at Illinois Institute of Technology. He is director emeritus of Fermilab.*

ARISE: American Renaissance in Science Education

Instructional Materials Guide

Part 1 – Physics

September 2004

ARISE Project Director
Leon M. Lederman

Compiled and edited by
Yvonne Twomey
LaMargo Gill

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ARISE Physics

Forward:

This is an interim version of the Volume 1 of a 3-volume "cut and paste" guide to the "Physics First" curriculum. It currently contains only our ideas on the topics that should be taught and the students' skills which need to be developed in the physics course which forms the first of the three science courses of the ARISE sequence.

Your comments would be very welcome. Please send e-mail to Dr. Lederman at lederman@fnal.gov

Curriculum Topics

The topics which have been chosen for the proposed first year of the ARISE high school sequence are those which we believe will best prepare the young minds of freshmen for the chemistry course of the following year. This means that a number of topics found in a "conventional" high-school physics course have had to be excluded. These topics will, we hope, be taken up in the elective physics course that students will take as seniors.

We believe that the topics listed below, done thoroughly, will provide a suitable introduction to a basic science discipline, physics, and also provide a good basis for chemistry. Enrichment of the course according to the teacher's interest or the student's demand is to be encouraged, but not at the cost of leaving out the necessities for understanding the concepts required for chemistry.

Traditional textbooks showing a similar sequencing to this would be:

Serway and Faughn, Giencoli, Bueche. These are all texts used at the college level by non- science majors but they are frequently used in high schools. These texts will be a useful reference for the teacher.

	Main Subject	Specific Topic
Topic 1	Vectors	Displacement Velocity Force Force Table Components
Topic 2	Kinematics	Displacement Velocity Acceleration One and two-dimensional motion
Topic 3	Dynamics	Force Newton's 1st Law Newton's 2nd Law Newton's 3rd Law Friction
Topic 4	Work and Energy	Work Kinetic energy and work-energy theorem Potential Energy Conservation of Mechanical Energy Power The very special role of energy in science

Topic 5	Momentum and Collisions	Center of gravity Momentum and Impulse Conservation of Momentum Collisions in 1-dimension Collisions in 2-dimensions
Topic 6	Circular Motion	Uniform Circular Motion Centripetal acceleration Centripetal force Universal Law of Gravitation Gravity at all locations Satellites
Topic 7	Electric Forces	Electric Charge and Fields Force between charges Electroscope Conduction and Induction The electric field
Topic 8	Electric Potential	Electric Potential Energy Potential Difference Equipotential Battery
Topic 9	Magnetism	Magnetic Field Mapping Earth Magnetic Field Magnetic Field Created by an Electric Current
Topic 10	Electromagnetic Waves	Oscillating Electric and Magnetic Fields
Topic 11	Geometric Optics:	Concept of light Speed of light
Topic 12	Vibrations and Waves	Periodic motion Hooke's Law and elasticity Potential energy Simple Harmonic Motion Wave terminology Wave interaction: reflection And transmission Wave Resonance in a string Transverse and Longitudinal waves Include ripple tank and sound demonstrations as examples of wave behavior.

Topic 13	Relativity	Postulates of relativity Speed of light as limiting speed Simultaneity Moving clocks run too slowly Relativistic length contraction Relativistic mass-energy relationship
Topic 14	Photons	Planck's discovery Einstein's use of Planck's constant Compton Effect
Topic 15	Quantum Mechanics	deBroglie wavelength Wave mechanics versus Classical mechanics Resonance in deBroglie waves The uncertainty principle
Topic 16	The Atom	Atomic structure Electron energy levels A glimpse at chemistry Nucleus Fission and fusion.

Development of Students' Skills

Fred Myers

One of the many advantages of following the sequence of science courses recommended by ARISE is that students' skills can be developed and nurtured as the need for those skills becomes apparent. Since concepts flow logically through each course, a skill once learned is used over and over as interdisciplinary connections are made. Skills that are learned in mathematics and in experimental work lead to an ability to think critically. Making sensible estimates and appreciating fine differences are essential for this kind of thinking and the laboratory is the ideal place to learn these skills.

The level of student mathematical skills is an important issue when implementing a ninth grade physics program. It is important to decide up-front if the students will be grouped heterogeneously or according to their mathematical skills. If you choose the heterogeneous route, general classroom presentations and expectations must be respectful of those students who are not yet proficient with algebra. Differentiated instruction and more advanced mathematical treatments should be provided for those students who are proficient with algebra.

Many schools have found it advantageous to offer ninth grade physics at two different levels. A more advanced level should be available to students who are proficient with algebra, and a separate level should be available for students who have not yet become proficient with algebra.

Some ninth grade physics programs have come under fire because they are called 'conceptual physics'. A quality ninth grade course should emphasize the importance of conceptualizing physics, but no course should be devoid of mathematics. A physics course begs to be both conceptual and quantitative.

Mathematics should always be used in experimentation, and mathematics should frequently be used in problem solving. However, algebraic dexterity should not be the focus. For decades, many physics students have become discouraged because they don't see the forest for the trees. That is, their difficulties and frustrations with algebraic dexterity often cloud their view so much that they do not recognize the power, beauty, and wide applications of the concepts of physics.

Basic Skills and Knowledge

Instruction for the following list of basic skills and knowledge should be embedded throughout this course and throughout all later science courses. It is not recommended that an introductory unit on these basic skills be taught in isolation. Students too often find it uninteresting and boring when taught in this manner, forever tainting their view of physics. Instead, students should receive instruction regarding these basic skills when the need arises and in context with real exploration or learning.

1. Units

Metric prefixes: k, c, m, n
Metric conversions
English/metric conversions
Distinction between derived and fundamental units

2. Measurement Skills

Students will use a variety of instruments to make measurements of the following:

- Length (meter stick, ruler)
- Time (stop watches, strobe devices)
- Mass (triple beam balance, electronic balance)
- Angles (protractor)
- Voltage (voltmeter)
- Current (ammeter)

Students will recognize that there is no such thing as an <u>exact</u> measurement

- Accuracy
- Precision
- Repeatability & fluctuation
- Round measurements to reflect reasonable accuracy
- Percent deviation/error = [Difference/"Accepted"] x 100
- Validity of experimentation

3. Data Tables

- Appropriate columnar structure
- Clear labeling

4. Graphing Skills

- Construct graph from given data (including selection of appropriate graph format, setting up proper and reasonable axes, title, labels, appropriate scale & range, and reasonable data points)
- Interpolation
- Extrapolation
- Conceptual description of slope from visual check of graph
- Draw visual (not mathematical) best-fit lines representing the data
- Determination of value of slope
- Write equation to represent data of straight-line graphs

5. Significant Digits

- Significant digits enable communication about measurements
- Use of significant digits should be 'reasonable'
- Recognize the number of significant digits in a reported measurement
- Report a reasonable number of significant digits when measuring
- Report a reasonable number of significant digits when performing calculations

6. Other Mathematical Skills

Students will be able to apply a variety of mathematical tools to the investigation of physics:

- Basic calculator functions: +, -, x, /, and √
- Rounding
- Calculate means of a set of values
- Express numbers in scientific notation
- Translate values written in scientific notation to numbers

Perform mathematical functions with numbers written in scientific notation (+, -, x, /, and √)

Use symbols to represent quantities

Solving equations

- Substitute quantity values into equations
- Solve equations for unknown (basic algebra)

Pythagorean Theorem

Characteristics of circles: radius, diameter, circumference

ARISE: American Renaissance in Science Education

Instructional Materials Guide

Part 2 – Chemistry

May 2004

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Leon M. Lederman

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LaMargo Gill

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ARISE - CHEMISTRY

Forward: by Leon Lederman

This is the second volume of a three-volume "cut and paste" guide to the "Physics First" curriculum. Each volume, Physics, Chemistry, and Biology, is tasked to supply guides to the best materials available for instruction in each of the traditional disciplines. However, the emphasis in a coherent three-year curriculum is to ease access to the connections between disciplines, to seek the most useful materials in physics, which will facilitate the understanding of the chemistry topic under discussion and to indicate those components of chemistry that will be most useful for molecular biology. We also provide a guide to storytelling, to history of who did what, and how.

The study of chemistry includes essentially all aspects of the behavior of atoms and molecules (a.k.a. elements and compounds). The structure of atoms is fundamental to chemical behavior and to the process by which atoms combine to form simple molecules such as H_2 all the way to the complex molecules of life. Applications of chemistry dominate the societal impact of science from the essential applications to life sciences, to energy sources, to nuclear chemistry and to the development of drugs. Chemistry, the central discipline, has a pivotal role in the three-year sequence that is designed to erase disciplinary boundaries, but to preserve disciplinary integrity.

Please send your comments and questions to me at lederman@fnal.gov.

Credits:

Three teachers contributed the chemistry resources:
Frank Cardulla, Niles North High School, Skokie, IL, (retired) editor of *ChemMatters,* indexed *ChemMatters.*
Bill Grosser, Glenbard South High School, Glen Ellyn, IL provided ideas and examples of cooperative learning and use of technology in the classroom.
Lee Marek, University of Illinois, Chicago, indexed Flinn ChemTopic Laboratory Manuals and provided ideas and examples.

Users Guide

A. CURRICULUM

B. SOURCE MATERIALS.

C. INDICES.

D. TEACHING CHEMISTRY: Ideas, Thoughts and Examples

A. CURRICULUM TOPICS

1 Matter and Change
2 Measurement
3 Problem Solving
4 Atomic Structure
5 Radioactivity, Fusion, Fission
6 Chemical Names and Formulas/Compounds and Elements
7 Moles
8 Chemical Reactions
9 Stoichiometry
10 Phases, Solids, Liquids and Gases (States of Matter)
11 Thermochemistry
12 Gases/Gas Laws/Kinetic Theory
13 Electrons in Atoms
14 Periodicity/Periodic Law/Metals, Nonmetals and Families.
15 Ionic and Metallic Bonds
16 Covalent Bonds, Molecular Shapes and Intermolecular Forces
17 Water, Aqueous Solutions
18 Reaction Rates and Kinetics
19 Equilibrium
20 Acid/Bases/pH
21 Organic Chemistry
22 Redox/Electrochemistry

B. SOURCE MATERIALS

Chemistry Textbooks

Textbooks are important in spite of the Internet. They affect both the student and teacher alike. Teachers rely upon textbooks; they serve as ready-made courses and define the material that students will learn from lesson plans, homework assignments and tests. Selection of a textbook is important because you will probably be using it for at least five years.

The American Chemical Society web site lists many textbooks available for high school chemistry: <http://www.umsl.edu/~chemist/cgi-test/mybooks.pl?category=16>

The following list of chemistry textbooks (some of them from the ACS list) gives the web links to their publisher. The order here has no particular significance. If your favorite book is not on this list, let us know. As you will see from the *The Textbook Letter* (in the following section), textbook selection is never easy and in some states rather "interesting."

Addison-Wesley Chemistry
6th Edition 2002 881 pp. 0-130-54384-5 (student edition); 0-130-58056-2 (student edition with CD-ROM); 0-130-54847-2 (teacher edition with resource CD-ROM)
Wilbraham, Antony C., Dennis D. Staley, Michael S. Matta, and Edward L. Waterman
<http://www.phschool.com/atschool/chemistry/index.html>
$69.95 (student edition); $76.21 (student edition with CD-ROM); $118.71 (teacher edition with resource CD-ROM)
4th edition reviewed in The Textbook Letter July-August 1997

Chemistry in the Community (ChemCom)

4th Edition 2001 ACS 0-7167-3551-2 (full version); 0-7167-3890-2 (minibook)
American Chemical Society
<http://www.whfreeman.com/highschool/book.asp?disc=CHEM&id_product=1124001763&@id_course=1058000061&disc_name=Chemistry&cd_booktype=CRTX>
$70.00
Reviewed in *The Textbook Letter,* July-August 1997

Chemistry: Matter and Change
The McGraw-Hill Companies (Glencoe/McGraw-Hill), Columbus, OH, ISBN 0-02-828378-3
Dingrando, Gregg, Hainen & Wistrom
<http://www.glencoe.com/sec/science/index.html>

Prentice Hall Chemistry - Chemistry: Connections to Our Changing World
2nd Edition 2000 960 pp. Prentice Hall 0-13-434776-5 (student edition); 0-13-434777-3 (teacher edition)
LeMay, H. Eugene, Herbert Beall, Karen M. Robblee, Douglas C. Brower
<http://www.phschool.com/atschool/chemistry/index.html>
Price unavailable
Previous edition reviewed in The Textbook Letter January-February 1995

Holt Chemistry: Visualizing Matter
"Technology Edition" 2000 864 pp. Holt, Reinhart and Wilson 0-03-052002-9 (student edition); 0- 03-053837-8 (teacher edition)
Myers, R. Thomas, Keith Oldham, and Salvatore Tocci
<http://www.hrw.com/science/hc/index.htm>
$52.95 (student edition); $70.50 (teacher edition)
Previous edition reviewed in The Textbook Letter November-December, 1996

Chemistry: Concepts and Applications
2nd Edition 2000, Glencoe 0-02-828209-4 (student edition); 0-02-828210-8 (teacher edition)
Phillips, John, Victor Strozak, Cheryl Wistrom wrote the previous edition; the publisher lists no author for this one.
<http://www.glencoe.com/sec/catalog/cgi-bin/secDisplay.cgi?function=display&area=science&category=productinfo&nameid=9>
$66.00
Previous edition reviewed in The Textbook Letter July-August, 1998

Modern Chemistry
19th Edition 1999 Holt, Reinhart and Wilson 0-03-051122-4 (student edition); 0-03-051389-8 (teacher edition)
Davis, Raymond E., H. Clark Metcalfe, John E. Williams, and Joseph F. Castka
<http://www.hrw.com/science/mc/index.htm>
$52.95 (student edition); 70.50 (teacher edition)
Reviewed in The Textbook Letter January-February 1998

The Real World of Chemistry
3rd Edition Kendall Hunt (I can no longer find it on the Kendall Hunt webpage). 1998 320 pp.
0-7872-4190-3
Fruen, Lois
$39.95 (wire coil)

Merrill Chemistry
7th Edition 1998 910 pp. Glencoe 0-02-825526-7 (student edition); 0-02-825527-5 (teacher edition)
Smoot, Robert, Richard G. Smith, and Jack Price
<http://www.glencoe.com/sec/catalog/cgi-bin/secDisplay.cgi?function=display&area=science&category=productinfo&nameid=10>
$44.98 (student edition); $59.99 (teacher edition)
Reviewed in *The Textbook Letter,* November-December, 1998

Active Chemistry
1st Edition, It's About Time 1-58591-113-5 (student edition); 1-58591-114-3 (teacher edition)
Anonymous
<http://www.its-about-time.com/htmls/ac/ac.html>
$23.95 (Student edition); $49.95 (Teacher edition)

World of Chemistry
McDougal Littell - A Houghton Mifflin Co., Evanston, IL, ISBN 0-618-13496-4
Steven Zumdahl, Susan A. Zumdahl, and Donald DeCoste
<http://college.hmco.com/chemistry/general/zumdahl/world_of_chem/1e/students/>
<http://college.hmco.com/chemistry/general/zumdahl/world_of_chem/1e/instructors/index.html>

Conceptual Chemistry: Understanding Our World of Atoms and Molecules
2nd Edition, 2004 ISBN: 0-8053-3228-6 John Suchocki
<http://www.aw-bc.com/catalog/academic/product/0,4096,0805332286,00.html>
Publisher: Benjamin Cummings
Format: Cloth Bound w/CD-ROM; 647 pp
$84.60

Chemistry in Your Life
2003, 600pp, Bedford, Freeman and Worth
Colin Baird, University of Western Ontario, Wendy Gloffke, Science Writer and Educational Consultant
Go to: <http://www.bfwpub.com/book.asp?2001002476> to access table of contents etc.

CHEMISTRY: Connections That Matter
W. H. Freeman and Company 2003
Joseph Krajcik, Brian Coppola, Alan Kiste
<www.whfreeman.com/highschool/book.asp?2001002486>

Meeting Tomorrow's Science Needs Today

<www.whfreeman.com/stw/>

ChemCom
Chemistry In The Community, Student Text; ISBN 0-7167-3551-2, $62.90
Wraparound Teacher's Edition, 0-7167-3918-6, $69.90
<http://www.acs.org/education/curriculum/chemcom.html>
For the Student:
Website: <http://www.whfreeman.com/chemcom/>

Textbook League

By Lee Marek

The Textbook League, which publishes The Textbook Letter (TTL), is an interesting group. I have been reading the letter for a number of years and really like the reviews and find them honest and refreshing compared to most, but go to their website and judge for yourself. <http://www.textbookleague.org/>. You will find that new material is added frequently to the web site and The Textbook Letter could help you in the choice of a suitable textbook for your course.

The textbook selection process can be really important. For one thing the teacher is liable to be "stuck with it" for five or more years. Textbooks affect not only the students but also the teacher. They "tell" the teacher "what is important and how it should be taught." As the Textbook League webpage says, "In many instances the books serve as ready-made courses, since many teachers depend on them to define a curriculum, to prescribe the material that students will learn, and to dictate how the material will be presented. This effect is all the greater because teachers often rely upon textbook publishers to provide ready-made lesson plans, ready-made homework assignments for students to execute, and ready-made tests for students to take — all keyed to the textbooks that the teachers have chosen." The following is culled from Textbook League's website, except for a few of my comments in parentheses. There are two sample reviews included.

> One might expect, then, that textbooks would undergo considerable scrutiny before they get into schools. Indeed, one might expect that the American education community would sponsor formal textbook-review proceedings, and would disseminate the results of such proceedings to teachers throughout the country, so that the teachers would be made aware of good books and would be warned away from poor ones.
>
> In fact, however, no national textbook evaluation processes exist, and the "evaluations" conducted by state departments of education or by local school districts are rarely anything more than bureaucratic shams—bogus proceedings where textbooks are judged by those who have no discernible qualifications for such work. In typical cases, the state education agencies and local districts approve textbooks without soliciting appraisals from persons who have expert knowledge of the relevant subject matter. As a result, classroom teachers can be stuck with biology books that have never been reviewed by any biologist, history books that have never been seen by any historian, geography books that have never been evaluated by any geographer, or health-education books that have never been reviewed by any physician. (Indeed I have seen such in my own district—tops in the world on the TIMMS test. We had a committee that I foolishly said I would be on for junior high textbook selection. We met off and on for over a year, then an administrator picked the textbook series for us because they got a good deal from the publisher!)
>
> In 1989 a group of Californians undertook to do something about this situation by founding an organization and a periodical devoted to providing the knowledgeable reviews that

> educators need. The organization is The Textbook League. The periodical is *The Textbook Letter*, which the League mails to subscribers throughout the United States. The subscribers include classroom teachers, officers of local school districts, officers of state or county education agencies, and private citizens who take a serious interest in the content and quality of the instruction offered in the public schools.
>
> Each issue of *The Textbook Letter* is built around reviews of schoolbooks, with emphasis on middle school and high school books in history, geography, social studies, health education, and the various branches of natural science. Reviews are augmented by articles on topics that are important to educators, who must choose and use instructional materials.
>
> A typical review in *The Textbook Letter* is contributed by a person who has professional credentials in the pertinent discipline. A physics textbook is reviewed by a professional physicist; a chemistry text is reviewed by a professional chemist; a health education text is reviewed by a practicing physician; an earth science text is reviewed by a geologist or a paleontologist; and so forth.
>
> Each review focuses strongly on the factual and conceptual content of the book in question. The reviewer's principal aim is to judge whether the book's factual information is solid, whether the book's conceptual syntheses and interpretations are up to date, and whether the material that the book presents will be meaningful to the intended audience.
>
> When the editors of *The Textbook Letter* send a book to a reviewer, they deliberately do not furnish any list of evaluation criteria for the reviewer to use. The editors' precept is that a textbook is (or should be) a tool for promoting intellectual development, and that intellectual matters cannot be reduced to checklists or catalogues of buzzwords. Their approach is to engage an expert, then let the expert use his own judgment in deciding which features of the book deserve to be described and analyzed in a review.

The website of The Textbook League is a resource for middle-school and high-school educators. It provides commentaries on some 200 items, including textbooks, curriculum manuals, videos and reference books. The Textbook League, P.O. Box 51, Sausalito, California 94966 <http://www.textbookleague.org/>

The following from the website describes the process of State Textbook adoption. I have only put part of it here. If you go to the website, you can read more. If you teach science, this can really scare you! The following webpage Annals of Corruption: Part 1 is about Richard Feynamn's "Judging Books by Their Covers" and proves to be an interesting read. I have included but a small part here. <http://www.textbookleague.org/103feyn.htm>

> In 1964 the eminent physicist Richard Feynman served on the State of California's Curriculum Commission and saw how the Commission chose math textbooks for use in California's public schools. In his acerbic memoir of that experience, titled "Judging Books by Their Covers," Feynman analyzed the Commission's idiotic method of evaluating books, and he described some of the tactics employed by schoolbook salesmen who wanted the Commission to adopt their shoddy products. "Judging Books by Their Cov-

ers" appeared as a chapter in "Surely You're Joking, Mr. Feynman!"—Feynman's autobiographical book that was published in 1985 by W.W. Norton & Company.

To introduce a series of articles about corruption in schoolbook-adoption proceedings, we present here (with permission from W. W. Norton & Company) an extended excerpt from Feynman's narrative. Readers will see that Feynman's account is as timely now as it was when he wrote it. State adoption proceedings still are pervaded by sham, malfeasance and ludicrous incompetence, and they still reflect cozy connections between state agencies and schoolbook companies.

Some Nasty Performances in Oklahoma: <http://www.textbookleague.org/106okla.htm>
By William J. Bennetta

Oklahoma is an "adoption state." It is one of 22 states, most of them in the South or the West, in which state agencies control the evaluation, selection and adoption of the textbooks that will be used in public schools. In Oklahoma, the agency that performs the evaluating and selecting and adopting is the Oklahoma State Textbook Committee.

Oklahoma law says that the State Textbook Committee shall comprise thirteen persons, all appointed by the governor. Twelve members must be employees of public schools, and a majority of those twelve must be classroom teachers. The thirteenth member must be a layman "having at least one child in the public schools of Oklahoma." The declared function of the Committee is to "select textbooks or series of textbooks for each subject, which are in its judgment satisfactory." The Committee must carry out "careful consideration of all the books presented (by publishers)" and must select for adoption "those which, in the opinion of the Committee, are best suited for the public schools in this state." The Committee may engage consultants, but the consultants must be "regular classroom teachers."

These prescriptions constitute a recipe for farce. Though the Committee is supposed to judge books in history, mathematics, biology, chemistry and many other subjects, there is little chance that the Committee ever will have a member (or will be able to engage a consultant) who possesses professional knowledge of any of those subjects. Hence there is little chance that the Committee ever will have a member (or will be able to engage a consultant) who is qualified to evaluate the treatment that is accorded to any of those subjects in a schoolbook.

In practice, Oklahoma adoptions are indeed farcical. The State Textbook Committee's proceedings serve chiefly to celebrate the invention of the rubber stamp, and the Committee commonly approves textbooks that any competent agency would immediately consign to the trash heap. . . .

A sample review of a physical-science book for grade 8 or 9:

Introductory Physical Science
Seventh edition, 1999. 268 pages. ISBN: 1-882057-18-X

Science Curriculum Inc., 24 Stone Road, Belmont, Massachusetts 02478
This Book Is the Best, by a Wide Margin
By Lawrence S. Lerner

About four years ago I had the pleasure of reviewing the sixth edition of Science Curriculum Inc.'s Introductory Physical Science. "This is an outstanding book," I reported in TTL, "written by authors who know what science is about, know their subject matter, and know how to teach it to 8th-graders and 9th-graders."

[Editor's note: Lawrence S. Lerner's review of the sixth edition appeared in TTL for November-December 1995, with this headline: "The Authors Are Knowledgeable, and the Book Is a Delight."]

That statement applies to the seventh edition, too, and the word "authors" is significant. The persons named on the title page of Introductory Physical Science are truly the book's authors, and they have maintained full control of its contents. Readers who are familiar with the schoolbook industry, and with the habits of the major schoolbook companies, will recognize that this is an atypical circumstance. In most schoolbooks, the lists of so-called authors are fictitious and have been devised to serve as sales-promotion features.

Introductory Physical Science has only 268 pages, so it is less than half as long as the other physical-science books I have reviewed—yet it offers far better content. Unlike those other texts, Introductory Physical Science is not bloated with gratuitous factoids, empty mentionings, environmental pieties and irrelevant sidebars.

The authors of Introductory Physical Science show the student how science is done, and they teach the student to think like a scientist. Their strategy, as I noted in my review of the sixth edition, is to take the student through a series of experiments and analyses that amount to an abridged account of the development of chemistry and physics from the mid-1700s to 1900 or so.

Comparing the Editions

A striking experiment in the earlier edition allowed the student to make a direct estimate of the size and mass of a molecule of oleic acid. These quantities were inferred after the student measured the area of a film of oleic acid that was floating on water. In the seventh edition, the procedure has been dramatically improved: Instead of using pure oleic, the student uses a dilute solution of oleic acid in alcohol. This enables the student to obtain better results (and all the satisfaction that goes with them). In keeping with this refinement, oleic acid's density—which the student must use in a calculation—is now given as 0.87 g/cm3 instead of 1 g/cm3.

On the other hand, a beautiful sequence of experiments that I admired in the sixth edition has been modified in a disappointing way. Let me describe this case in some detail:

Most textbooks treat the difference between a chemical element and a compound simply by asserting that every compound consists of more than one element, but the authors of

Introductory Physical Science prefer a scientific approach to this topic. In the sixth edition, the authors used a number of experiments and comparisons to show the student that certain solid substances, when they participate in chemical reactions, invariably yield solid products that have greater mass. The student then was led to understand—indeed, to define—such substances as elements. Likewise, the student found out that other solid substances, when they participate in reactions, may yield products that have greater mass or products that have lesser mass. The student then came to comprehend that any substance which gives such variable results must be a compound. The supporting evidence came from several sources, including an experiment in which the student observed the thermal decomposition of baking soda, then a narrative account of the thermal decomposition of mercuric oxide, and later an experiment in which the student watched the thermal decomposition of sodium chlorate and measured the difference between the initial mass and the final mass of the solid in the test container.

Looking at the seventh edition, I find that the experiment with sodium chlorate has been excised, presumably in the interests of safety. (The decomposition of sodium chlorate sometimes proceeds very vigorously.) Now the authors simply remind the student about the example of mercuric oxide and about the earlier experiment with baking soda. The excision of the sodium-chlorate experiment has not diminished the general argument, but the argument has lost some of its punch—especially because the case involving mercuric oxide still appears only in a narrative, not in an experiment that is actually performed by the student.

The sixth edition didn't contain many errors, and in the seventh edition most of them have been corrected—but not all:

- Page 110: The student again is asked to write an essay about the "sludge test." But there is still no indication of what is meant by this term.
- Page 115: The "tiny bubble" mentioned in the caption for figure 6.2(b) is not visible.
- Page 119: Problem 12 should come before problem 11.
- On page 132, figure 6.9 still shows an aluminum cell in which molten aluminum is siphoned from a lower to a higher level.
- Page 166: Here a radioactive atom is said to emit a particle "which affects a counter . . . ." But this is true only if the particle happens to be headed in the direction of the counter. It would be better to say that the particle "can affect" a counter.
- Page 204: In a passage about the production of hydrogen in two electrolysis cells, it is still unclear that the authors are referring to the rate of production in each cell, not in both cells together.
- Pages 231 through 234: The description of the operation of a dry cell is still vague, and the function of sacrificial electrodes is still not explained clearly.

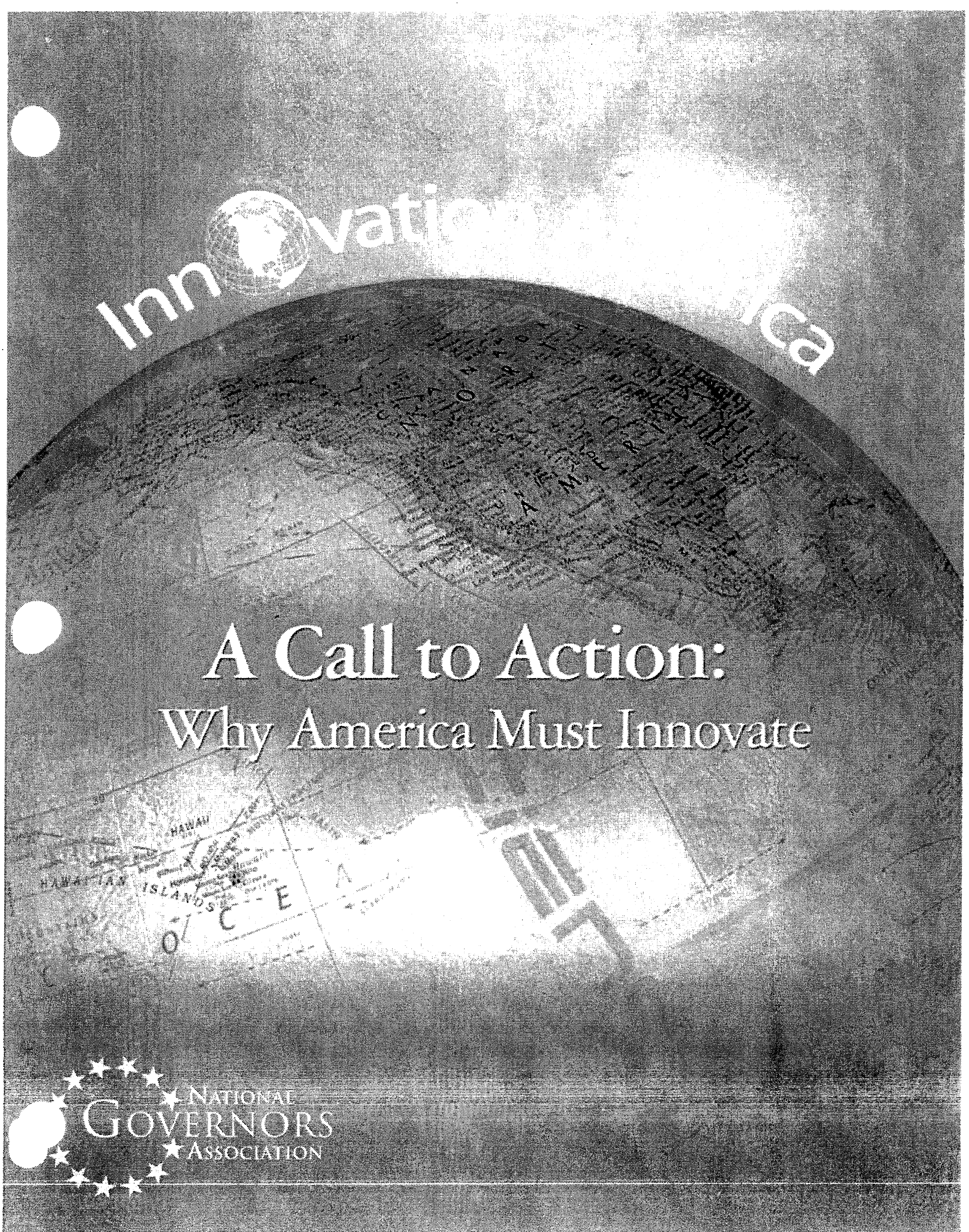
In the sixth edition, some of the photographs weren't clear, and some of the graphs were too crude. Many of these have been replaced, usually for the better, but a few of the photos in the seventh edition demand further improvement. Alternatively, it may be profitable to replace them with line drawings. Figure 1.1 can serve as a case in point: In the sixth edition, it was an indistinct photograph of a pneumatic trough, and it failed to show the water level inside the collection bottle. The seventh edition has a new photo that is much clearer overall, but the crucial water level still can't be discerned. The same difficulty occurs in figure 1.4—and here the new photo is less clear overall than the older one was.

These, however, are but minor matters. Taken as a whole, Introductory Physical Science is an excellent book.

The thorough, clearly written Teacher's Guide and Resource Book for the seventh edition is largely a laboratory manual, designed to lead the teacher through the experiments that appear in the student's text. This Teacher's Guide is much like the guidebook that came with the sixth edition, but the "Introduction" has now been expanded by the addition of new pedagogic information and suggestions. The teacher, whether experienced or inexperienced, will find the Guide to be a trusty and valuable companion during the planning of a course based on Introductory Physical Science.

Students who work through Introductory Physical Science and do the experiments will be well rewarded, for they will acquire a good understanding not only of the subject matter but also of the way in which science is done. I recommend this book strongly. It is the best, by a wide margin.

Lawrence S. Lerner is a professor emeritus in the College of Natural Sciences and Mathematics at California State University, Long Beach. His specialties are condensed-matter physics, the history of science, and science education. His university text Physics for Scientists and Engineers was issued in 1996 by Jones and Bartlett Publishers, Inc. (Sudbury, Massachusetts). His report State Science Standards: An Appraisal of Science Standards in 36 States was issued in March 1998 by the Thomas B. Fordham Foundation (Washington, D.C.).



A Call to Action:
Why America Must Innovate

National Governors Association

Founded in 1908, the National Governors Association (NGA) is the collective voice of the nation's governors and one of Washington, D.C.'s most respected public policy organizations. Its members are the governors of the 50 states, three territories and two commonwealths. NGA provides governors and their senior staff members with services that range from representing states on Capitol Hill and before the Administration on key federal issues to developing and implementing innovative solutions to public policy challenges through the NGA Center for Best Practices. For more information, visit *www.nga.org*.

Foreword

The National Governors Association's *Innovation America* initiative focuses on strengthening our competitive position in the global economy by improving our capacity to innovate. The goal is to give governors the tools they need to encourage entrepreneurship, improve math and science education, better align post-secondary education systems with local economic growth, and develop regional innovation strategies.

To guide the *Innovation America* initiative, we have assembled a bipartisan task force of governors and members of the academic and business communities. Working with the NGA Center for Best Practices, the task force is developing innovation-based education and economic strategies. Through a variety of forums and publications we will collect and share best practice information to ensure every state — and the nation — is equipped to excel in the global economy.

Governor Janet Napolitano, Arizona
Co-Chair, Innovation America Task Force

Governor Tim Pawlenty, Minnesota
Co-Chair, Innovation America Task Force

Innovation America Task Force

Governors:

Gov. Janet Napolitano, Arizona — Co-Chair
Gov. Tim Pawlenty, Minnesota — Co-Chair
Gov. Kathleen Sebelius, Kansas
Gov. Matt Blunt, Missouri
Gov. Edward G. Rendell, Pennsylvania
Gov. Jon Huntsman, Jr., Utah

Business and Academic Leaders:

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Dr. G. Wayne Clough, President, Georgia Institute of Technology
Dr. Michael M. Crow, President, Arizona State University
Jamie Dimon, CEO, JPMorganChase
Charles O. Holliday, Jr., Chairman and CEO, DuPont
Dr. Shirley Ann Jackson, President, Rensselaer Polytechnic Institute
Dr. Judith A. Ramaley, President, Winona State University
Dr. Mary Spangler, Chancellor, Oakland Community College
John Thompson, Chairman of the Board and CEO, Symantec
Kevin Turner, COO, Microsoft
Margaret C. Whitman, President and CEO, eBay

About the Author

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Introduction

Today's U.S. economy has created a remarkable paradox. It has grown at an average of 3 percent annually since the bottom of the 2001 recession, a reasonable rate by historical standards. After several years of flat employment growth, the economy has created two million new jobs in 2004 and 2005 and is on track to do the same in 2006. Yet, at the same time many — if not most — American families have a feeling of uncertainty and concern about the economy and their future.

Their concerns can be seen in the headlines and predictions we see daily.

- Despite the economy's overall, long-term success, Americans' median earnings are stagnating. In 1978, the median earnings (corrected for inflation) of full-time American workers were $37,004. In 2005, 27 years later, they were $37,447 — a mere 2 percent increase over the previous 27 years. American workers have, on the whole, lost a generation of economic growth.[1]
- This stagnation conceals a market divide in the labor force: the earnings (corrected for inflation) of workers who have finished college or acquired a post-baccalaureate education have risen in the last 20 years, but the wages of all those with less educational attainment have fallen.[2]
- When placed on an apples-to-apples basis, the U.S. produced 137,000 new engineers in 2004, while India produced 112,000 and China produced 352,000 (on an uncorrected basis, India produces 350,000 engineers and China produces over 600,000). But even these corrected numbers show that these emerging economies are capable of one day creating a high-tech economy the size of our own.[3]
- America's trade deficit has ballooned from $31 billion in 1991 to $362 billion in 2001 to $717 billion in 2005. Our bilateral deficit with China has grown from $13 billion to $83 billion to $201 billion in those same three years.[4] China, by the end of 2006, will have amassed *one trillion dollars* in reserves and will have the potential to exercise considerable influence over the course of the U.S., and world, economies.[5]
- The human resources consulting firm A.T. Kearny estimates that the financial services industry will send 500,000 jobs abroad in the next eight years, producing annual savings of $30 billion. Is any job untouchable? A leading investment bank recently relocated 50 junior equity research analyst jobs to Mumbai, where new MBAs earn $30,000, as compared to $150,000 in the United States![6]

This paradox of concern amidst growth is even greater when we step back and look at the economy in a longer-term context. New technologies create products and services unimaginable a generation ago and revolutionize the way the products of a generation ago are produced today. The world has become linked in a way that only the most daring theorists of prior decades would have thought possible. And yet, these changes have brought many American families uncertain job prospects and stagnant incomes, even as they help the economy grow.

The powerful forces that drive today's economy come with no instructions on how to harness them. How will we create good jobs? How will we promote growth in our local economies? In short, how can we improve our *competitiveness?*

The answer is innovation. In this *Call To Action*, we discuss how competitiveness occurs, how it relates to innovation, and what states can do to promote it within their borders.

Let's begin by defining our terms.

The "Competitiveness Problem"

"Competitiveness" is a word with as many meanings as people who use it. To some, it represents technological prowess and being at the scientific "cutting edge;" to others, it means the ability to export and balance a nation's trade. Definitions such as these miss some aspect of the problem. Technological progress is hollow if it isn't accompanied by investment, which makes it part of the economy's daily workings. Exports do little good if they are won by cutting wages to win markets. This paper defines *competitiveness* as an economy's ability to generate high-wage jobs and support a high and rising standard of living. It can be seen in such measures as Gross Domestic Product per worker or per capita income,

[1] DeNavas-Walt, Carmen, Bernadette D. Proctor, and Cherly Hill Lee, U.S. Census Bureau, Current Population Reports, P60-231, *Income, Poverty, and Health Insurance Coverage in the United States: 2005* U.S. Government Printing Office, Washington D.C., 2006, Table A-2.

[2] Current Population Survey, Annual Social and economic Supplements, U.S. Census Bureau, Washington, D.C.

[3] "Does the U.S. Face and Engineering Gap?" *The Christian Science Monitor*, December 20, 2005

[4] U.S. Census Bureau

[5] *The London Times*, "Chinese Foreign Reserves to Exceed $1 trillion," March 29, 2006.

[6] *Banking Strategies*, Vol. LXXX, no.1, January-February 2004, Chicago, IL

which measure the standard of living; or the growth in hourly wages and benefits or level of productivity (output per worker), which measure the value of workers and whether they receive commensurate benefits. As we'll see, the sources of competitiveness are complex, but the result is simple — creating high-wage jobs that support a high and rising standard of living. This is the heart of the matter.

Consider the issue from this perspective: China is growing rapidly, and has impressive rates of productivity growth. However, the growth and productivity is caused in large part because the wages its workers earn are low and its products cheap. The U.S. could emulate this growth by lowering its wages and incomes and churning out more goods and services, but we would obviously not be better off. The challenge for the U.S. is to maintain our share of the global market for goods and services without cutting the wages of American workers.

The definition of competitiveness used here demonstrates this fundamental distinction. The Chinese economy is *growing quickly* and has strong rates of *productivity growth* — factors that are helping it *become* competitive. But, by American terms, it is not yet fully *competitive* — China cannot yet generate enough jobs that would recreate the American standard of living. However, as more and more high-technology, high-wage jobs migrate to China, its opportunity to become fully competitive grows.

This is the concern that creates the great dissonance many American families feel about the economy. It is growing, to be sure, and its productivity is increasing, but not to their benefit. In fact, it may be growing at their expense. The income data cited above shows that this is a long-term trend in the American economy, despite economic growth and growth in productivity. These trends demonstrate that the U.S. economy is dividing itself in two — a more competitive half that takes advantage of new technology and global trade opportunities, and a less competitive half that is at the mercy of these forces. The challenge facing policy makers at all levels of government is to move as rapidly as they can from the latter to the former — to take the innovative "high road" in terms of growth and competitiveness.

The U.S. is not rising to this challenge in the way it should. Perhaps the best summary measure of the economy's slipping competitiveness can be found in the World Economic Forum's September, 2006 *Global Competitiveness Report*, which dropped the U.S. from first to sixth in its ratings of national competitiveness, trailing Switzerland, Finland, Sweden, Denmark, and Singapore.[7] Can our economy really be less "competitive" than Denmark's or Singapore's, despite its remarkable history and advantages? Responding to this lackluster performance is the motivation behind this *Call to Action*. It demands that we rethink how to induce the economy to grow and create good jobs and, from the perspective of governors, reconsider how the states participate in that process.

To do so, we must start considering how jobs and economic growth actually occur and the central role innovation plays in the process.

Where Do Growth and Jobs Come From? The Role of Innovation

How does an economy grow? How are new jobs created? The questions are simple, but the answers economists provide are often so elaborate or theoretical that they are of no use. However, an understanding of the process is necessary to promote growth and create new jobs.

At any moment in time, the economy produces a list of goods and services and uses various assets, or "factors," to produce them. These factors include physical capital, such as plant and equipment; financial capital, the wealth that funds investment; and intellectual capital, the accumulated knowledge mankind has embodied in its science and technology, engineering, and business practices. It also has a stock of labor and the skill that labor has, that is, the ability to harness knowledge to a task — sometimes called "human capital." Every product or service we see in the market is the result of combining these factors in some way.

If this is how economies produce, how do we increase their production? One way is to simply "double the recipe" — to have more factors — more investment, more workers, and so on. However, doubling the recipe produces a cake that's only twice as big — in doesn't produce more output *in proportion* to the inputs. In economic terms, it doesn't lead to increases in productivity, or "output per worker," which is the basis for our standard of living. Instead, we need to get more out of the economy than we put into it, to make the economy more *productive*.

Economic history shows us that there are, at any point in time, a myriad of ways to become more productive. Economists put great store in the idea of "learning by doing," the continual stream of tinkering that leads to incremental changes in every aspect of production. In the short term, these increments add up to ongoing productivity gains. They may come about by reconfiguring the

[7]The Global Competitiveness Report, 2006-2007, World Economic Forum, Geneva, Switzerland

plant floor, changing the software that directs customer service telephone calls, using artificial intelligence to do bureaucratic tasks, or repackaging an existing product to position it better for the consumer. All of these steps improve productivity — they create more and new output using available factors.

While these increments are valuable and important, they taper off when some natural limit is reached. Humans have reduced the four minute world record for the mile run, for example, by 17 seconds, but there are no three minute miles because human anatomy is not up to such a task. This reality has an important parallel in the economy. At some point, the improvements in productivity that are possible given the resources at our disposal — including the equipment, workers, and skill levels of the workers — will start to taper off. If we are going to continue to grow the economy's productivity and competitiveness, we will have to think of a new approach. There are no three minute miles because human physiology is a constant. Fortunately, nothing about the economy is constant.

This is where *innovation* enters the picture. *Innovation* is the process by which new ideas enter the economy and change what is produced, how it is produced, and the way production itself is organized.

Consider the epochal innovations of our lifetime: the integrated circuit and the resulting microprocessor and computer. This suite of new technologies has created entire new classes of products with embodied intelligence, from portable music players to flat screen televisions. It has changed the way most goods are produced, using such techniques as robotics, intelligent materials handling, or computer-assisted design. It has revolutionized the very way production is organized — substituting networks for pyramidal organizations, blurring the lines between suppliers and their customers through "just-in-time" delivery and value-chains, allowing companies to enter markets all around the world, and intensifying competition and consumer choice. All of these transformations increase productivity in their own right, by finding ways to make "new" and "more" output from the same stock of resources. By setting loose these larger changes, the computer has unleashed a vast new frontier in which businesses can experiment, learn, and create a new wave of incremental improvements that allow productivity to continue to grow. The result is more income per person, greater productivity, and the potential for new and high-value jobs — in a word, competitiveness.

All of this may seem old hat, but the process that led to these changes was as complex as the outcome was simple. Think about what was necessary to bring this transformation to fruition. New technologies don't appear out of nowhere. Someone must have the knowledge and imagination to conceive of them, and devote the resources to the experimentation that leads to them. Someone must take on the risk associated with designing and investing in their production. The scientific and engineering knowledge that is a prerequisite to inventing, producing, and using the innovation must exist and be disseminated. Only if all of that happens — only if all of those preconditions are met — could an economy take great leaps ahead. But if all of it did take place, the economy would grow and create many new and "good" jobs — jobs that allow people to become more productive and raise their standard of living.

The word that summarizes this economic leap forward is *innovation*. An economy can't sustain its productivity growth unless it continues to innovate. This is all the more true when we think about the role of foreign trade. We already have seen how Japanese, Taiwanese, and Korean auto and electronics firms have captured markets in which American producers were more competitive in the past. They have done this by combining the most modern production technologies – thanks to the mobility of capital and scientific knowledge – with a workforce that is highly skilled but not as highly paid as its American counterpart. Now that China and India have opened their economies and started making heavy investments in increasing their technological capacity, they are threatening to do what others have already done, only on a much larger scale. To make matters worse, recent developments in information and communications technology have "globalized" the market for many service and manufacturing industries. Digitalization and the Internet enable programmers, accountants and radiologists abroad to compete directly for jobs that once had to be done on-shore. The only way our economy can compete in this brave new world without reducing wages is by out-innovating the competition and thus reaping the market premium gained by "first movers."

This reality poses stark choices; in response to this inevitable competition, we can take the "high road" of innovation or the "low road" of reduced incomes. We can innovate and improve ourselves, or we can allow wages to fall and compete by making ourselves poorer. Only the "high road" leads to competitiveness — and, once again, *competitiveness* depends upon *innovation*.

But *innovation* is not just *invention*. One needs all of the steps of the *innovative process* to improve competitiveness. An educational system must produce the knowledge that allows people not only to conceive of new inventions, but to figure out how to produce them and develop the skills necessary to use them. There must be a pool of savings available to invest in the research and development needed to produce these inventions and the investments that must be made to bring them into production. The economic environment must be conducive to growth — it must be stable, avoiding booms and busts and debilitating inflation. The economy must have the flexibility that allows for change — allowing production to be reorganized quickly and efficiently, giving workers the tools to move from old employment to new ones (a workforce with transferable knowledge and skills), and distributing the benefits of these innovations in ways that create and maintain a strong social consensus that economic change works for the benefit of all.

Moreover, in order to innovate, businesses must have a model and culture of innovation — and a system of governance — that lead them to take the risks necessary to shepherd these inventions into useful products. Innovation depends on reinventing strategies, products, and processes and creating new business models and new markets. It is about selecting the right ideas and executing the business strategy quickly and efficiently. It requires vibrancy and alertness in our businesses; new ideas sometimes come from laboratories, but many come from being in contact with customers or suppliers, adopting existing technology for a new purpose, or research that becomes incorporated into a firm's product development strategy via a local business network or collaboration.

Innovation is a hallmark of a successful economy, and it lies at the heart of how economies grow and where good jobs come from. Moreover, *innovation* is the only means by which a high-skill, high-wage economy can successfully compete with high-skill, lower-wage economies without reducing wages. Thus, *competitiveness* for the U.S. in particular depends on the rate at which we *innovate*. The process that creates innovation is a multi-faceted and goes far beyond invention alone. This leads us to consider how government at all levels — and, principally, states — can affect the innovative process.

The Role of Policy and the States

While competitiveness is a national phenomenon, states play a critical role in determining it and in making the economies within their boundaries more competitive, as well. This is not hollow theory — it is the real-world stuff of which jobs and growth are made. Let's return to the World Economic Forum international competitiveness rankings mentioned above. The U.S. slide from first to sixth in the world was based on the Forum's assessment of our performance in all of the diverse steps of the innovative process. For example, the U.S. was regarded as either number one or two in the world in market efficiency and technological innovation, as would be expected. But it was twelfth in infrastructure (immediately trailing Belgium), 27th in the quality of its public institutions (including prominently the quality of public services and government management, behind Chile and barely ahead of Portugal) and, shockingly, 40th in the world in the areas of education and health — directly behind Bosnia and Bulgaria, and immediately ahead of Ecuador, Malaysia, and Estonia. U.S. macroeconomic policies were regarded as 69th in the world — between Slovakia and Poland! Seen in their totality, these rankings tell us the private sector has been doing the job asked of it, but the public sector — the custodian of American infrastructure, education, health care, and economic policy — has failed to live up to its responsibilities.

The magnitude of the competitive challenge to the United States demands a response, and governors must respond proactively and aggressively. They must increase public awareness of both the problems we face and the opportunities to address them, by speaking out and setting expectations.

Innovation combines human, intellectual, and financial capital. Promoting innovation, therefore, requires expanding those sources of capital and improving the way we combine them. Human capital heads this list. But, as we've seen, American students are not attaining the level of knowledge they need in science, technology, engineering, and math, and are falling behind their peers in many other countries. Nor is the United States producing sufficient numbers of the skilled scientists and engineers needed to create tomorrow's innovations. An innovative economy requires well-aligned investments in education, R&D, and entrepreneurship, particularly at the early-stages of investing on which innovative entrepreneurs depend. But U.S. non-defense R&D still lags major competitors such as Japan and Germany as a share of our economy.[8]

This *Call to Action* focuses on two tasks — "setting the stage" for broad economic growth, and "building on strengths" through targeted programs to build local economies. Governors need to develop and implement both strategies over two different time frames; both approaches are critical to preparing states to compete in the 21st century world economy.

Policy's First Job: "Setting the Stage"

The failures highlighted by the World Economic Forum share a common bond. Each is a failure of government to create a landscape on which economic activity can flourish — a failure to "set the stage" for competitiveness. Some of these deficiencies can be remedied by the federal government, but others fall directly to the

[8] National Science Foundation, Science and Engineering Indicators, 2006

states. At the highest level, the federal government must provide stage-setting policies that support innovation and economic growth. These include creating macroeconomic balance (including low inflation, stable growth, and adequate saving); providing public infrastructure; overseeing the governance of the largest private economic actors and the integrity of capital markets; putting in place a quality education system, particularly at the post-secondary level where the federal role is larger; performing the basic research that provides a foundation for other innovative efforts; and providing incentives and programs to promote scientific progress, among many others.

States play an equally compelling role in these stage-setting policies. While the federal government pays for about 7 percent of the nation's K-12 education costs, and local financing is also pivotal, the states are the primary drivers of educational policy and innovation, and the decisions they make will determine whether the K-12 education system succeeds or fails. States have taken the lead in setting standards and developing assessments and accountability systems for the nation's elementary and secondary schools, and, as the NGA Action Agenda for Improving America's High Schools noted, they play a leading role in aligning our high schools with the modern realities of the world economy. States are the lead actors in the nationwide effort to restore American excellence in science and math education.

This is also true of the higher education system, in which states fund the core of the post-secondary education system. States also play a central role in the provision of infrastructure, where their added funding has offset real declines in the federal role, and in the heath system, where they are the active partners of the federal government. States are playing an even more important role in establishing the broadband networks that will be a part of the infrastructure of the unfolding century.

States clearly have a central role to play in establishing the landscape on which innovation takes place, but they have a second role to play that is equally important.

Policy's Second Job: Building on Strengths

States, unlike the federal government, must operate in two worlds — the "general" world of providing a helpful economic landscape, and the "specific" world in which government must work with their local economy's strengths and weaknesses. This unique positioning — on the boundary between the diverse global economy and the realities of the local economy — drives state economic development efforts.

The global economy is eclectic and complex. Its markets tie together diverse products in far-flung places through intricate networks of transportation, communications, and finance. The economy of a small town ultimately must obey the same laws of economics, but its structure is completely different. A local economy may be dominated by a large employer — a feedlot, a factory, a hospital, or a tourist destination — and much of the locality's activity may be tied to that facility. When the facility prospers — when it invests and expands, takes on more employees, or pays higher wages — the locality prospers. The interests of the two are not identical, but they inevitably coincide.

State economies exist on the boundary between these two worlds, and the right mix of state-level economic development policies has aspects of both as well — both the *general* application of broad, stage-setting policies, and the *specific* targeting of their local economies' competitive strengths and weaknesses. The leading participants in any state's economy are known with certainty, much like the large employer in a small town. Instead of an individual feedlot or factory, however, state economies are typically built around one or more groups of firms and closely-related industries that give each state its own distinctive competitive advantages.

Some of these groupings – sometimes referred to as "clusters" — are well-known, such as Silicon Valley, or the postwar auto industry around Detroit. Others are less well-known but still important locally, whether they're in finance, health, polymers, jewelry, mobile home-building, furniture, or any other industry or sector. These local champions attract other economic activity to them. Relevant skilled workers are attracted to these places because they find opportunities for advancement. Supplier industries want to be near their customers in order to anticipate their changing needs. Investors, from banks to venture capitalists and early-stage "angels" who back startup companies through their initial stages of development, stay abreast of industry developments, compare firms, and meet businesspeople with track records of success.

This stew of investors, firms, suppliers, and workers in close proximity leads to exchanging information and making productivity and innovation possible. Perhaps most importantly, their proximity makes it easier to start new businesses, which not only generate new jobs but also create competitive pressure on established firms and force them to stay at the cutting edge of productivity and innovation.

Thus, even after states play their central role in the "stage-setting" policies that support economic growth and competitiveness, there is much left for them to do. The central theme of this second set of tasks is to identify state economies' competitive advantages and use the tools available to build upon them.

Making It Work

States, therefore, have two responsibilities in fostering economic development. The first is to be an active partner with the federal government in setting the stage — creating a landscape on which economic growth can take root. The second is to identify the state's competitive advantages and build a specific, targeted policy around them. These two strands come together in a variety of areas that fall within the purview of the states. Let's briefly examine three here: K-12 education, post-secondary education, and research and development.

K-12 Education

The common denominator of high-paying jobs is high-level knowledge and skills. Our nation's performance in preparing our young people for these jobs is uneven, as measured by our progress and when compared with our international peers. The task of preparing for a technological future in a global economy begins in grades K-12, as our children learn about math and science. The latest statistics from the National Assessment of Educational Progress (NAEP) showed across-the-board improvement in mathematics from 2003 to 2005 for fourth and eighth graders.[9] A higher percentage of both fourth and eighth graders were performing at or above the Basic and Proficient skill levels. However, the relative standing among international peers of U.S. fourth graders on the Trends in International Mathematics and Science Study (TIMSS) math exam declined between 1995 and 2003.[10] In addition, U.S. 15-year-olds ranked 24th out of 39 countries that participated in the 2003 Program for International Student Assessment (PISA) of students' ability to apply mathematical concepts to real-world problems.

The news for science is also mixed. Compared to the next most recent NAEP test from 2000, fourth graders improved their scores and the percentage of children testing at or above Basic and Proficient skill levels rose in 2003. However, eighth graders showed no improvement for the third assessment in a row, and the percentage of students testing at or above Basic levels also remained stagnant. The scores for twelfth graders rose slightly over their 2000 levels, but they are still behind their 1996 levels by a significant margin. U.S. eighth graders have improved in science relative to their international peers on the TIMSS between 1995 and 2003, but the scores for U.S. fourth graders on the TIMSS have declined over the same period. U.S. 15-year-olds score slightly below the average OECD score in science literacy.

States must rise to this challenge, just as they have risen to the challenge of measurement and assessment, or the need to redesign the American high school. Teaching math and science, as well as technology and engineering, in our elementary and secondary schools is a vital "stage-setting" function — it allows students to acquire highly valued skills in their later education, solve problems, become innovators and experimenters, and be effective citizens of a society that will require growing awareness of scientific issues. At the state level, it has specific advantages, as building literacy and "numeracy" allow employers to avoid training costs they would otherwise have to undertake.

Post-Secondary Education

The states play a leading role in determining the character of post-secondary education, primarily through their stewardship of state universities and community colleges; here, again, the evidence is mixed. While our nation's colleges are conferring ever larger numbers of degrees to computer and information science and biology students, the number of students with degrees in mathematics, the physical sciences, or engineering is significantly lower than it was 20 years ago. The number of Ph.D.s in these areas has improved, but now 55 percent of new engineering Ph.D.s and 38 percent of new physical science Ph.D.s go to foreign students on temporary visas.[11] Similarly, the last four years have seen resurgence in the number of B.A.s issued in math and science-related fields, led by computer and information sciences, and mathematics and statistics degrees. Taken out over 10 years, however, only degrees in computer and information sciences have grown significantly faster than the rate of growth for all degrees, and the number of degrees in engineering, mathematics, and the physical sciences have all declined.

Beyond improving their post-secondary institutions' production of math and science related degrees, states have the opportunity to make them relevant to the clusters inside their boundaries. The state university and community college institutions can work with leading firms and industries to define the skills necessary to maintain the cluster's competitiveness. Community colleges, in particular, are ideally situated to focus on the disciplines and skills needed by large and growing employers. Regular interplay between the

[9] *The Nation's Report Card*, National Center for Education Statistics, U.S. Department of education.

[10] *Trends in International Mathematics and Science Study*, 2003, National Center for Educational Statistics, U.S. Department of Education.

[11] *Digest of Education Statistics*, 2005, National Center for Education Statistics, U.S. Department of Education

post-secondary education school system and the state's strongest business sectors also allow the two institutions to get to know each other, allowing firms to recruit personnel and the schools to place their students.

The nation's post-secondary system is confronted with an even broader, longer-term question. The American higher education system has been a centerpiece of the U.S. economy, producing much of the nation's innovative talent — scientists, engineers, technicians, and managers — and the majority of its publicly funded research. Over the past several years, however, other nations and regions have entered the global marketplace by successfully duplicating and even improving upon this model. Moreover, American universities are now racing against each other to enter foreign markets by locating branches abroad, rather than bringing students to the U.S.

All of these trends require that we rethink the role of higher education. The goals of higher education have always been to produce individuals with the tools for social, business, and cultural citizenship and leadership. But these concepts are changing rapidly. Entrepreneurship and the capacity to imagine the unseen and unknown are now more highly valued. The ways in which people solve problems have changed, as well, as computing automates analytic work and places a greater premium on the ability to harness facts using judgment, intuition, and creativity. Integrating diverse subject matter is as important as mastering individual subjects. The ability to work in groups and teams, often with people who are spatially and culturally disparate and are linked only by networks, is a vital, modern skill. How will we use our colleges and universities to develop citizens and leaders of the emerging century, and build an economic base relevant to the interrelated challenges of globalization and technological progress? How does the university system relate to the challenge of innovation and entrepreneurship? The answers to these questions are not obvious, but it will be up to this generation of governors to rethink the role of higher education: what are the new models that will carry our country to the next level of innovation and prosperity?

Research, Development, and Building Businesses

The federal government is the key public sector funder of research and development, but, again, states can play a central role. Federal research is generally "basic" — the kind of scientific work that underpins subsequent discoveries — as opposed to "applied," which extends those findings into areas in which they are relevant to solving day-to-day business problems. In fact, the funding of basic research has risen gradually as a share of the economy for decades, while federal applied research efforts have remained roughly constant.

Applied research and development involves specific industrial targets and, for that reason, states are ideally suited to target and support it. Some of them are starting to do so. Moreover, these states are linking their R&D support to new business creation and promotion within their boundaries. In 2004, California voters authorized the creation of the California Institute for Regenerative Medicine (CIRM) and provided the Institute with the power to issue up to $3 billion in bonds over the next 10 years. CIRM's main purpose is to provide grants and loans to public and private organizations throughout the state to support stem cell research. California, through CIRM, also retains a portion of the licensing rights for any commercial product developed by utilization of a CIRM grant as a condition of the grant. Other states, such as Connecticut, Ohio, and Wisconsin have also funded stem cell research.

Michigan developed its SmartZones initiative in 2000 to approach this issue from a different direction. The SmartZones are 10 partnerships among municipalities, local business interests, and institutes of higher education seeking to spur innovation in their regions.

Each of the 10 sites has a dedicated research purpose. For example, the Kalamazoo SmartZone focuses on drug discovery. In 2002, an acquisition led to the layoff approximately 800 scientists in the Kalamazoo area. Some of the laid off scientists entered the Kalamazoo SmartZone to form their own enterprises. Today, those numbers account for almost 30 technology companies employing almost 500 people.

Overall, the state of Michigan estimates that the 10 SmartZone sites have combined to retain over 3000 jobs in the state, and created over 3300 more. Aside from the state government's initial investment of $25 million for startup costs, funding for the SmartZones has come from local governments, which are then leveraged to attract funds from other local institutions, both private and public. In total, the SmartZones have accumulated over $400 million in investment.

A final example is Ohio's Third Frontier Project, a 10-year, $1.6 billion initiative designed to build world-class research capacity, support early stage capital formation leading to the development of new products, and finance advanced manufacturing technologies to improve productivity in existing industries. Grants from the Third Frontier Project allow higher education, non-profit research groups and Ohio companies to speed the commercial development of products resulting from research conducted in the state. Estimates from the Third Frontier Project indicate that almost 2000 jobs have been created in Ohio as of the end of 2005. The average salary of these positions is almost $75,000.

A common denominator of these programs, beyond their focus on innovation, is their emphasis on encouraging entrepreneurship and business formation. New businesses are typically the vehicles through which new ideas, new inventions, and new investment enter the local economy. Moreover, national studies have shown that a full one-third of all manufacturing jobs created in the economy occur in startups and another one-third in establishments that grow by 25 percent or more in that year.

States can spur the growth of these new startups and fast-growing companies — often referred to as "gazelles" — by having an entrepreneurial policy alongside their R&D efforts. They can provide "incubators" for new and small businesses that help them with the cost and logistics of their early stages as well as access to other resources. They can use their own funds, as do the states in these examples, or work with funding "angels" to target fast-growing new firms or startups that build on the strengths of the state's existing clusters. They can use their post-secondary education system to teach entrepreneurship, as many programs now do.

Building State Competitiveness: The Road Ahead

All of these policies rely on the willingness of states to look at their competitive strengths and weaknesses in concrete and realistic terms. This requires competence and judgment on the part of state policy makers, as well as the ability to negotiate with private parties using public standards of transparency. But states no longer have the option of providing a broad and neutral "framework" that lets the chips fall where they may — instead, they are obliged to use policy to lever the assets they already possess. And states can no longer use their public dollars in an ever-greater bidding war for ever-fewer plants or facilities. These "transplants," auctioned to the highest bidder, inevitably expand the demand for public services without building any synergies in the local economy, and often escape before their obligations are fulfilled.

This *Call to Action* points to a new and different approach — one that calls on states to strengthen the innovative process within their boundaries. The global competition unleashed by the computing and communications revolution has made every location on the globe a competitor in its own right. Paradoxically, this leveling of the global playing field has made what happens at the state level more important, not less. Each state now has the opportunity to further its own competitive interests by working not only to set the stage for economic growth, but also to build the innovative process as it relates to that locality's individual circumstances. That is the "high road" — the road to genuine competitiveness that results from innovation and sustained productivity.

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The Ford Partnership for Advanced Studies

FORD PAS CURRICULUM

FORD PARTNERSHIP
FOR ADVANCED STUDIES
High Standards for High Achievement

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Introduction

The Ford PAS curriculum consists of five semester-long courses that link classroom learning with the challenges students will face in post-secondary education and the workplace of the future.The curriculum integrates academically rigorous, standards-based content with realistic applications in areas such as design and product development, information systems, environmental sustainability, global economics, business planning, and marketing. Ford PAS courses are designed to be taught in sequence over two and a half years in grades 10, 11, and 12. Each course consists of three six-week modules. A Ford PAS module is comprised of six extended activities that typically last for two to six standard class periods. Each module has a coherent theme and a final project.

The Ford PAS curriculum is designed so that skills and content knowledge developed in a particular module are built upon in later modules. However, modules 3, 8, 10, 12, and 13 are designed so that they can also be used independently as units in existing courses in social studies (U.S. history), statistics, engineering, physics, and economics, respectively. These modules offer the opportunity to participate in Ford PAS to schools that may not have the capacity to offer a full complement of electives; want to encourage students to apply in real-world contexts some of the knowledge and skills they acquire in traditional courses; or would like to try out the Ford PAS teaching and learning approach before committing to full-scale implementation of the program. Following is an overview of the Ford PAS courses and modules.

Ford PAS Course and Module Sequence

The five semester-long courses of the complete Ford PAS program are designed to be taught in sequence over two and a half years, beginning in the sophomore year. Some schools opt for an alternate sequence, beginning the program at the start of 10th grade, which allows students to select another elective at the end of their senior year.

Ford PAS Course	Module Titles	Suggested Sequence by Grade Level
Course 1: Building Foundations	1. From Concept to Consumer: Building a Foundation in Problem-Solving 2. Media and Messages: Building a Foundation of Communication Skills 3. People at Work: Building a Foundation of Research Skills	10th grade, second semester
Course 2: Adapting to Change	4. Careers, Companies, and Communities 5. Closing the Environmental Loop 6. Planning for Efficiency	11th grade, first semester
Course 3: Managing and Marketing with Data	7. Planning for Business Success 8. Ensuring Quality 9. From Data to Knowledge	11th grade, second semester
Course 4: Designing for Tomorrow	10. Reverse Engineering 11. Different by Design 12. Energy for the Future	12th grade, first semester
Course 5: Understanding a Global Economy	13. The Wealth of Nations 14. Markets Without Borders 15. Global Citizens	12th grade, second semester

Ford PAS Course and Module Content

Course 1: Building Foundations

Building Foundations **introduces students to the worlds of business, product development, and manufacturing while building a foundation of skills important for academic and workplace success—skills that are used throughout the Ford PAS curriculum. In Module 1, students learn to work in teams to solve problems related to planning, developing, and producing products. In Module 2, students develop communication skills through reading, writing, and role-play activities as they expand the product line of a fictional business. In Module 3, students develop skills in research and analysis as they examine and compare the circumstances and lives of people working in different periods of United States history.**

MODULE 1

From Concept to Consumer:
Building a Foundation in Problem-Solving

From Concept to Consumer introduces students to various aspects of manufacturing, such as product design, product development, production planning, manufacturing processes, and quality assurance. Students learn about the historical context in which manufacturing occurs by investigating the evolution of everyday objects in relation to social and technological change. Students also attempt to solve a variety of problems similar to the problems people must solve in the various departments of manufacturing organizations. By the end of this module, students will know what it takes for a product to make its way from concept to consumer.

In Module 1, students also learn that effective communication, collaboration, and compromise are essential aspects of work in manufacturing organizations. Throughout the module, students develop and practice these skills through role-playing, hands-on simulation, and team-based research activities. This module relies heavily on guided Internet research and requires that student teams develop and give several presentations, including one presentation that uses Microsoft® PowerPoint® software. In addition to developing oral presentation skills, students also develop skills in communicating ideas graphically through process flowcharts and tables.

MODULE 2

Media and Messages: Building a Foundation of Communication Skills

Media and Messages engages students in addressing a variety of communication challenges encountered by a fictional food chain called Quick 'n Tastee—a company that is expanding its product line through a partnership with a company based in another country. As employees of Quick 'n Tastee, students select a new line of food, decide on the best locations for introducing their new line, prepare to interview potential employees, analyze styles of communication appropriate for different contexts, develop logos and slogans, and plan an ad campaign. In an ongoing assignment, students analyze advertisements to discover ways that the media communicate messages.

The goal of Module 2 is to introduce students to communication issues in the workplace. The Quick 'n Tastee scenario provides the context in which students learn and apply a variety of written and verbal workplace communication skills, such as summarizing and organizing written and verbal information, giving and receiving feedback, writing and speaking persuasively, writing and then revising a short report, and making oral presentations. Students develop an awareness of issues of diversity in communication and the importance of shaping information for a specific audience and purpose. Students also practice developing communication skills using presentation software.

MODULE 3

People at Work: Building a Foundation of Research Skills*

People at Work challenges students to trace changes in the workplace by looking closely at key periods in United States history. Students learn how such factors as immigration, the economy, technological innovation, and legislation affected people's work experiences in the past, shape working conditions today, and will affect the workplace of tomorrow. Students research different periods of U.S. history by analyzing primary and secondary sources of information, including documents, art, and photographs, that portray work life from various perspectives. They also conduct interviews of present-day workers in order to collect information about the workplace of today.

In Module 3, students learn and apply a variety of research and communication skills, including finding and evaluating sources, paraphrasing, and citing sources appropriately. In an ongoing project, students develop technology skills as they build a class Web site that explains how the workplace has changed throughout U.S. history.

* *Possible Independent Module: Social Studies*

Course 2: Adapting to Change

Adapting to Change begins with an exploration of evolving career, job, and internship possibilities and then engages students in a study of two issues that are driving change in business and industry today: environmental concerns and efficiency. Module 4 gives students an opportunity to explore their own interests and values, as well as a chance to match these interests and values to changing employment opportunities in their communities. In Module 5, students explore how industry can respond to the challenge of becoming environmentally sustainable by changing products, processes, facilities, and supply chains. In Module 6, students respond to another current-day challenge—making the most efficient use of time, human, and material resources in a customer-driven market.

MODULE 4

Careers, Companies, and Communities

Careers, Companies, and Communities introduces students to three interwoven themes that continue throughout this course. The first, "The Changing Nature of the Workplace," is introduced through the Change in the Workplace assignments that students complete in each of the six activities. The second and third themes, "Interplay Between Industry and Community" and "Industry Clusters," are explored through both in- and out-of-school activities, as well as through a Career Exploration Journal. Students are given a Career Exploration Journal assignment in each of the first five activities, and they use those assignments, and their new understanding of both industry clusters and the interactions between industry and community, to create a career presentation.

In Module 4, students learn about the businesses and industries in their region, the range of positions companies may offer, and the changing nature of the workplace. They gain information through interviews, classroom speakers, a worksite visit, and other resources. Throughout the module, students develop technology skills: working with databases, creating and delivering presentations, and doing Internet research. By the end of this module, students will have a better understanding of careers they may want to pursue, places they may want to work or intern, and the ways that people and companies adapt to change.

MODULE 5

Closing the Environmental Loop

In *Closing the Environmental Loop*, students investigate how industry is changing in response to today's environmental issues and learn about a range of incentives for reducing the environmental impact of products and processes. They first look at how every stage in the life cycle of everyday products affects the environment. Then, through video, case studies, and Web research, they learn how industries are redesigning products for easier remanufacture or recycling, changing their production processes, improving their facilities, developing eco-industrial parks, and "greening" their product supply chains.

Module 5 introduces students to the use of data for monitoring progress toward environmental goals. Through a role-play activity, students develop the negotiation skills needed to build financially and environmentally sustainable business partnerships. Throughout the module, students apply what they learn about products and companies to a product of their own choosing. In a final activity, they present proposals for making their chosen products more environmentally sustainable.

MODULE 6

Planning for Efficiency

Planning for Efficiency focuses on how companies can make the best use of time, materials, and human resources in the context of changing social, environmental, and market realities. Students learn about historical changes in the ways that people think about time and work, and explore how these changes, along with advances in technology, have shaped the ways in which businesses manage their resources. Through role plays, simulations, and case studies, students try out and analyze various approaches to resource management and production planning.

In Module 6, students learn how to use resource management tools including the critical path method and value stream mapping. Then they apply these tools to planning and scheduling tasks in their own lives and in several business settings. Students also develop skills for conducting effective meetings. In an ongoing project, teams research and observe a local business to see how it manages its time, materials, and human resources.

Course 3: Managing and Marketing with Data

In *Managing and Marketing with Data*, students learn how businesses use data for a wide range of decision-making and strategic-planning activities. In Module 7, students use data to run a successful marketing campaign and make effective business decisions. In Module 8, they master statistical tools used in business to ensure high-quality services and products. In Module 9, students look at ways that information systems are used in business to manage and share the data needed to make informed decisions.

MODULE 7

Planning for Business Success

In *Planning for Business Success*, students take on the role of manager of NoNaymz, a local band trying to break into the national music scene, and, through case studies and a computer simulation, they learn about marketing and finance. Students apply their NoNaymz experience to create a realistic business plan for a small business of their own. In a closing activity, students present their plans to visitors from the community in an effort to recruit potential "investors."

In Module 7, students develop a range of entrepreneurial skills. They identify a business's target audience, design market surveys and analyze their results, develop a marketing plan to reach a particular audience, determine costs and revenues, calculate profits and losses, conduct a break-even analysis, and analyze the effect of supply and demand on prices. Students also debate ethical issues involved in marketing. The module utilizes Microsoft Excel as a financial management tool.

MODULE 8

Ensuring Quality*

In *Ensuring Quality*, students face a series of challenges that show how business and industry use statistics and data analysis to improve the quality of products and services. The goal is for students to be able to apply statistical analysis in several business contexts in order to measure, analyze, and control quality. To do this, they take on the roles of members of various departments in Xavier Automotive Company (XAC) and use statistics to make business decisions that members of these departments would

* *Possible Independent Module: Statistics*

make. Students learn how companies measure and control for quality and about the role of data analysis in ensuring quality. In addition, students learn how data are used to make long-term business decisions.

In Module 8, students learn statistics concepts relevant to analyzing data and then apply these concepts to a final company scenario, in which they create a status report for one XAC division. Students also become familiar with a variety of ways to present statistical information visually. Using MINITAB® Statistical Software*, a statistical analysis software package, or Microsoft Excel, students analyze consumer information to inform design and marketing decisions, make personnel decisions based on data about employees' previous performance, and monitor production for the presence of defects.

MODULE 9

From Data to Knowledge

MODULE 9

From Data to Knowledge introduces students to the purposes and uses of information systems, and gives students the opportunity to create their own information systems. Considering the health care industry as an example, students research ways that information systems, including geographic information systems, are used by businesses. Through observation, hands-on projects, and case studies, students find out how different types of information systems allow users to create, manage, and share information for a variety of purposes.

In Module 9, students develop a solid understanding of information systems. They learn skills that will help them analyze different kinds of data and make decisions using those data. They learn and apply skills in database development and learn the pros and cons of spreadsheets and databases. Students also grapple with ethical issues related to information systems as they consider the potential benefits of and drawbacks to using information systems in business and explore and evaluate new trends in the field.

* *MINITAB® is a registered trademark of Minitab Inc.*

Course 4: Designing for Tomorrow

Designing for Tomorrow engages students in the process of product design and focuses on key design issues of the 21st century. Students begin in Module 10 with the challenge of reverse engineering–analyzing products from the perspectives of consumers and manufacturers. In Module 11, students experience the design process themselves, redesigning an existing product in order to meet specific needs or goals. Finally, in Module 12, students explore innovative technologies that may transform energy use in this century.

MODULE 10

Reverse Engineering*

In *Reverse Engineering*, students analyze products, determining how they can be designed to meet the needs of their intended users and considering other factors that influence product design. First, students focus on using reverse engineering to make good products for the consumer by analyzing features of existing products, considering design factors that determine the ease of product assembly, and looking at the manufacturing processes used to create products from different materials. Students then focus on reverse engineering from the perspective of product failure, and analyze communication failures in written and visual instructions. Students also test different materials as they explore engineering failures related to material choice. For their module project, students analyze a case study and role-play its situation.

As students explore the process of reverse engineering in Module 10, they develop a number of valuable skills. Students are introduced to logbooks and their use in scientific and technical fields, and make log entries of experiment results, team meeting notes, and sketches of products. In addition, students continue to develop their teamwork skills, focusing on meeting facilitation.

MODULE 11

Different by Design

In *Different by Design*, students take on the challenge of redesigning an existing product. They first consider how the features and functions of a product are directly related to consumer needs. They learn about the procedures that design teams use to develop products, including the screening and scoring of potential concepts to find the one that best matches the team's goal. Students then complete a basic cost analysis of

** Possible Independent Module: Engineering* a product, addressing the economic factors that affect a product's development. They learn basic principles of industrial design and consider how such factors as appearance and user-friendliness may influence both a company's image and a product's success. Students are also introduced to the idea of intellectual property rights, and they conduct searches for patents. Finally, students learn how to visually represent a design idea to different audiences, from tradespeople to consumers, using technical drawings and illustrations.

Throughout Module 11, students work in teams to apply the design tools they've learned to a product of their choice. Teams compare and contrast different brands and models of a similar product, exploring how the products meet customers' needs. At the conclusion of the module, teams present a complete plan for a redesigned product. This module teaches students how to think and work like engineers: They learn techniques used to turn customer feedback into useful design information and how the creative aspects of the design process can fulfill customers' needs in unique ways.

MODULE 12

Energy for the Future*

Energy for the Future introduces students to innovative ways in which renewable energy sources and technologies are used to provide energy for society. Students become familiar with the different forms and sources of energy and learn about renewable and nonrenewable energy sources. They analyze case studies to determine the pros and cons of several energy sources and analyze the availability, practicality, safety, and environmental impact of different energy technologies. They construct simple energy systems and learn to calculate work, power, potential energy, and efficiency. They also learn about the principles of electricity and how to determine the energy needs of different systems, such as homes or schools.

MODULE 12

In Module 12, student teams further develop their Internet research skills as they gather information about one energy-generation technology. Teams share their findings with one another and consider the merits and drawbacks of the different energy technologies for meeting the energy needs of a particular building. In a culminating project, students design a plan to meet some of the energy needs of their school with renewable energy sources.

** Possible Independent Module: Physics*

Course 5: Understanding a Global Economy

In *Understanding a Global Economy*, students learn basic economic principles while developing an understanding of the nature of our global economy. In Module 13, students become familiar with the varied resource bases of different nations and the impact of production, trade, and investment on the economic health of these nations. In Module 14, students focus on the international movement of material and human resources, potential intercultural problems, and the effect of international agreements and regulations on businesses and individuals. In Module 15, they learn how companies are responding to a globalized economy and the challenges that such an economy presents.

MODULE 13

MODULE 13

The Wealth of Nations*

In *The Wealth of Nations*, students analyze the factors that affect the wealth of different countries and consider different ways to measure the health of an economy. They examine the consequences of declining natural resources and learn how investments in resources affect a country's productivity and the standard of living of its citizens. Students compare standards of living among countries and predict how current population trends may affect the workforce as well as the market for particular goods and services. Students also compare the way that resources are used in different countries and consider the potential economic, environmental, and social consequences of a declining natural resource base. In an ongoing project, students become familiar with CleanWater Tech, a fictional U.S. company that produces water filtration and disinfection technologies and is interested in opening a facility abroad. Students apply what they've learned about the country's economic health in order to justify their decision about whether to expand CleanWater Tech into their chosen country.

In Module 13, students analyze and interpret data such as real and nominal GDP, inflation rates, and unemployment rates to better understand how economists measure the health of economies. Students further develop their research and analytic skills in this module, using them as economists do to analyze a country's economic climate. Finally, students use their analyses of the various indicators they've learned about to develop their own economic indicator for analyzing the economic health of a country.

** Possible Independent Module: Economics*

MODULE 14

Markets Without Borders

In *Markets Without Borders*, students become familiar with the interdependence of different countries in today's global economy. They examine the role of trade in the global economy and analyze the purposes and effects of quotas, tariffs, and trade agreements on businesses, governments, and individuals throughout the world. Students analyze the challenges of conducting intercultural business and trade, and they develop international agreements that balance the conflicting interests of different nations.

Throughout Module 14, students participate in Global Economic Exchange, a Web-based international relations simulation in which they take on the roles of policymakers for particular countries. In an attempt to serve the best interests of their project country's citizens, students propose and negotiate trade agreements, set trade policy, and cast their votes on international regulations. Students create a Country Briefing Handbook, a compilation of information about their project country's economy, trade relations, laws, and social and environmental issues related to globalization. (In Module 15, students draw on the information and resources in these handbooks to make recommendations to a fictional company that has recently located a facility in another country.)

MODULE 15

Global Citizens

Global Citizens introduces students to the concept of corporate citizenship—the responsibility companies have to enact policies and practices that address emerging social and environmental issues around the world. Students also examine the effects these practices may have on the company's stakeholders, including shareholders and customers. Through case studies and role plays, students learn about the different kinds of social and environmental issues—such as pollution, labor practices, and worker health—that arise in different business contexts around the world and look at how companies have addressed these issues.

Throughout Module 15, student teams take on the role of employees in the corporate citizenship department of a company. Each team recommends how its company can responsibly manage one social or environmental issue in a particular country. As part of the module, students also examine the potential impact that individual citizens can have on a company's actions, and develop an experiment and survey to determine if and how corporate behavior affects consumer behavior. This capstone module allows Ford PAS students to demonstrate the variety of skills and breadth of knowledge they have developed throughout this program.

Ford PAS in Action: Snapshots from the Classroom

Ford PAS can best be understood through vignettes showing students at work. Here are four vignettes–one each from Module 1, Module 4, Module 5, and Module 7.

The ACME Soft Drink Company Business Simulation

Module 1: From Concept to Consumer: Building a Foundation in Problem-Solving

Students meet in teams representing key departments in the ACME Soft Drink Company: finance, marketing, production, and corporate citizenship. This manufacturing company is making some critical decisions about marketing a new soft drink and all four departments are involved in this decision-making. The teams discuss a document that describes their department's responsibilities and priorities and provides specific information about the new product. After students become familiar with the challenges facing their departments, each team develops proposals for the company to consider.

With their department proposals in hand, students reorganize into planning teams consisting of one member from each department. Each planning team pools the knowledge from all four departments to come up with a plan that maximizes opportunities for the company to profit from the new product. These teams develop formal presentations to make to the class, who represent the company's board of directors. After all of the presentations, the students decide whether to adopt one team's plan or create a new plan combining features from several of the plans.

This simulation teaches students how a business is organized and the kinds of information that go into making important company decisions. Rather than reading about organizational structure and decision-making in a text, students gain this knowledge through active involvement and problem-solving. Students are required to read and synthesize complex information and prepare alternative plans. Effective communication skills, both speaking and listening, are essential: every student's input is required before the team can make a decision. Every decision requires making tradeoffs among important objectives. These are skills that students will need for success in higher education, work, and daily life.

This interdisciplinary activity addresses academic standards in English language arts, social studies, and business education. Learning goals are correlated with the relevant standards. Students are assessed directly on what their team accomplishes: the credibility of their production plan and the skill with which they present it to their classmates. On the module test, they answer questions that assess skills and concepts learned during the activity.

Building a Database of Local Companies

Module 4: Careers, Companies, and Communities

MODULE 4

In this module, students have been working in research teams to gather data about companies in their community. How large are they? Where are they located? Are they accessible by public transportation? What are their primary products or services? How do they contribute to the community? Now students are engaged in entering data into a computer database. They download a database template from the Ford PAS Web site. In addition to learning about the businesses in their communities, students learn the terminology and the mechanics of using a computer database: fields, records, categories, keywords, and queries. When students finish merging data from all the research teams, the class has a large, searchable database with practical information about companies in their community. They can use this database when they explore job shadowing opportunities, internships, and summer or after-school employment, and as they begin to think about future careers.

In this activity students are learning an important, transferable business and life skill: the use of a computer database. By entering the data themselves—and dealing with the inevitable errors—they also learn that the value of a database is no better than the quality of the data that went into it and the accuracy with which the data was entered. By querying the database, they learn both the power and the limitations of the tool. The learning goals for this activity address English language arts standards for comprehending and organizing information, business education standards related to information systems, and academic standards for educational uses of technology. Students are assessed on their skill in designing fields and queries that allow for effective access to the information in a database.

Reducing Energy Consumption

Module 5: Closing the Environmental Loop

MODULE 5

Students take on the role of consultants to Tough Ride Jeans (TRJ), a clothing company that wants to lower its energy costs and, at the same time, reduce its dependence on fossil fuels in order to cut back on emission of greenhouse gases. An earlier analysis has shown that lighting technologies, along with heating, ventilation, and air conditioning, consume almost 95% of the energy at TRJ's conference facility. Students work in teams to investigate the energy savings possible with one of four alternative energy solutions. Students use spreadsheets to estimate the cost savings and reduction in fossil fuel use for each potential solution. They construct tables and graphs to compare the impact of the approach they are researching with TRJ's current energy costs and fossil fuel consumption. When they complete the detailed studies, members of each team will compare notes and recommend which technology or combination of technologies will best meet TRJ's energy and cost reduction goals.

This scenario focuses on shared decision-making, problem-solving, and communication in the context of designing for environmental sustainability. Students consider costs and benefits in order to make the necessary tradeoffs among possible alternatives. Information technology is a critical tool for organizing and representing data, making decisions, and crafting persuasive arguments. The learning goals are correlated with academic standards in mathematics, English language arts, social studies, business education, engineering, and technology. Teams are assessed on their use of spreadsheets to create accurate depictions of energy consumption, and on their analysis of the effects of each energy-saving technology on costs and greenhouse gas emissions.

Rags to Riches, a Business Simulation

Module 7: Planning for Business Success

In the opening activity of this module, students playing a computer simulation called Rags to Riches are trying to maximize their profits as managers of a small, up-and-coming rock band. Although they have not yet learned the formal language of business planning, most of them are quite comfortable making decisions in the informal setting of the simulation. The students will soon learn about the 4 Ps of marketing (product, place, promotion, and price), but for now, it's all play–serious play. Some things are already clear to them. If they lower ticket prices, they know they'll probably attract a larger audience. But they may not yet realize that before renting a larger hall or moving to a larger city, they'll need to spend more money for promotion if they hope to fill the hall or attract a new audience. Later students will reflect on factors that influence the success and failure of a small business venture. And they will begin to apply that knowledge as they make a realistic small business plan in order to apply to a panel of local businesspeople for $25,000 of simulated venture capital.

The learning here is active, collaborative, and intensive. Some students work in pairs, while others prefer to try the challenge on their own before comparing strategies. In addition to realizing that business can be fun, students learn that they need to track their choices, costs, and income precisely in order to make effective decisions and maximize profits. The learning goals align with national standards in business education, and evaluation of the learning is immediate and practical: Students ask themselves, "Were we successful or not? What factors contributed to our success, or lack of it? How can we use what we've learned here in future business planning activities?"

Frequently Asked Questions

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Questions about Implementing Ford PAS

1. ***What type of student is Ford PAS designed for?***

   Ford PAS will appeal not only to students who are already interested in careers such as engineering, technology, but also to students who may not think they would like, or be qualified for these and othe careers. Each Ford PAS module has certain academic prerequisites which are listed in the Module Teacher Guide and on the Ford PAS Web site. In general, students are expected to be reading at gr completed Algebra I. However, the program was developed with the assumption that all students cou PAS learning experiences and, in fact, has shown success with certain at-risk students.

2. ***What is the Ford PAS approach to teaching and learning?***

   Ford PAS uses a hands-on, project- and inquiry-based approach to teaching and learning. Rather th to facts, definitions, and terminology and then allowing students to solve related problems, Ford PAS for students to explore. Students then acquire information and develop skills in the context of investig individually and in groups, with guidance from the teacher. Students apply the knowledge, skills, and acquire through the module's learning experiences to carry out long-term projects and create end pr to project-based and inquiry-based learning. Beginning summer 2006, Ford PAS will offer profession institutes focused on these and other aspects of the Ford PAS approach. Go to the homepage of the specific information about current professional development opportunities.

3. ***What subject-area specialist is best suited to teaching a particular Ford PAS module?***

The Ford PAS staff has identified the subject areas that match up best with each course and module Course and Module Academic Subject Areas document which lists suggested academic specialtie module. In addition, the content focus and the prerequisite skills needed to teach each module appe Summaries (coming soon). Because Ford PAS courses and even individual modules are interdiscipli always be an exact match between an individual's previous teaching experience and a Ford PAS cou materials provide suggestions and resources to help teachers master the content. Be creative and ac your colleagues from other subject areas, or even consider team teaching.

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4. ***What ancillary materials do I need to use the Ford PAS modules?***

In addition to the curriculum guides, videos and supplementary software needed for the modules can online catalog. View the price list for costs by module. Note that a few videos may not be available th Information about how to obtain these videos is included in the Materials List. This list includes mater carry out various science activities, primarily in Course 4 (Modules 10 and 12).

5. ***Do I have to implement the full Ford PAS curriculum?***

Ford PAS is designed so that skills and content knowledge developed in earlier modules are built up Students will gain the maximum benefit if they experience all five courses. However, the curriculum is flexible. You may use any modules, courses, or sequence of modules and courses that you wish. Th unit of the program and we do not encourage pulling individual activities out of modules, although yo some adaptations in order to meet your students' specific needs. If you choose to teach a module or sequence, students may not have developed the knowledge and skills necessary for that particular m these cases, you can use materials from the Skill Resource Library (you will need to log in to the For access this resource) to help prepare students for the modules you plan to teach. Skill Resources are skill-related reference materials, and skill assessments; they are described more fully in Using the F Materials.

6. ***Can I adapt Ford PAS to fit into my existing courses?***

Ford PAS is designed so that skills and content knowledge developed in earlier modules are built up Students will gain the maximum benefit if they experience all five courses. However, Modules 3, 8, 1 designed to be used individually as units in existing academic courses in social studies (U.S. history) physics, and economics, respectively. Other Ford PAS courses and modules may be used independ other courses. We also encourage thoughtful adaptation or sequencing of modules to offer courses a theme, for example:

- Business and Entrepreneurship—Modules 1, 2, 7
- Engineering—Modules 5, 10, 11
- Technology—Modules 4, 6 or 8, 9
- Economics—Modules 7, 13, 14

See Guidelines for Ford PAS Adaptations and Extensions

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7. *What kind of a commitment do I need to make to the Ford PAS program?*

Ford PAS teachers need to receive initial Ford PAS training, participate in ongoing professional deve school/program site or a partner organization, register themselves and their students on the Ford PA data collection efforts undertaken by their school/program site, participate in the broader Ford PAS c greatest extent possible—including submitting student work and participating in Web-based events, a implementing the key features of the program. These features include the inquiry- and project-based philosophy, integration of technology throughout the curriculum, and partnerships with business, high community organizations. Ford PAS coordinators at a school, program site, or partner organization a additional responsibilities (see Ford PAS Coordinator Roles and Responsibilities). Other commitr teachers may be required by a particular school/program site or partner.

8. *How much does the Ford PAS program cost?*

The Ford PAS Teacher and Student Guides can be downloaded as PDF files from the Ford PAS We (once you have completed the free registration). Spiral-bound print versions of the teacher and stude at cost through the online catalog. We highly recommend that teachers have a bound copy of the Te coded pages) for each module they are teaching. Student Guides may be purchased or reproduced f Bound Teacher Guides range in price from $48 to $72. Bound Student Guides, which are intended tc range from $18 to $22. In addition, some modules require videos and other resources, most of which at cost through the online catalog. (A few videos are not available directly through the site, but inform obtain these videos is available.) A price list for all of the curriculum guides and resource materials th through the online catalog is available.

9. *Are student field trips an essential part of the Ford PAS program?*

Coordinated Learning Experiences (CLEs), including some field trips, are various types of learning e: Ford PAS students' classroom learning with the workplace, higher education, and the commur modules integrate CLEs into students' learning, and the Ford PAS Web site lists possible CLEs for e to field trips, CLEs include speaker and expert visits to classrooms, as well as mentoring and job-sha The Business/Education Advisory Council (BEAC) for your program may be able to help with fundrai: transportation and other costs associated with field trips. CLEs are considered essential components program, however, and we encourage you to make every effort to assure that students have a range

10. *What is the role of a Ford PAS coordinator?*

Each Ford PAS partner organization and school/program site must designate a coordinator to be the person for the Ford PAS Technical Assistance Group.

The **partner coordinator** is based at a college, university, or other partner organization that support: school or other program sites and may also offer its own Ford PAS program at its campus or other fa partner coordinator can be a faculty member, administrator, or outreach specialist at the partner insti

The **site coordinator** is based at a school or other program site. The site coordinator can be an adm teacher, or counselor. One or more site coordinators are usually affiliated with a partner coordinator.

The partner and site coordinators fulfill a number of responsibilities that are crucial to the success of coordinator role calls for an experienced educator with the ability to communicate well with students, business and university partners, and other educators and school officials. The partner and site coor overlapping areas of responsibility, depending somewhat on local circumstances. The coordinators' r

- Planning and facilitating Ford PAS program implementation
- Promoting the Ford PAS program in the school
- Ensuring access to Ford PAS learning tools for teachers and students
- Ensuring teacher preparedness
- Providing ongoing teacher support
- Advocating for the program in the community, including establishing and maintaining the Busi Advisory Council (BEAC)
- Overseeing Coordinated Learning Experiences (CLEs) for Ford PAS students
- Participating in program documentation and evaluation
- Participating in the broader Ford PAS learning community
- Contributing to program capacity building and sustainability

A complete list of partner and site coordinator roles is available.

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Questions about Standards

1. ***We have so many demands on us. All our school cares about is our students passing the test help?***

   All Ford PAS module learning goals are aligned to national academic standards. Each module identi content and skills that are taught and assessed, as well as the knowledge and skills that students ap are designed to build on and extend what students learn in their other academic courses. In addition, modules are interdisciplinary and incorporate real-world applications, they can motivate students to r expectations and work harder to achieve success in other academic courses. Participating in Ford P students acquire knowledge and skills that they will need throughout their college and working lives.

2. ***Is Ford PAS aligned to my state standards?***

   Ford PAS has been aligned to national standards in all relevant subject areas. Guidelines identifying content in each module and a template for "cross-walking" Ford PAS to state standards are available Ford PAS to individual state standards. Currently, Ford PAS partners in Ohio, Tennessee, California, process of aligning the curriculum to their state standards. If you are interested in learning more or al your state standards, please contact the Ford PAS Technical Assistance Group.

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Questions about Teaching Ford PAS

1. ***My students don't have the skills to do the level of work required for Ford PAS. How do I help skills?***

   The document Using the Ford PAS Curriculum Materials offers suggestions for supporting studen program. The Ford PAS Web site provides access to audio recordings of Student Guide readings wh for free or purchased as audio CDs through the online catalog. Those who might benefit from these a students for whom English is not their native language and students who are not reading at grade le courses are completed in sequence, students should acquire the skills necessary to complete each s courses or modules are taught out of sequence, an alphabetized Skill Resource Library provides acc Resources by title (you will need to log in to the Ford PAS Web site to access this resource). These r to help refresh students' skills or bring them up to the necessary level to complete the work of a spec Skill Resources for each module are listed under the Module Resources for that module.

2. ***My students don't have the computer skills to complete some of the Ford PAS modules. How these skills?***

   Skill Resources are available to help students master many of the specific technology applications us students who need more help, you may use online tutorials and other online resources for particular : Occasionally, you may allow students to use a "low-technology" approach to carrying out an activity, calculations by hand instead of using Excel. However, since technology skills are essential for studer and careers, and are therefore a key focus of the Ford PAS curriculum, building students' capacity to be a priority.

3. ***What help is there for English language learners?***

   Information about supporting students with limited English or reading proficiency is provided in Usinç Curriculum Materials. Audio recordings of Student Guide readings can be downloaded for free fror located in the Classroom Resources section of the Web site or purchased as audio CDs through the addition, the Student Guide for Module 1 is available in Spanish and Module 2 will be translated into 2006; additional modules may be translated in the future.

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Questions about Professional Development

1. ***How much training do teachers need to use the Ford PAS program? What training is availabl***

   Ford PAS recommends that teachers attend at least one in-depth training session for each module tł depth training session consists of more than an overview or sampling of the materials. During the prc the only official Ford PAS trainings available were those held during the annual Ford PAS training an conference and those held for specific groups of schools/program sites. In 2006, Ford PAS will begin regional professional development institutes that will provide more in-depth training for teaching the F Additional trainings can be arranged for large groups. Beginning in 2007, online training opportunitie: most up-to-date information about training opportunities on the Ford PAS Web site.

2. ***What assistance is there for me (the teacher) if I don't have the computer skills required for a***

   The Ford PAS program expects you and your students to use Microsoft® Office software, specificall PowerPoint®, Excel, and Access. See the Technology Requirements on the Ford PAS Web site. Spe required to teach particular modules are listed in the Module Content Summaries. (Coming soon: For module's Teaching Suggestions available under Module Resources in the Classroom Resources.) F(Resources, designed for students, may help you to some extent with Microsoft Office applications, ar resources are available to help you learn to use these programs; a technology teacher or specialist a organization may assist you or point you to useful online courses and other help. The Ford PAS prog information, tutorials, and other resources to help you (as well as your students) learn to use other le and software programs.

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Question about Assessment

How does a teacher assess students' learning in Ford PAS?

The Ford PAS curriculum provides multiple types of assessments to facilitate evaluation of students' module's learning goals. The assessments are integrated into the curriculum and include teacher an assessments of products, self-assessments of core skills, and quizzes and tests. *Product assessme* delineate the criteria on which students are being assessed and identify the content requirements of such as a presentation, report, or long-term project. *Peer assessments* focus students' attention duri presentations and give classmates the learning experience of evaluating another person's work and receiving) constructive feedback. *Self-assessments* provide a consistent structure for students to refl evaluate their skill development over time, as well as take responsibility for their own learning. Modul tests require students to apply the skills and knowledge they have acquired in order to solve problem teachers are also encouraged to use portfolios to collect and track students' achievements over time. Ford PAS Curriculum Materials for more information about assessment.)

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Questions about Partners

1. ***What is a Ford PAS partner?***

   A Ford PAS partner is an institution or organization-typically a college or university, community-base school district-that promotes and supports the implementation of the Ford PAS program at several si partner would participate in a Business/Education Advisory Council (BEAC), provide technical suppo coordinated learning experiences (CLEs) for students. CLEs are community-based, real-world experi and expert visits to classrooms, mentoring and job-shadowing experiences, and worksite and campu

2. ***What is the role of the Business/Education Advisory Council?***

   The Business/Education Advisory Council (BEAC) is an integral part of the Ford PAS program and is supportive link between the school program and local businesses, community organizations, and insi education. The BEAC may provide volunteers to enrich classroom experiences, facilitate workplace learning opportunities for Ford PAS students, and help establish other valuable contacts with organiz school. The BEAC may also help with program planning, budgeting, fundraising, and public relations include business and industry representatives, faculty and staff of colleges and universities, commun teachers, school administrators, and students and members of their families. Additional information a establishing and maintaining a BEAC are available in the BEAC Toolkit.

3. ***We already have a group in our school that is like the Business/Education Advisory Council (create a new group?***

   No. If you already have a group representing the different constituencies in your community-business community organizations-you do not need to develop a new one.

4. ***Our school is one of several working with a local university partner. Does each school associ need its own Business/Education Advisory Council (BEAC)?***

   Several schools or other program sites may share a BEAC that is organized with assistance from a p

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Questions about Student Opportunities

1. ***Can students receive college credit for taking Ford PAS courses?***

   Students in a number of schools are receiving two- or four-year college credit for their successful cor courses. (See the list of school/program sites and partners offering college credit.) Each postse its own criteria for offering credit to Ford PAS students. You may contact the Ford PAS Technical As: the articulation agreements that have been established to date.

2. ***Are internships provided for Ford PAS students?***

   Ford Motor Company does not financially support an internship program for Ford PAS high school st Business/Education Advisory Council (BEAC) for a particular Ford PAS program may offer or help to other workplace opportunities for Ford PAS students. Also, as internships relevant to Ford PAS stude they are posted under Scholarship Announcements in the Student Center.

3. ***Are scholarships available for Ford PAS students?***

   A number of scholarships, awarded by organizations supported by Ford Motor Company Fund and o available each year to students who have participated in a Ford PAS program. To qualify for scholars seniors applying to college (or currently in college) and must be registered, or have previously been r PAS Web site. See the Scholarship Announcements in the Student Center for additional information

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Questions about the Ford PAS Web Site

1. ***Why is it necessary to register on the Web site and get a password?***

   It is important to register on the Web site because it will allow you access to information and resource available to you as a teacher. Access is restricted in order to ensure confidentiality and so that some accessed by appropriate users. Your registration also allows the Ford PAS Technical Assistance Grc partners and schools/program sites are doing in order to better serve you, and helps track the numbe downloaded from the Ford PAS Web site for copyright purposes.

2. ***How does a teacher sign up on the Ford PAS Web site? How do I obtain a password?***

   Registration on the Ford PAS Web site is free. As a teacher, go to the green 'Classroom Resources' your school has not already registered as the Ford PAS coordinator, you will need to register as a co school's information. (If someone else is later designated the coordinator for your school, the coordin changed.) If others at your school have already registered, register as a teacher and select your schc down menu.

3. ***How do students, partners, and BEAC members sign up on the Ford PAS Web site?***

   For detailed information about how to register on the Web site, go to Register with Ford PAS.

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Other Questions

1. ***Why did Ford get involved in curriculum development?***

   Ford Motor Company Fund recognizes a critical need to develop a diverse workforce, with strong prc thinking, teamwork, and communication skills, that is academically prepared for careers in mathemat engineering, and technology. Ford PAS builds on the long history of Ford Motor Company involveme began in 1929 with Henry Ford's founding of a high school dedicated to learning by doing, connectin world, and learning in community. The Fund has supported the development of Ford PAS to help hig develop the necessary knowledge and skills and provide them with real-world experiences to enhanc postsecondary education and future careers. The Fund has worked closely with Education Developm an experienced developer of high-quality education programs, to create and support the implementat

2. ***Has Ford PAS been pilot tested and evaluated?***

   Ford PAS modules were reviewed by content experts from universities and businesses and by teach tested with different types of students around the country. Feedback from reviews and pilot testing w materials as they were developed. Currently, an external evaluator is undertaking an evaluation of th program at a number of sites around the country. The goals of the evaluation are to determine (1) the on participants; (2) which aspects of the program and its implementation work well and which do not provide feedback to improve the program; and (3) how the program impacts may vary across studen previously high-achieving vs. low-achieving students or male vs. female students). The Ford PAS Te Group and the evaluation team will ask you for information about your program and your students to evaluation, and will share with you what we learn from the evaluation as it proceeds.

3. ***What is EDC?***

   Education Development Center, Inc. (EDC) is an international, nonprofit organization dedicated to en promoting health, and fostering a deeper understanding of the world. EDC manages more than 300 p and has 650 employees in the U.S. and 500 staff members in other countries around the world. EDC worlds of research, policy, and practice in fields such as early childhood development, K-12 educatio workforce preparation, community development, learning technologies, literacy, institutional reform, a developer of innovative curricula since 1958, EDC has been collaborating with Ford Motor Company years, first to develop the Ford PAS curriculum, and now to offer support for program implementation assistance.

4. ***How is Ford PAS different from Project Lead the Way?***

   Project Lead the Way (PLTW) is the leading national pre-engineering program that focuses on specif relevant to engineering careers. It offers a series of courses that, combined with strong academic pre mathematics and science, qualifies students for college-level engineering study. Educators who are f and Ford PAS agree that Ford PAS is complementary rather than competitive with PLTW. Ford PAS a range of careers, of which engineering is just one, and it focuses on a broader range of skills that a success in postsecondary education and the workplace. Both programs have a strong focus on probl partnerships with higher education and business professionals.

5. ***Where is Ford PAS being used?***

A map of Ford PAS sites and partners shows the extent of the Ford PAS network.

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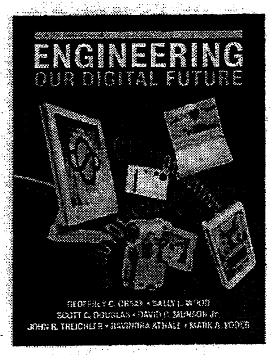
EDC **A project of EDC.** Education Development Center, Inc., works closely with Ford Motor Company Fund to support and deliver the Ford PAS program, providing curriculum development and technical assistance.

THE INFINITY PROJECT

TECHNOLOGY AND ENGINEERING EDUCATION FOR THE NEW CENTURY



ENGINEERING
OUR DIGITAL FUTURE

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Preface

ABOUT THE INFINITY PROJECT

As we move into the 21st century, engineering and technology will have an ever-increasing impact on our daily activities. Yet as our lives have become more and more dependent on technology, public awareness and knowledge about technology-related issues has declined. All of this is compounded by the fact that young students today continue to see little relevance in traditional math and science curricula—sadly suggesting that this unfortunate trend may continue into the foreseeable future, resulting in a reduced ability of our population to deal with society's challenges.

The Infinity Project was created to address just this problem by developing an innovative approach to applying fundamental science and mathematics concepts to solving contemporary engineering problems. This nationwide program, designed by leading college engineering professors in cooperation with education experts, is sponsored and run by the Institute for Engineering Education at SMU, with generous support from Texas Instruments, the National Science Foundation, and the Department of Education.

The Infinity Project engineering and technology curriculum encourages students to be curious about math and science by connecting their relevance to prized personal technologies such as MP3, CD, and DVD players; cellular phones; pagers; and handheld video devices. The perennial question "Why do I need to learn this?" is answered in ways that are both relevant and fun. The Infinity Project curriculum sharpens math- and science-based problem-solving skills, and encourages students to be innovative, to go beyond what is, and to dream of what can be.

The Infinity Project supplies schools and teachers with a complete turnkey solution that includes this first-of-its-kind engineering textbook. *Engineering Our Digital Future* covers a selection of topics and hands-on activities to inspire and excite students. The Infinity Project curriculum encourages young people to learn about engineering, inspires them to understand the relevance of technology and the importance of mathematics and science, and shows how these concepts can lead to rewarding, challenging, and creative career opportunities. And although we emphasize the current leading-edge digital technologies that are important and exciting to today's youth, the approach to problem solving emphasized throughout the book applies to all fields of engineering and many other professions as well.

The Infinity Project provides a complete answer for effectively and easily incorporating engineering and technology into standard curricula today: stimulating, well-thought-out content; comprehensive teacher training; cutting-edge classroom technology; lab materials and lab activities; and an outstanding supplements package. On-line Web support guarantees that you are never alone.

CURRICULUM

The Infinity Project curriculum is typically covered in a yearlong class. Students learn how to apply math and science concepts to design new technologies involving digital music and images, special effects for films, personal communication devices such as cell phones, and the Internet—all while clearly understanding how information in the digital era is collected, stored, processed, and moved around the globe.

The curriculum is significantly enhanced by many hands-on experiments that are carefully integrated with the course materials. The classroom and lab equipment produced by the Infinity Project, in partnership with Texas Instruments and Hyperception, Inc., is based on new cutting-edge digital signal processing technology and has been made available by our industrial partners as the Infinity Technology Kit. This very low cost kit converts standard PCs found in classrooms and laboratories into a modern engineering design platform and allows instructors to clearly demonstrate engineering design in the digital era. The modern design tools that are part of the Infinity Technology Kit allow instructors and students to design and build remarkably capable and complex systems from simple function blocks.

Engineering Our Digital Future is designed for students who have completed mathematics through a second course in algebra (Algebra II) and who have had at least one laboratory science course. This innovative engineering and technology course allows students to see firsthand the applications of math and science to engineering and technology early enough in their studies to encourage them to pursue more advanced math and science courses and to begin to consider future careers in technology and engineering. The book focuses squarely on the math and science fundamentals of engineering during the information revolution and teaches students how engineers create, design, test, and improve the technology around them. Applications are drawn from a wide array of modern devices and systems seen today.

Scope and Focus of Content: Engineering is an exceptionally broad field—so broad, in fact, that no single course or book could adequately capture all the application areas that engineers are working in today. However, what makes *Engineering Our Digital Future* directly relevant to every area of engineering is the application of math and science concepts to the creative aspects of engineering design.

The members of the Infinity Project had to make a number of difficult decisions in choosing which topical areas of engineering to emphasize in this book. Our choice was made all the easier by talking to students and teachers, who stated clearly that they love high technology, particularly those areas that touch students' everyday lives. So, the Infinity Project assembled one of the best teams in the country to create this innovative engineering textbook. The content within the book focuses on the engineering applications of basic math and science concepts used by engineers to dream up, design, and build many of the new high-tech innovations that are changing our world. While we wish we could have shared the full breadth of engineering applications with students, we believe that the material contained in this book shows clearly how engineers, armed with knowledge of math, science, and technology, have the ability to impact nearly every aspect of our lives.

Engineering Our Digital Future is composed of nine separate chapters, each emphasizing different application areas of engineering and each using different areas of math and science commonly seen in high school and early college.

Chapter 1 introduces students to the engineering design process and the basics of modern technology, including integrated circuits, computer chips, and mathematical concepts such as Moore's Law, binary numbers, and simple exponential functions that describe constant growth rates.

Chapter 2 exposes students to some of the most important engineering ideas associated with the creation of digital music. Students learn how basic ideas drawn from the right triangle, such as sines and cosines, are fundamental to making computer music.

Chapter 3 develops the basic concepts behind digital imaging technologies, including capturing and storing digital pictures. Various mathematical concepts are developed, explored, and shown to be interesting and relevant to manipulating these images.

Chapter 4 extends the ideas in Chapter 3 to using digital images and video in several interesting human applications. Additional mathematics are developed wherein images are treated as matrices, and operations to improve image quality or extract information from images are defined in terms of simple matrix operations.

Chapter 5 focuses on the general ideas associated with the digitization of a wide range of information, from text in books and magazines, to speech and music, to images and video. Students learn the details of how all these types of information are captured and stored in digital form. They also learn about the various practical trade-offs when real-world, or "analog", information is converted to numbers and stored with finite precision.

Chapter 6 focuses on some of the more interesting opportunities for coding information when the information is stored on a computer, using only bits. Problems in computer security and encryption as well as redundancy of numbers and data compression are both highly relevant and interesting to students. The basic concepts of detecting and correcting errors in digital data are discussed. This chapter gives students some very interesting applications of simple polynomials and random numbers.

Chapter 7 exposes students to the basic ideas behind wireless and radio communications. Students see firsthand how sines and cosines enable all wireless communications. They learn such important fundamental concepts as bandwidth and data rate.

Chapter 8 gives a very good overview of computer networks and the Internet from both a modern and an historical perspective. Students will be fascinated to learn how similar the Internet is to many other networks, including the U.S. Postal Service and the telegraph system. In this chapter, students have the opportunity to undertake some very interesting mathematical calculations involving simple economic trade-offs in system and network design.

Chapter 9 looks at the big picture of engineering. By examining the engineering concepts and social implications of ten important engineering feats throughout history, this chapter shows how these accomplishments changed they way people live, work, and play. Various fields within engineering are introduced, and certain myths and misconceptions of engineering are discussed and dispelled.

Course Options

A typical course using *Engineering Our Digital Future* begins with Chapter 1 and ends with Chapter 9, with the instructor judiciously selecting a subset of chapters from the book in accordance with the anticipated pace of the class. The well-paced classroom can expect to complete the entire book taken in order. Classrooms with a more conservative pace will want to select an appropriate subset of chapters that will ensure a high-impact course.

In selecting chapters that will be of interest to students, the instructor should consider the mathematical level of the students taking the class. If the students have had a successful experience with mathematics up to a second course in algebra and have had reasonable exposure to the most basic ideas from geometry and trigonometry, then all of the chapters can be selected without any fear of the students not having the appropriate background. In this case, the selection criteria should then be based on the level of student interest in the various chapters. For classes with a high interest in music and video, the educator should focus on Chapters 1–5 and 9. For classes with an interest in cell phones and the Internet, the educator should focus on Chapters 1 and 5–9.

For classes with larger percentages of students with little exposure to trigonometric ideas, some topics in Chapter 2 and in Chapter 7 might come across as a bit challenging. However, the material is relevant and the engineering designs are exciting, so the educator might want to consider covering only the first few sections of these chapters. Similarly, if a large percentage of the class has had little exposure to mathematical abstraction, some parts of Chapters 5 and 6 may be omitted without losing continuity.

For classes that want to sample the entire book, but don't feel that they have the time to thoroughly cover the full scope of the material, teachers should feel comfortable covering the first few sections of each chapter without fear that they are leaving important material out that will be necessary for future chapters. Each chapter is fairly well contained, and important supporting material, if it is needed, is easy to find.

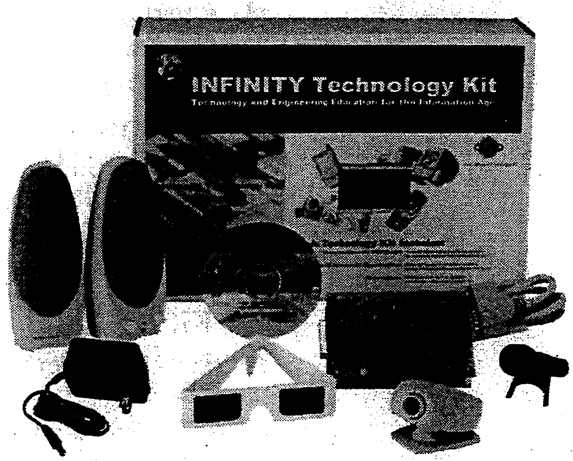
PEDAGOGICAL FEATURES

- Hundreds of four-color illustrations that demystify engineering and technology concepts
- Real-world examples that are actually fun
- Notes and facts in the margins that emphasize important points and interesting facts
  - Definitions
  - Interesting Facts
  - Key Concepts
  - Keep in Mind

- Infinity Project experiments fully integrated within the text that are designed specifically for use with the Infinity Technology Kit
- Infinity Technology Kit—a complete engineering design platform for today's most relevant and interesting new technologies
- Interesting applications presented in boxes within the text
- Exercises divided by pedagogical approach
  - Mastering the Concepts
  - Try This
  - In the Laboratory
  - Back of the Envelope
  - Master Design Problems
- Chapter review and summary
  - Big Ideas
  - Math & Science Concepts Learned
  - Important Equations
  - Building Your Knowledge Library
- Comprehensive glossary

INFINITY TECHNOLOGY KIT

Engineering is about doing things. Therefore, throughout this book, students will have the opportunity to master engineering and technology concepts by building and testing new designs—while using digital technologies, including video, audio, and graphics, that are engaging for students and teachers. To aid in the classroom or laboratory, the team behind the Infinity Project has created the cutting-edge Infinity Technology Kit, a multimedia hardware and software system for converting standard PCs into engineering design environments. The Infinity Technology Kit brings to life the engineering concepts taught in The Infinity Project engineering curriculum. The predesigned lab experiments and engineering designs allow students to experience firsthand the full range of the engineering design process of envisioning, designing, building, and testing modern technology.



The technology used within the Infinity Technology Kit is based upon Texas Instruments' Digital Signal Processor (DSP) chips and a new and innovative graphical programming environment called Visual Application Builder, designed and developed by one of the Infinity Project partners, Hyperception, Inc. With the Infinity Technology Kit, students with limited experience can act like real engineers—creating innovations that are relevant and exciting. No previous experience with any programming languages is required.

Components:

Hardware: High-performance digital signal processing board based on TI DSP technology.

Software: Easy-to-use, yet powerful, graphical computer programming software created and produced by Hyperception, Inc.

Accessories include Web camera, PC powered speakers, PC microphone, and all the necessary cables for easy installation

SUPPLEMENTS

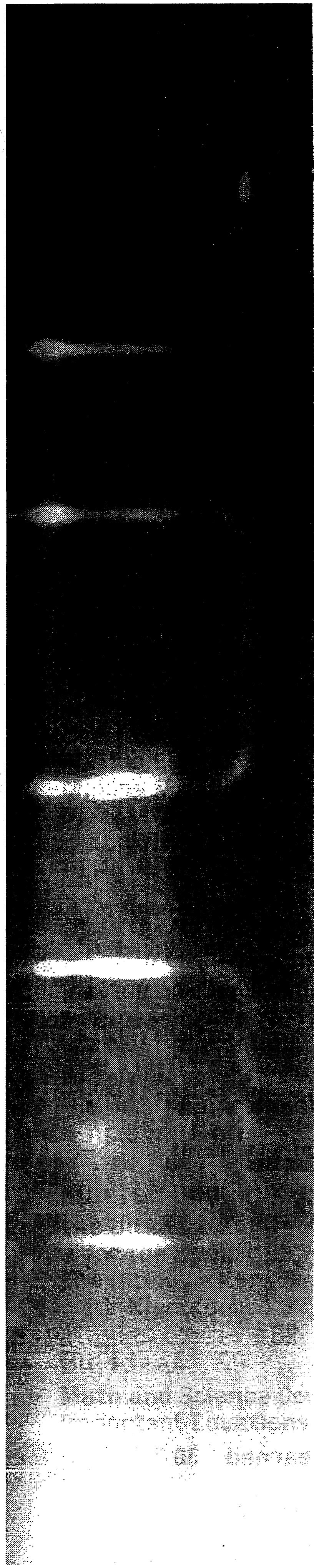
The Infinity Project supplements offer comprehensive additional resources and classroom support:

- Instructor's manual containing
  - Microsoft PowerPoint lecture notes
  - Lab exercise handouts
  - Extensive test-item file with complete solutions
- Laboratory manual

WEBSITE

The Infinity Project website, at http://www.infinity-project.org, provides ongoing classroom support and resources:

- Curriculum updates, including additional on-line chapters related to new and exciting topics such as robotics and the physics of engineering
- Infinity Project engineering experiments and updates
- Discussion groups for teachers and educators, monitored and supported by the staff of the Infinity Project
- Training materials
- Installation instructions and support for the Infinity Technology Kit
- Links to interesting and related websites



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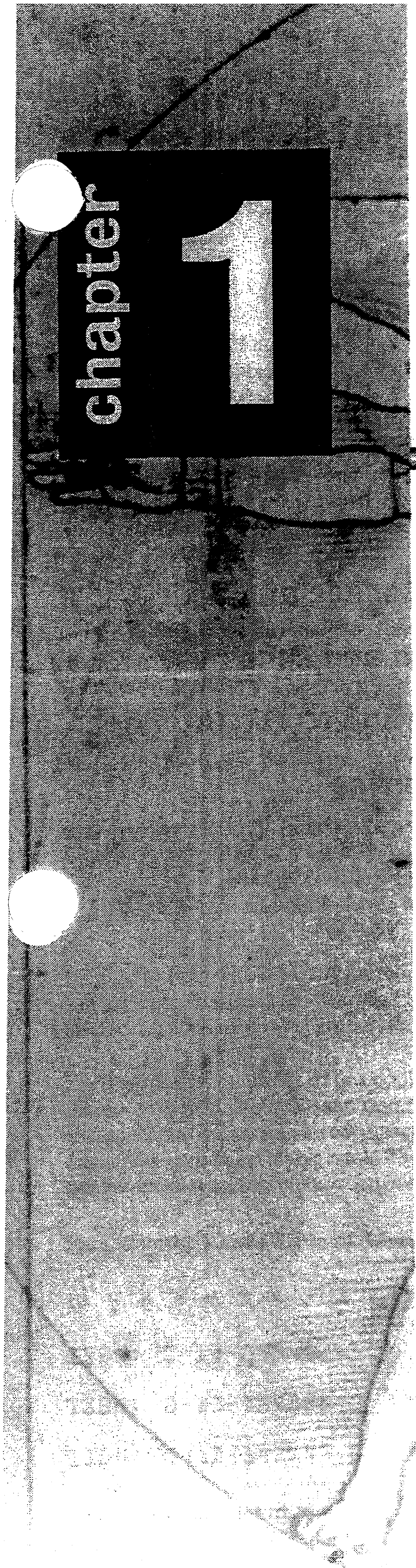

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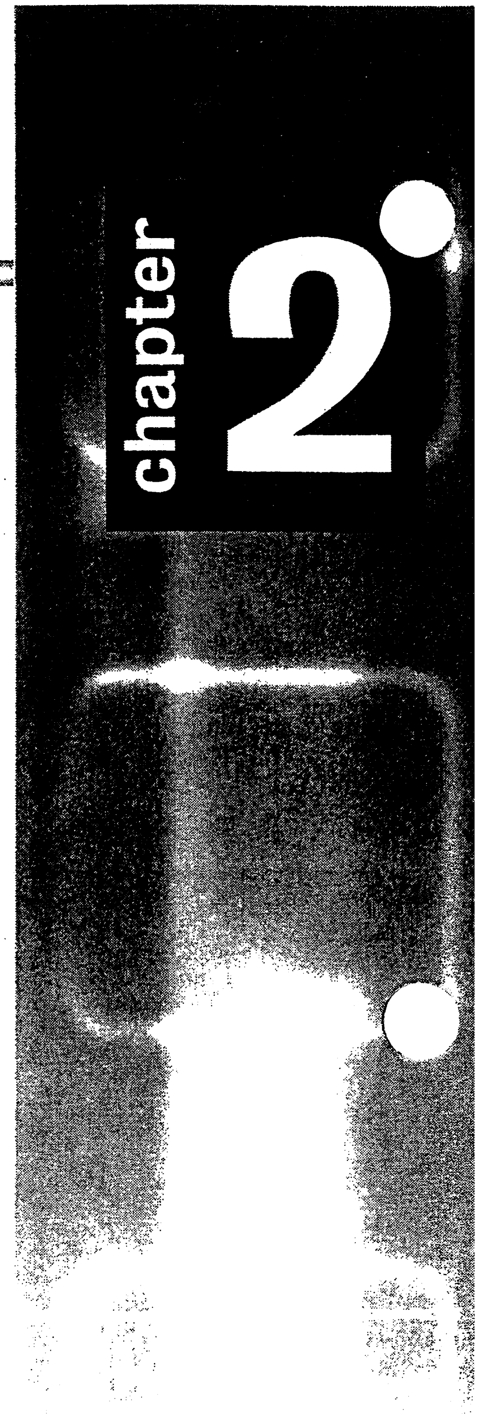

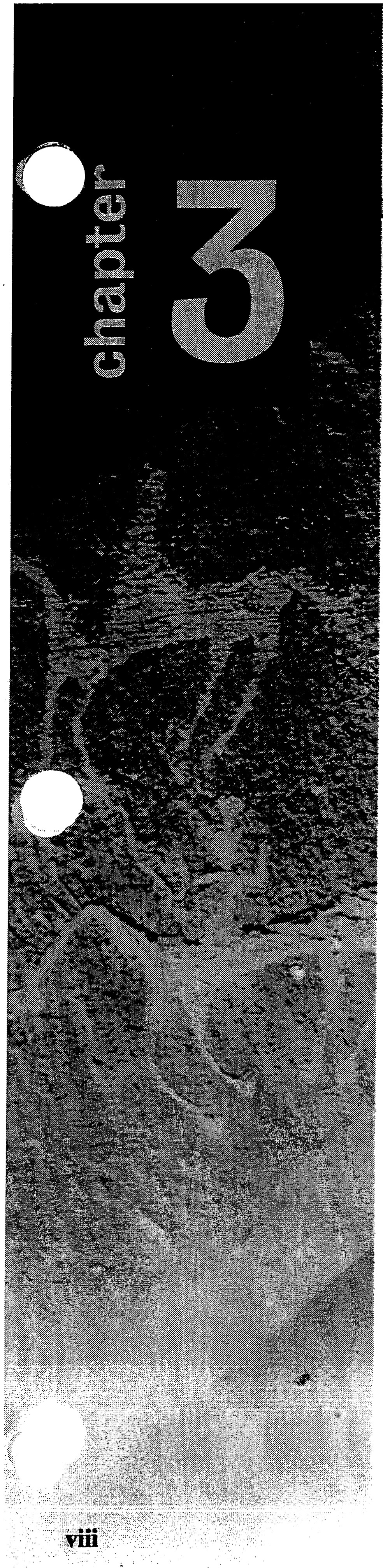

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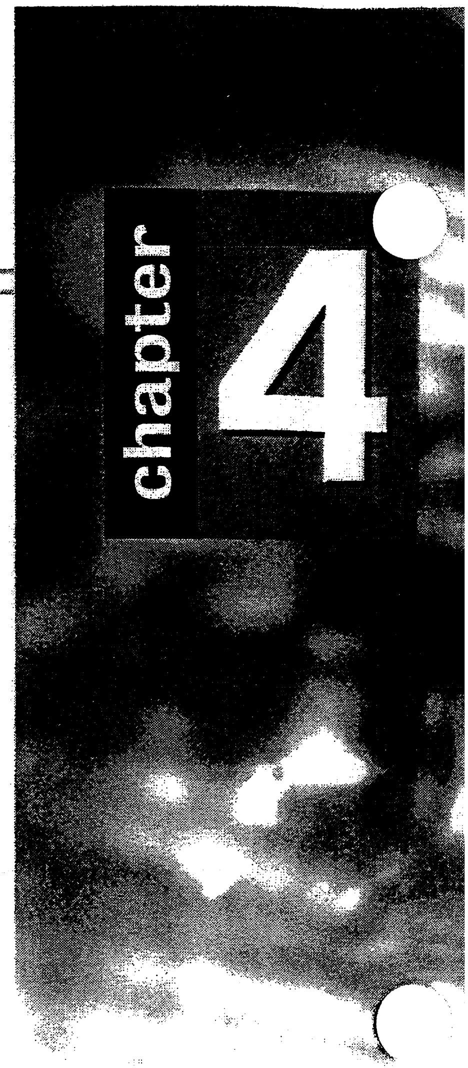

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The World of Modern Engineering

chapter 1

Where did all this great "stuff" come from? Who designed and created the TV you watch, the car you ride in, the computer you use to surf the Internet, and your cell phone? Nearly everything you touch had to be thought of, designed, and built (Figure 1.1). Who did all of this? And how did they do it?

The answer is simple: *Engineers, armed with their ingenuity.*

It might come as a surprise to learn that engineers, as a group, are some of the most creative and inventive people working today. Society calls upon engineers not only to envision what the world will look like tomorrow, but, more importantly, to make "tomorrow" happen.

Can you imagine what your life would be like if engineers hadn't designed and built TVs,

OUTLINE

- **What Exactly Do Scientists and Engineers Do?**
- **Birth of the Digital Age**
- **Moore's Law**
- **Block Diagram—Organizing Engineering Designs**
- **Summary**

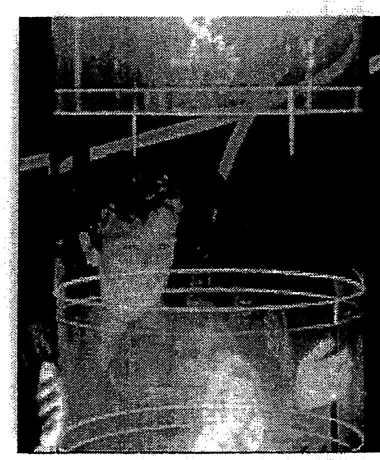

Figure 1.1 People use all sorts of technology to enhance their lives.

radios, recording studios, stereos, and automobiles? What would your life be like if you couldn't call or e-mail your friends at night, or if there were no radios, CDs, or DVDs to entertain you? What if there were no X rays and CAT scans to help doctors diagnose injuries and illnesses? What if the only way for you to get to school were to walk or ride a horse?

We often take today's great creations for granted, again thanks to engineers. What new high-tech health treatment, communications device, digital entertainment experience, transportation vehicle, or manufacturing method will we all take for granted in the coming years? Computers that talk to us or even "think" for us? Cars that drive themselves? Engineers are already working on these devices today!

INTERESTING FACT:
The word "engineer" stems from the French word *ingénieur*, which means "ingenuity." Contrary to popular belief, its root is not the English word "engine."

1.1 What Exactly Do Scientists and Engineers Do?

Making Dreams a Reality

Let's go back in time to the 1950s, before humans ever ventured into space. Back then, there were science fiction movies that suggested what life could be like in space, what our spaceships might look like, what the surfaces of planets might look like, and even what aliens might look like. Yet, until the 1960s, these images were all largely figments of Hollywood's imagination.

However, on May 25, 1961, then-president John F. Kennedy proclaimed that the United States would put a person on the Moon "in this decade." Who did he think was actually going to make this dream a reality? Politicians? Bankers? Lawyers? No, he knew it was going to be engineers and scientists.

Did engineers and scientists know how they were going to achieve this remarkable goal at the time of President Kennedy's speech? No, but they had confidence that, by working together, breaking the problem of space travel into manageable pieces, solving these smaller individual problems, putting all the components together, and then testing the final solution, they would have a very good shot at placing a human on the Moon before 1970.

Well, the engineers and scientists were right. Through their hard work and with the help of many, on July 20, 1969, the Apollo 11 mission placed Neil Armstrong and Buzz Aldrin on the surface of the Moon (Figure 1.2), culminating all their efforts into one of the greatest achievements in all of human history and registering a triumph for engineering and science.

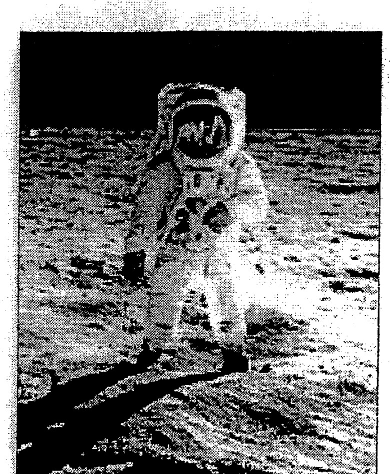

Figure 1.2 Photo of Buzz Aldrin on the surface of the Moon, taken by Neil Armstrong, July 20, 1969.

What Makes Engineers Different from Scientists?

What makes engineers unique? And how are engineers different from scientists and mathematicians? You have had years of experience taking math and science courses. These classes have helped you understand and describe the world around you. As you have probably already learned from these courses, the primary purpose of science and math is to help humans *understand and describe* their world: How do cells divide? What makes objects fall to the ground? What are the basic building blocks of life? What is the distance between the Earth and the Moon?

To answer these questions, scientists throughout history have followed the **scientific method**. This five-step process, or **algorithm**, is the basic roadmap for discovery and understanding. Scientists who have sought to answer the fundamental questions about our world have used the scientific method as their guidepost. The five steps are as follows:

Scientific Method: The five-step process by which scientists explain natural phenomena.

Algorithm: A step-by-step process to achieve a goal.

1. Observe some aspect of the universe.
2. Invent a tentative description (hypothesis) consistent with what you have observed.
3. Use the hypothesis to make predictions.
4. Test those predictions by experiments or further observations, and modify the hypothesis in light of your results.
5. Repeat Steps 3 and 4 until there are no discrepancies between theory and experiment and/or observation.

While scientists seek to explain how the world works, engineers attempt to create new objects and devices that are important to humans and society, such as cutting-edge medical devices, innovative video games, safer cars, and high-tech communication devices. While scientists rely on the scientific method for discovery, engineers rely upon the **engineering design algorithm** to create nearly every object around you. The engineering design algorithm includes the following nine steps:

Engineering Design Algorithm: A nine-step process followed by engineers to create new objects or systems.

1. Identify the problem or design objective.
2. Define the goals and identify the **constraints**.
3. Research and gather information.
4. Create potential design solutions.
5. Analyze the viability of solutions.
6. Choose the most appropriate solution.
7. Build or implement the design.
8. Test and evaluate the design.
9. Repeat ALL steps as necessary.

Constraints: Limits that are placed on the design problem. For example, a constraint might be that the final design should not cost more than $X or weigh more than Y pounds.

As indicated by Step 1 of this list, the engineer must first answer the fundamental question: *What do I want to create today?* Very few professions place such a high premium on the creative spirit of the individual.

EXAMPLE 1.1 Designing the Cell Phone of Today

As a way of understanding the engineering design algorithm, let's apply it to a piece of existing technology—the cell phone—as if we were the engineers about to begin its design process.

Step 1: *Identify the design objective.* We want to build something that will allow humans to communicate with one another between any two locations on the globe at any time.

Step 2: *Define goals and constraints.* Some of the design goals and constraints for this device include the following:

- *Movement:* The device should not be connected physically to anything else that would limit our movement when using it. For example, it shouldn't need to be plugged into a wall outlet or a network jack.
- *Size:* The device should be small and portable so that we can carry it in our hand, a pocket, a bag, or backpack.
- *Form:* It should be large enough to be easy to hold in our hand, since devices that are too small are hard to grip. It should also provide a way for us to talk into it and for us to hear the caller at the other end of the call.
- *Energy use:* It shouldn't require too much energy in its operation, or else we'll need to change or recharge its energy source too often.
- *Cost:* It should be inexpensive enough so that people will buy it.

Step 3: *Research and gather information.* Has anyone ever done something like this before? Wireless radio telephones were being researched by the American Telephone and Telegraph Company in the 1930s, but these systems were more like modern family radio systems and "walkie-talkies" than cell phones. The Citizen Band (CB) radio craze of the 1970s brought point-to-point, two-way radio communications to large numbers of automobile travelers. But neither system reaches around the globe, and neither can be used easily to contact a wide variety of individuals. It wasn't until the 1990s that a system such as the one described in Step 1 was put into widespread use.

Steps 4 to 8: *Create, analyze, choose, build, and test.* We are all fortunate that engineers at international companies such as AT&T's Bell Telephone Laboratories, Nokia, Ericsson, Qualcomm, and Motorola completed these steps and designed, built, and tested a wide variety of cell phones that meet the design goals and constraints.

Solution

How well do you think current cell phones meet the objectives specified in Step 1 and satisfy the constraints given in Step 2? Are you pleased with current cell phone technology? Would you change anything about the goals or constraints?

EXERCISES 1.1

Mastering the Concepts

1. Identify five items designed by engineers. What did these items do that was new and innovative at the time of their creation? What items did these new creations replace? How is the world a better place because of these designs?
2. Identify five items that you suspect were not designed by engineers. How do they differ from those designed by engineers?
3. Apply the engineering design algorithm to the following processes:
   a. Making the family dinner
   b. Creating new laws
   c. Treating illness in a patient
   Be specific about each step in the design algorithm.
4. Determine the likely constraints applied by the engineer in designing these items:
   a. Cash register
   b. Bicycle
   c. Office lamp
   d. Sneakers
   e. Calculator

Back of the Envelope

5. Select a device designed by an engineer. Discuss each step of the engineering design algorithm, and describe the likely path taken by engineers in creating the device.
6. Evaluate the effectiveness of the following engineering designs:
   a. Conventional telephone
   b. Medical CAT scan
   c. Desktop computer
   d. Cell phone
   e. MP3 player
   f. PDA
   Make sure to describe the strengths and weaknesses of the designs. Try to guess what capabilities these technologies will have in the future as engineers continue to improve the current designs.

1.2 Birth of the Digital Age

Before Digital There Was Analog

To understand where engineers will be taking our world in the future, it is important that we briefly look back. Up until the middle of the 20th century, the technology designed by engineers was primarily **analog**; more specifically, the devices and systems that engineers created relied primarily upon physical forces and matter for their basic operation rather than some abstract quantity, such as numbers.

Analog: Phenomena that are characterized by fluctuating, evolving, or continually changing physical quantities, such as force or mass.

For example, analog audio records introduced in the first part of the 20th century use the physical bumps and indentations in the grooves on vinyl discs (albums) to store audio data. The stylus at the end of the tone arm of a turntable rides in these grooves and vibrates nearly identically to the original sound waves of the audio. This mechanical motion is then converted to an identical electrical version of the audio that is subsequently amplified and played through speakers. The entire process of re-creating audio from bumps and indentations is purely physical. Never is the sound waveform converted to numbers to be stored or manipulated; in other words, the system is analog.

Analog systems like turntables and albums are quite functional. However, like all designs, they suffer from a number of shortcomings:

- Analog systems can be large.
- Analog systems can consume lots of energy.
- Analog systems are not easily modified to solve new or different tasks.
- Analog systems are prone to breakdowns due to their physical operation.

Building Blocks for Analog Designs

Vacuum Tube: An early technology that was used in nearly every piece of electronics. Today, it is rare to find vacuum tubes other than in very high-end audio systems, guitar amps, and radar devices.

Early electronic technology was built using an important analog device called a **vacuum tube.** Figure 1.3 shows a vacuum tube. Such tubes were used to control the electrical current and voltage in systems such as radios, radar, and very early computers. Unfortunately, like lightbulbs, these vacuum tubes got very hot, and burned out regularly. Your older family members might remember how often TVs used to break down due to vacuum tubes burning out.

The Mathematics and Engineering That Gave Birth to the Digital Age

During the middle of the 20th century, mathematicians and engineers discovered a process for converting most physical quantities found in the world (such as sound waves, light intensity, forces, voltage, current, or charge) to *numbers or digits.* This discovery should not be surprising, since scientists had been using mathematics to describe the physical world for centuries. This remarkable, yet simple, discovery was the mathematical foundation that gave birth to the **digital age.**

Digital Age: The era born with the creation of the transistor. The digital age is generally thought to have reached full maturity at the time that computers gained widespread use, during the mid-1980s.

Digital: Describing technology or phenomena that are characterized by numbers.

Figure 1.3 A vacuum tube next to an early transistor in the palm of a hand.

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There are many advantages to "digitizing" analog quantities. For example:

1. Numbers are much less sensitive to physical problems caused by the physical nature of the device used to store or manipulate them.
2. Numbers are easier to store than an equivalent physical "amount" of something.
3. Numbers can be moved through space, using electronic, optical, or acoustic means.

To illustrate these advantages, let's revisit the re-creation of audio systems as discussed earlier in this section. Unlike analog systems, today the sounds of most audio are converted to numbers at the recording studio and stored on a compact disc (CD) or DVD. A CD player simply reads the numbers from the CD and then converts these numbers back to the original audio. We will learn about the details of this process in Chapter 5, *Digitizing The World*. If you have ever compared the quality of audio between an average turntable and an average CD player, you should have little doubt that digital technology is significantly better than the earlier analog technology. Also, can you imagine trying to jog or walk with a turntable strapped to your waist or inside your backpack? Table 1.1 lists some analog devices and the corresponding digital devices. Which do you prefer to use?

Still a Long Way To Go

Unfortunately, there was a major problem in building new digital devices when they were first conceived. Engineers just didn't have the right parts to build new digital systems. Not to be deterred, engineers working during the first half of the 20th century tried the smart and reasonable thing: They attempted to use readily available vacuum tubes as basic digital building blocks. Following this approach, in 1945, engineers successfully produced the first digital computer, called the ENIAC. It was built out of more than 17,000 vacuum tubes, weighed 30 tons, and filled a 30-by-50-foot room, as seen in Figure 1.4. Just think of the heat produced by 17,000 lightbulbs all burning in the same room!

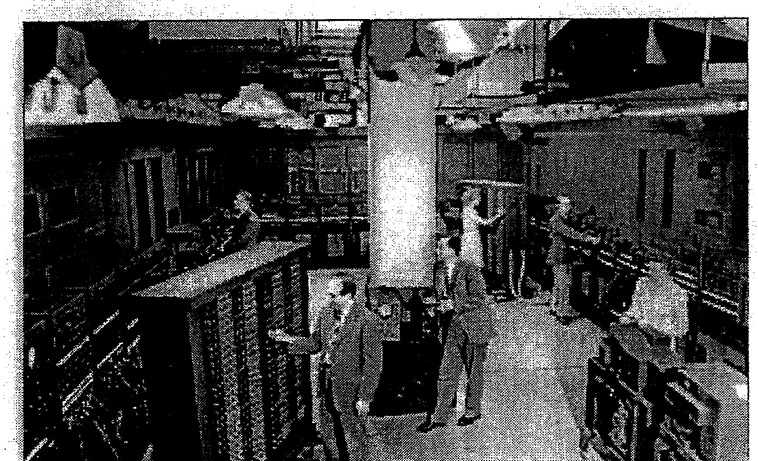


Figure 1.4 The ENIAC computer.

INTERESTING FACT:

You should not be surprised to learn that the first computer programmers were actually women. Early pioneers, like Grace Hopper, Kay McNulty, Betty Snyder, Marilyn Wescoff, Betty Jean Jennings, Ruth Lichterman, and Frances Bilas, programmed the ENIAC to calculate trajectories of missiles during World War II. Previously, a single trajectory's calculations took 20 to 40 person-hours.

Table 1.1 Analog versus Digital Devices

Analog Devices	Digital Devices
LPs	CDs
Film cameras	Digital cameras
Dial watches	Digital watches
Standard TV	HDTV
VHS camcorders	Digital camcorders

INTERESTING FACT:
The ENIAC, short for Electronic Numerical Integrator and Computer, was capable of multiplying 5000 numbers every second. Compare this rate with that of today's computers, which can execute billions of mathematical operations every second and can fit into your backpack.

While primitive by today's standards, the ENIAC was a major advance in engineering and technology. Never before in human history could we do math so fast and so accurately. While the ENIAC opened up new digital horizons for society, these first computers were so large and so expensive that only governments and the largest of companies could ever hope to own or even use one.

The Transistor Replaced the Vacuum Tube

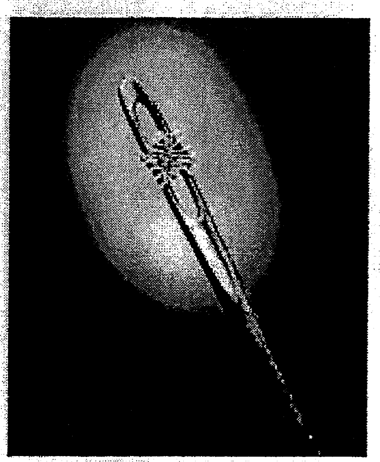
Transistor: A switch that regulates the voltage or current flow through electrical circuits. It is the basic building block for all digital electronic technology.

What the digital age needed was a truly digital component that could replace the vacuum tube. It would have to run fast, use much less power than the vacuum tube, and, most importantly, be small and inexpensive. Fortunately, in 1947 engineers at AT&T's Bell Laboratories developed that component, called the **transistor** (Figure 1.5). Its creation changed the world forever. Bill Shockley, Walter Brattain, and John Bardeen won the Nobel Prize in 1956 for their joint discovery and development of the transistor, which, within a few decades, had completely replaced the vacuum tube in nearly every piece of technology.

Now, engineers could unleash their imaginations to create smaller, portable devices that could run on the relatively small amounts of energy contained in batteries and were rugged in normal use. For this reason, many people believe that the transistor is the most important invention of the 20th century. Just look around you today to see the nearly infinite array of small gadgets and pieces of technology built from transistors.

The Integrated Circuit (IC)

Integrated Circuit: A single computer chip that is built from many different components. Typically, nearly all of the individual components on an IC are transistors.



As engineers designed devices for more complex tasks, such as in robotics or medicine, the resulting systems required ever more transistors. This push for more transistors made the devices large and hard to wire together. The next critical step forward into the digital age was the ability to put many transistors onto a single small part that could be used for these increasingly complex tasks. Jack Kilby accomplished this remarkable feat in 1958 at Texas Instruments when he invented the **integrated circuit**, or IC,

Figure 1.5 (a) The first transistor. (b) A vacuum tube, a modern transistor, and an integrated circuit.

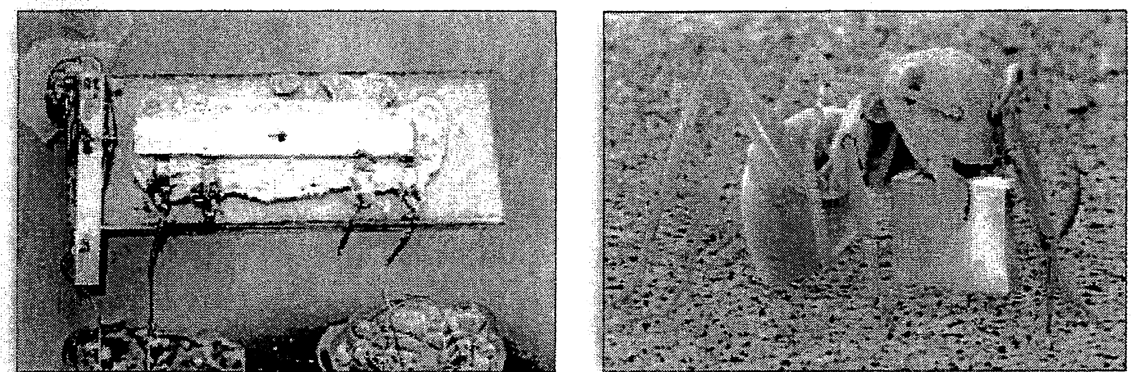


Figure 1.6 (a) The first integrated circuit produced by Jack Kilby. (b) A modern integrated circuit.

shown in Figure 1.6(a). For this discovery, Kilby was awarded the 2000 Nobel Prize in physics. This groundbreaking invention was coined the "integrated circuit" because it cleverly integrated many parts, typically transistors, into a single small package like that shown in Figure 1.6(b).

With the invention of the IC, engineers were able to undertake more complicated designs, because they now had modern digital parts that could do significantly more complicated math on the newly digitized version of the real analog world. Interestingly, the integrated circuit has become so pervasive in devices from computers to anti-lock brakes that it is difficult to find individual transistors in modern technology today—they are now all part of integrated circuits.

KEY CONCEPT

What do transistors actually do? Transistors behave just like electronic doors in digital circuits. They are either open or closed; they either allow current to pass through or prevent it from doing so. So from a mathematical perspective, we can assign the number 1 to the state when the transistor is open (current doesn't flow) and the number 0 to the state when the transistor is closed (current does flow).

Why are Bits So Important?

Modern engineers and computer scientists always seem to be making reference to **bits**. What are they, and why are they so important? As we discussed previously, technology and engineering are steadily moving away from an analog world into a digital world. The advantage to doing this is that engineers can create devices that are smaller, faster, more reliable, and more powerful than their predecessors. The basis behind this shift from analog to digital is the engineer's ability to convert the physical or real world into numbers—the same process used to convert audio into numbers and then store it on a CD or DVD. No matter how complex, these numbers are all stored on computers, calculators, or any other digital technology by using bits instead of digits.

Bits: "Bit" is short for ***bi****nary digi****t***. A bit takes only the value of 0 or 1.

Base-10 Arithmetic Nearly all numbers that are used in society today are expressed in the base-10 system of numbers—the traditional number system adopted by Western society. This number system uses powers of 10 and the digits 0, 1, 2, . . . , 9 to express all numeric quantities. For example, the number 361 really means the following:

3×10^2, or three 100s

6×10^1, or six 10s

1×10^0, or one 1s

INTERESTING FACT:

A typical human hair is 50 to 100 micrometers (microns) in diameter. While this may seem small, it is quite large when compared with the size of modern transistors. Today, transistors on computer chips are much smaller than a millionth of meter (micron) on a side.

If we add up these powers of 10 appropriately multiplied by 3, 6, and 1, we get $(3 \times 100) + (6 \times 10) + (1 \times 1) = 361$. So the number 361 in base-10 is really shorthand for three 100s, plus six 10s, plus one 1.

This choice of base-10 for our number system was completely arbitrary and likely driven by the fact that humans have 10 fingers, or digits. To understand why early mathematicians chose base 10, try this simple experiment: Pick a three-digit number like 361 and attempt to describe this number to a friend using only your hands, and without talking or writing anything down. You will discover that it is hard to efficiently convey the number without understanding base-10 numbers.

Now, if humans had evolved with only one finger on each hand, they would have likely chosen base 2 for their everyday number system. In this case, we would have used only the numbers 0 and 1 when expressing quantities, rather than the familiar $0, 1, 2, 3, \ldots, 9$.

Transistors, the building blocks of the digital age, have only two states in digital circuits: on and off. So, it made perfect sense to the earliest digital engineers to choose the base-2 number system for digital technology, rather than the base-10 system. These "binary digits" were coined "bits," and the concept of a bit was born. Eight consecutive bits equal one **byte**.

Byte: Another very common computer term, a byte is eight consecutive bits, such as 10010011.

Now, this doesn't mean that you and I need to switch from the familiar base-10 system to the base-2 system. Computers and other digital systems today automatically convert digits to bits and back again. Think about your calculator: You type in digits because you are familiar with them. These digits are converted to bits, or base-2 numbers, and then the appropriate **binary**, or base-2, mathematical function is applied to these bits in accordance with your wishes, such as addition, subtraction, or taking the square root. The base-2 result stored within the calculator is then converted back to base-10 digits and displayed for your convenience.

Binary: A term referring to a quantity that takes on one of two different values.

It is not difficult to change a number from one base to another. In fact, many modern calculators can do it automatically for you with just a click of a few buttons. However, to be a modern digital engineer, it is critical that you understand how to do this simple mathematical operation by hand. Chapter 5 of this book has a thorough treatment of simple binary mathematics, but we can give you a preview here so that you can understand the basics of **binary numbers**.

Binary Numbers: Mathematical representation of numbers using the base-2 system of numbers rather than the familiar base-10 system.

You will remember that the quantity "361" in base 10 means that there are three 10^2's, or hundreds, six 10^1's, or tens, and one 10^0's, or ones. Well, in the base-2 number system, we follow the same process, but express the binary number in terms of 2^N, such as $8(2^3)$, $4(2^2)$, $2(2^1)$, and $1(2^0)$, rather than 10^N, such as $1000(10^3)$, $100(10^2)$, $10(10^1)$, and $1(10^0)$.

EXAMPLE 1.2 Converting a Base-2 Number to a Base-10 Number

What is the binary number 1110 in base 10?

KEY CONCEPT

Bits are the numbers of the digital age.

Solution

To determine the base-10 value of 1110, we need to scale the appropriate powers of 2 by the values 1, 1, 1, and 0:

1×2^3, or one 8;
1×2^2, or one 4;
1×2^1, or one 2;
0×2^0, or zero 1.

Summing these results together, we get

$$(1 \times 2^3) + (1 \times 2^2) + (1 \times 2^1) + (0 \times 2^0) = (1 \times 8) + (1 \times 4) + (1 \times 2) + (0 \times 1) = 14$$

This simple process can be reversed to convert base-10 numbers into binary numbers. To demonstrate this, let's consider the following examples:

EXAMPLE 1.3 Representing a Decimal Number in Binary Form

Represent the decimal number 361 in binary form, or base 2.

Solution

You can try it yourself, starting with $N = 8$. See if you can demonstrate that

$$361 \text{ (base 10)} = 101101001 \text{ (base 2)}$$

And, with just a little bit of arithmetic, it is easy to show that

$$(1 \times 256) + (0 \times 128) + (1 \times 64) + (1 \times 32) + (0 \times 16) + (1 \times 8) + (0 \times 4) + (0 \times 2) + (1 \times 1) = 361$$

The process of converting base-10 numbers to binary numbers can seem a little tedious, but it is easy if you follow the rules.

EXAMPLE 1.4 Converting a Base-10 Number to a Base-2 Number

What is the base-2 version of the number 5?

Solution

We need to write the number 5 as a sum of powers of 2, such as 8, 4, 2, and 1, to determine the number of each that add up to 5. It is very easy to do once you understand the approach.

Step 1: If we start with $N = 3$, then we first need to determine the whole number of 2^3, or eights, in 5. Since there is not a whole 8 in 5, the answer is 0, giving us the largest (or most significant bit) as a 0.

Step 2: Proceeding to $N = 2$, we determine the whole number of 2^2, or fours, in 5. The answer is 1, with a remainder of 1.

Step 3: Carrying the remainder forward, we now let $N = 1$ and determine the whole number of 2^1, or twos, in the number 1, which, of course, is 0 with a remainder of 1.

Step 4: The final step is to let $N = 0$ and therefore determine the whole number of 2^0, or ones, in the final remainder of 1, which is 1.

Step 5: So, putting it all together, starting with the most significant bit on the left, the number 5 is 0101 in base 2. As an important style note, if the leftmost bit value (the most significant bit) is a zero, we typically drop it in order to conserve space when we write the number down on paper. We do the same thing with base-10 numbers; for example, we don't write 54 as 054. Thus, the bit representation most commonly used for the number 5 is 101—one four, plus zero twos, plus one one.

EXERCISES 1.2

Mastering the Concepts

1. Why is modern technology based on binary mathematics?
2. State three differences between vacuum tubes and transistors.
3. Why was Jack Kilby's creation so important to the advancement of technology?

Try This

4. Write the following binary numbers in base-10 form:
   a. 111
   b. 01001
   c. 10010001
   d. 100100100
5. Write the following base-10 numbers in binary form, or base 2:
   a. 6
   b. 27
   c. 42
   d. 18
   e. 167

Back of the Envelope

6. Determine whether the following designs are digital or analog:
   a. Car speedometer
   b. Car radio
   c. TV
   d. VCR
7. Identify five modern systems that are completely analog. Do you think these systems will stay analog or be converted to digital systems?

1.3 Moore's Law

Predicting the Future

A recent newspaper headline reads as follows: "Engineers predict that in 10 years computers will be able to talk to us." How do they know this? What is the basis for their predictions?

Well, we are fortunate that history has shown that technological evolution often follows a fairly predictable path. Engineers routinely take advantage of this condition when determining if and when to design and build some new piece of fantastic technology.

Moore's Law and the Future Growth of Technology

Is there a systematic way to predict the future growth of technology? Well, in 1965, Gordon Moore, co-founder of Fairchild and the Intel Corporation, made a startling observation. Moore looked back in time and noticed that every two years, the number of transistors on his company's integrated circuits had doubled. This meant that his company's ICs were roughly twice as powerful or twice as fast as they had been two years earlier. And, as it turned out, this remarkable observation was true for nearly every computer chip manufacturer's products, irrespective of whether, the IC was a microprocessor or digital signal processor (DSP). This insightful observation has since been known as **Moore's law** and is used as one of the strongest principles for predicting the future of technology.

Moore's Law: The number of transistors on an IC will double every two years. Equivalently stated, the computing power of ICs doubles every two years.

What was particularly bold about this prediction was that Moore said that the doubling of speed, computing power, or number of transistors on digital ICs would continue indefinitely and, as such, computers would continue to get faster and faster. To fully understand the remarkable implication of Moore's law, we need first to understand the power of doubling, which is at the heart of his observation.

INTERESTING FACT:

Gordon Moore stated Moore's law when there were fewer than 100 transistors on an integrated circuit. Today, there are many millions of transistors on an integrated computer chip!

The Power of Doubling

Have you ever heard someone say "double or nothing" when gambling? If you have watched someone bet like this, then you no doubt noticed that the gambler either wins or loses a lot of money very fast. Doubling gets you to large numbers quite quickly. This observation can be quantified by developing some simple mathematical relationships that describe the power of doubling.

Assume that you begin with $\$X$, where X is any number you choose. If you double it, you will have $\$2X$. If you double it again, you will have $\$(2 \times 2)X$, or $\$2^2X$. Doubling once more gives you $\$(2 \times 2 \times 2)X$, or $\$2^3X$. From this set of results, it follows that if you double $\$X$, exactly N times, you will have $\$2^NX$.

To make this example more concrete, let's assume that we start with \$1, or $X = \$1$. If N were 5, that is, we double \$1 five times, we would have $\$2^5 = \$32$. If N were 10, that is, we double \$1 ten times, we would have $\$2^{10} = \$1024$. If N were 50, we would have $\$2^{50} = \$1.125 \times 10^{15}$. That is more than \$1 quadrillion. Wow!

INTERESTING FACT:

Periodically, people predict the death of Moore's law. They state that Moore's law eventually will end because of some future technological or scientific barrier. However, to date, engineers and scientists have found a way around these problems, and Moore's law continues to be an accurate means of predicting the future development of technology.

Doubling just 50 times turns $1 into a staggering amount of money. So, the "power of doubling" takes small numbers (e.g., corresponding to dollars or numbers of transistors on an IC) and turns them into absolutely gigantic numbers very fast.

We can plot the value of $1 doubled N times for increasing values of N to see firsthand how fast money or the number of transistors grows through the power of doubling. In Figure 1.7, we have plotted the value of $1 doubled N times against increasing values of N, using two different types of plots: One is the standard linear scale plot that simply plots the value 2^N versus N, and the other is a semilog plot that plots 2^N on a logarithmic scale versus N. Both plots show the exact same data, but depict them in slightly different ways.

You will notice in Figure 1.7 that the semilog version of this plot shows that the increase in monetary value appears to be linear (following a straight line). Be aware that, while the graph is in fact a straight line, the data read from this graph do not grow linearly; on this plot, the y-axis is actually on a logarithmic scale.

To gain some practice reading the plots, see if you can confirm that at $N = 2$, the y value on both plots is 4, and at $N = 7$ the y value is $2^7 = 128$. The semilog version of the graph demonstrates an important fact: Quantities that grow by doubling over time always appear as straight lines on a semilog plot (plots with the y-axis on a logarithmic scale) with the slope of the line being controlled by the rate of doubling; the more frequent the doubling, the larger is the slope. So, if you see a straight line on a semilog plot, you immediately know that the quantity being plotted is actually doubling at some regular rate that you can measure.

What does the power of doubling tell us about Moore's law and its impact on digital engineering or computer technology? No matter how

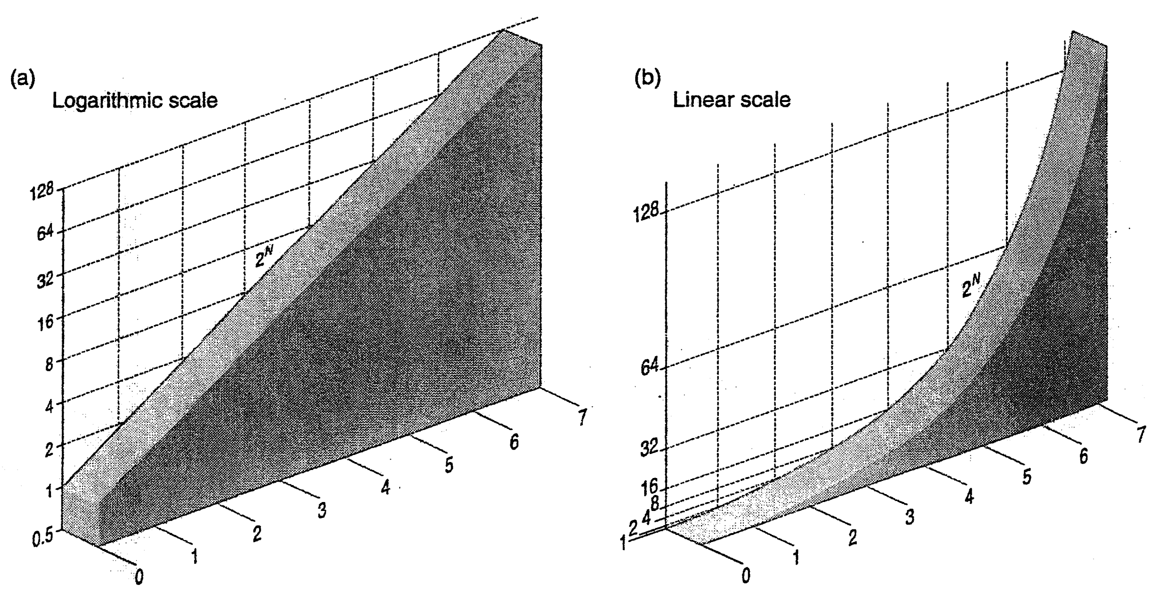


Figure 1.7 Plots of 2^N versus N for increasing values of N on (a) a logarithmic scale, and (b) a linear scale.

limited computer chips were when they were first introduced in the early 1960s, by doubling their computing power every two years in accordance with Moore's Law, we arrive at staggering amounts of digital power that will enable engineers to design systems that can do almost anything. If it can be dreamt of, Moore's' law tells us that we can build it at some predictable time in the near future.

The Mathematics of Moore's Law

Now that we have a good understanding of the power of doubling, we can translate Moore's law into simple mathematics to solve some of our own technological prediction problems. Let's say that in the year Y_1, there happen to be exactly N_1 transistors on a computer company's chip. Then, following Moore's law, two years later, or in year $Y_1 + 2$, there should be $2N_1$ transistors on the next version of the chip. We can generalize this relationship to determine the number of transistors on an IC in a later year Y_2, given that we know the number of transistors in year Y_1.

First, let's calculate the number of "doubles" that will occur between years Y_1 and Y_2:

$$\text{Number of doubles} = \frac{Y_2 - Y_1}{2} \tag{1.1}$$

For example, if Y_1 is the year 2004 and Y_2 is the year 2010, then there would be $(2010 - 2004)/2 = 3$ "doubles" in the number of transistors on computer chips between the years 2004 and 2010. And, if there happened to be X transistors on a computer chip in the year 2004, then there would be

$$2 \times 2 \times 2 \times X = 2^3X = 8X$$

transistors in the year 2010.

From this exercise, we are now able to identify the general relationship that predicts the number N_2 of transistors, or equivalent computing power, in any given year Y_2 if we happen to know the number N_1 of transistors, or computing power, in any other year Y_1:

$$N_2 = 2^{\frac{Y_2-Y_1}{2}} \times N_1 \tag{1.2}$$

Gordon Moore made these same calculations roughly 40 years ago. To verify his result, Moore plotted the actual number of transistors on his computer chips for various years and compared these values with those obtained from the previous formula. What he found was absolutely remarkable and still holds true today: The predictions made by Moore's law were nearly identical to the actual values.

To see how accurate Moore's law has turned out to be over the last three decades, look at Figure 1.8, in which we compare Moore's predictions of the number of transistors over time with the actual numbers on a semilog plot. Remember that straight lines on a semilog plot imply that the number of transistors on a computer chip is actually doubling at some regular interval—in this case, every two years.

Moore's startling observation means that from the first days of digital technology, computers and other digital devices have been increasing in speed and power at a staggering and predictable rate, giving us computer chips with such enormous power that nearly any design will be possible in the future.

KEY CONCEPT

The number of "doubles" used in Moore's law does not have to be an integer, like 1, 2, 3, or 4. The equation works even when the number of doubles is 3.3, 4.5, or any other positive number, for that matter.

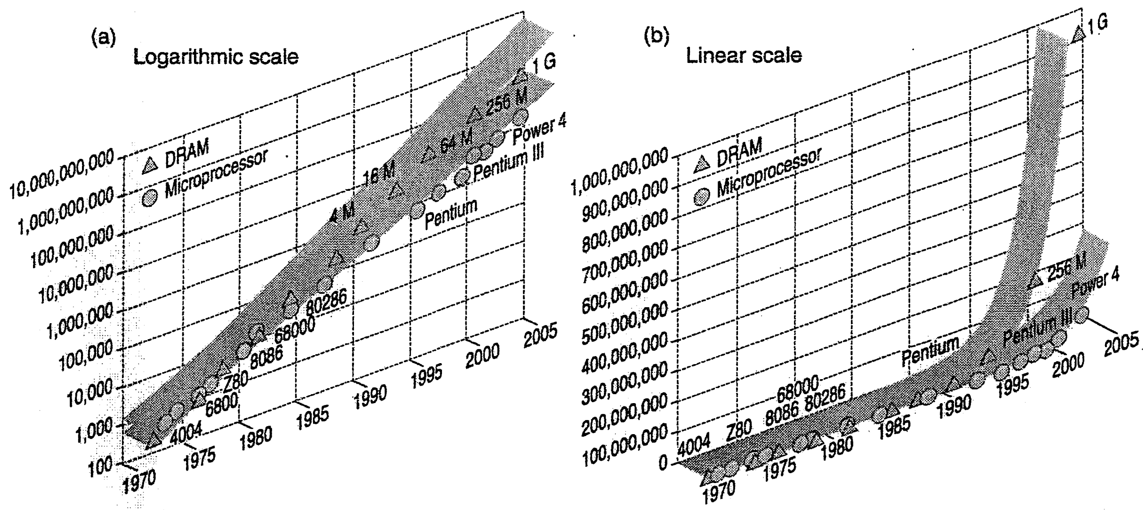


Figure 1.8 Moore's law for various digital components. The lines represent the predictions; and the marks represent the actual numbers of transistors. DRAM are memory chips, microprocessors are the chips used inside computers. The same growth rate is seen in graphics chips, and DSP or digital signal processors used in cell phones and MP3 players. All are forms of ICs.

INTERESTING FACT:

The time interval over which the number of transistors doubles can be different for different kinds of integrated circuits. Moore's Law tells us it is two years for standard computer chips, but the doubling interval can be as short as 18 months for simpler integrated circuits like memory circuits.

EXAMPLE 1.5 How Many Transistors Will Be on a Chip in the Future?

The Pentium 4 microprocessor (IC) made in 2001 had 47 million transistors in it. How many transistors should be in the Pentium chip made

a. 10 years later?
b. 30 years later?

Solution

The result is easy to find by applying Moore's law:

$$Y_1 = 2001 \text{ (the date of manufacture of the Pentium 4)}$$
$$N_1 = 47{,}000{,}000$$

For part (a), $Y_2 = 2011$, and for part (b) $Y_2 = 2031$. From the formula, we have for part (a)

$$N_2 = 2^{\left(\frac{2011-2001}{2}\right)} \times 47{,}000{,}000 = 2^5 \times 47{,}000{,}000 \approx 1{,}503{,}000{,}000$$

and for part (b)

$$N_2 = 2^{\left(\frac{2031-2001}{2}\right)} \times 47{,}000{,}000 = 2^{15} \times 47{,}000{,}000 \approx 1{,}503{,}000{,}000$$

Moore's law predicts that 30 years from now, we will have $2^{15} = 32{,}768$ times as much computing power on a single microprocessor as we have today, putting the power of more than 30,000 computers into a single device.

The Units of Modern Technology

As you have just learned from the previous section, the numbers that modern engineers deal with can be very small (such as the size of a transistor) or very large (such as the number of transistors on a single IC). Carrying around all those digits can make the mathematics tedious and lead to errors. So, to make engineering mathematics easier, engineers rely upon names for different-sized numbers.

You are no doubt familiar with the terms "mega" and "giga," but have you heard of "peta" and "femto"? Table 1.2 lists the size of various numbers as a multiplication factor, along with the name or prefix, the mathematical symbol, and the definition (ranging from the exceptionally small to the remarkably large).

For example, a typical DVD can store 37,600,000,000 bits. Using the terminology presented in Table 1.2, engineers would say that a DVD holds 37.6 gigabits, or 4.7 gigabytes, of data, where you should remember, a byte equals eight bits. Isn't it easier to say "giga" than to say 1,000,000,000?

Converting Numbers Just as it was important for us to learn how to convert base-10 numbers to binary numbers, it is important that engineers be able to convert numbers from one format or scale to another.

EXAMPLE 1.6 Converting Nanoseconds to Minutes

How many nanoseconds are in a minute?

Solution

From Table 1.2, we observe that one nanosecond lasts $1/10^9$ of a second, or is 10^{-9} seconds long. This means that in 1 second, we have $1/10^{-9}$, or 10^9; nanoseconds. Each minute has 60 seconds; therefore, one minute has $60 \text{ sec} \times 10^9 \text{ nsec/sec} = 60 \times 10^9 \text{ nsec} = 6.0 \times 10^{10} \text{ nsec}$.

Table 1.2 Number Sizes, Prefixes, and Symbols

Multiplication Factor	Prefix	Symbol	American Term
10^{18}	exa	E	One quintillion
10^{15}	peta	P	One quadrillion
10^{12}	tera	T	One trillion
10^9	giga	G	One billion
10^6	mega	M	One million
10^3	kilo	K	One thousand
10^2	hecto	h	One hundred
10^1	deka	da	Ten
10^{-1}	deci	d	One tenth
10^{-2}	centi	c	One hundredth
10^{-3}	milli	m	One thousandth
10^{-6}	micro	μ	One millionth
10^{-9}	nano	n	One billionth
10^{-12}	pico	p	One trillionth
10^{-15}	femto	f	One quadrillionth
10^{-18}	atto	a	One quintillionth

EXAMPLE 1.7 How Many People Would It Take to Reach the Moon?

The Moon is 384,402 km from the Earth. How many humans standing on each other's shoulders would it take to reach the Moon?

Solution

Let's assume that the distance from an average person's shoulders to the ground is five feet. So a thousand people standing on each other's shoulders would reach 5000 feet high. To determine the number of people required in order to reach the moon, we need only follow the conversion rule given below:

$$384{,}402\text{ km} \times 1000\text{ m/km} \times 3.2808\text{ feet/m} \times 1\text{ person/5 feet} = 252{,}229{,}216\text{ people}$$

384,402 km	1000 m/km	3.2808 feet/m	1 person/5 feet	252,229,216 people
distance in km to the moon	# meters in a kilometer	# of feet in a meter	height in feet of average person from shoulders to ground	# of people standing on each others shoulders required in order to reach the moon

Interestingly, that is about 4% of the world's population and a little less than the entire U.S. population in the year 2000.

Putting These Numbers into Human Terms We can see from Table 1.2 that peta means 10^{15}. However, it is very hard to put numbers of this scale into any human context. How big is 10^{15}? How small is 10^{-15}?

Figure 1.9 will help you better understand such big and small numbers by relating items from your daily lives with some of these numbers.

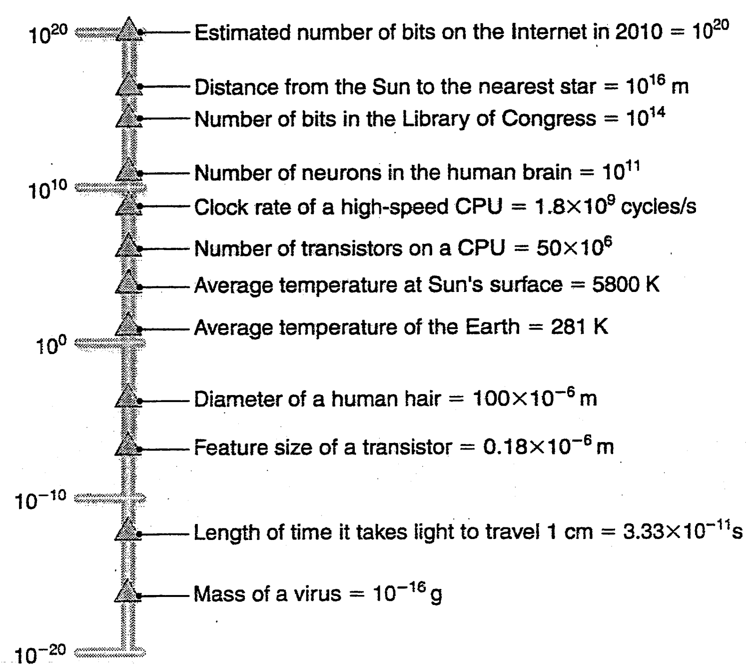


Figure 1.9 How big is big? How small is small?

EXERCISES 1.3

Mastering the Concepts

1. According to Moore's law, how many months does it take engineers to double the number of transistors on a computer chip.
2. Does it make sense to measure the distance between two cities in millimeters? Is it wise to measure the size of a transistor in meters? Why or why not?
3. How many picoseconds are in an hour?
4. How many pounds are in a megaton?

Try This

5. What is more valuable, one penny doubled 30 times or $1 million?
6. Using the Pentium 4 as your reference point, determine the number of transistors on the version of the Pentium to be released in 2015.
7. Make the following conversions:
   a. Convert 0.34 seconds to milliseconds.
   b. Convert 18 miles to inches.
8. Convert 0.00005 milligrams to nanograms.
9. How many times does $1000 fit into a terra of dollars?
10. How many nanometers are in a hectometer?
11. How heavy is a typical virus in terms of femtograms?
12. Determine the equation that tells you the correct monetary value in terms of dollars of a penny doubled N times.
13. How much money would you have at the end of a year if you had $1 on January 1 and
    a. you doubled it once a month;
    b. you doubled it once a week;
    c. you doubled it every day.
14. If Moore's law said that the number of transistors would double every three years, how many transistors would be on the Pentium computer chip to be released in 2015?
15. Derive equations that predict the number of transistors on computer chips if
    a. Moore's law said that the number of transistors tripled every two years.
    b. Moore's law said that the number of transistors doubled every three years.

Back of the Envelope

16. Assume that you want to build a computer system that can carry on a natural conversation with you. Engineers predict that it will take a very fast computer to achieve this goal. One prediction says that the computer will have to be able to execute 10^{12} instructions per second. Predict the year that this will happen, assuming that the number of instructions per second

also doubles every two years and that computers today run at 500 million instructions per second.

17. Moore's law predicts that the number of transistors on an integrated circuit will double every two years. Assume that the size of the IC chip stays the same over time and that transistors are square. Show that if a transistor is X_1 micrometers (microns) per side in year Y_1, then it will be $X_2 = 2^{-1/4(Y_2-Y_1)}X_1$ microns per side in year Y_2.
18. Assume that the side of a transistor is 1.6 microns in 2002 and that the diameter of a human hair is 100 microns. Using Moore's law, determine the number of transistors that would fit across a human hair in the year 2010.
19. What is the diameter of the following atoms?
    a. Hydrogen
    b. Silicon
    c. Iron
    d. Uranium
20. How big are transistors today, in square micrometers? Assuming that transistors are square, how many transistors would fit on a U.S. postal stamp?
21. Estimate the number of people required in order to circumnavigate the globe at the equator if they were all to hold hands. *Hint*: Assume the average human arm span is four feet.
22. Assuming that Moore's law continues to be accurate, predict the year that transistors will be the size of the atoms in Exercise 1.3.19 given that they are 1.5 square micrometers in area in 2003.
23. Assuming Moore's law continues, do you think engineers will be able to build systems that create
    a. Academy Award–winning movies?
    b. Prize-winning literature?

    Explain your answers.
24. How has engineering technology changed popular music?
25. How has engineering technology changed popular films?
26. How has engineering technology changed the way in which people purchase products such as clothing?
27. Imagine three new technologies that you would like to see in the cars of the future. Can you predict when these technologies might be implemented?
28. An atom of sodium is a cube approximately 0.4 nm on each side (nm = nanometer). How many sodium atoms are in a cubic millimeter.
29. How far does light travel in a single nanosecond? *Hint*: The speed of light is 3×10^8 m/s.

1.4 Block Diagrams—Organizing Engineering Designs

Suppose that engineers want to design a relatively complicated system, such as a high-performance video game player or the flight control system on the space shuttle. Do you think they would just gather together some parts and then sit down at a workbench, emerging some time later from the lab with a working system? No! Most systems designed and built by engineers today are so complex that one person or even one team of people couldn't reasonably design the whole thing alone.

Real-world, cutting-edge designs typically are created by breaking the complete system into collections of simpler elements that are then organized through a **block diagram**. Individuals or individual teams are typically responsible for one of the elements in the block diagram. Usually, there is another team of so-called systems engineers who have the responsibility of making sure that all of the elements of the block diagram operate together to create the final total system.

Block Diagrams: Block diagrams graphically describe how a particular system works or how a particular activity is to proceed. Block diagrams are used in nearly all creative endeavors, including advertising, manufacturing, computer science, medicine, and engineering.

As a good example, video game engineers created the block diagram shown in Figure 1.10 as the first step in designing a recent video game console.

As you can see in Figure 1.10, this new video game console has a variety of individual components or elements with separate names. Each of these components has a different responsibility in the overall design. The components are connected to one another in the block diagram with arrows that describe the "flow" of information or activity in the system.

As a general rule, each element, or block in the block diagram, has an **input**, an **output**, and a job to do. The inputs control the actions of the various blocks in the system, and the outputs are the resulting actions produced by the individual blocks. It is interesting to note that one block's output is often another block's input. Knowing this, it is very easy to read block diagrams if you just follow the flow of activity as directed by the arrows in the block diagram.

Input: Instructions or data used by a system to carry out a task.

Output: The final product of a system or device.

Let's try it: If you view the block diagram in Figure 1.10 as a whole, you will notice that the overall video game has three inputs and four outputs. The three inputs allow the user to actually play and interact with the game in various different ways. Let's just focus on the most obvious input—the game controller. The controller is what the player actually holds in his or her hands to play the game.

Notice that the controller is one of three possible inputs into the block called the I/O processor. ("I/O" stands for "input and output.") The I/O processor converts the raw information from the controller into information useful to the actual game program.

The three video game outputs come from two separate blocks: the video synthesizer and the sound synthesizer. These two blocks produce the video images and the sounds of the game, respectively.

The other blocks within the video game console system serve various functions that allows the game to operate:

1. RAM is a form of memory to store the software and the data.

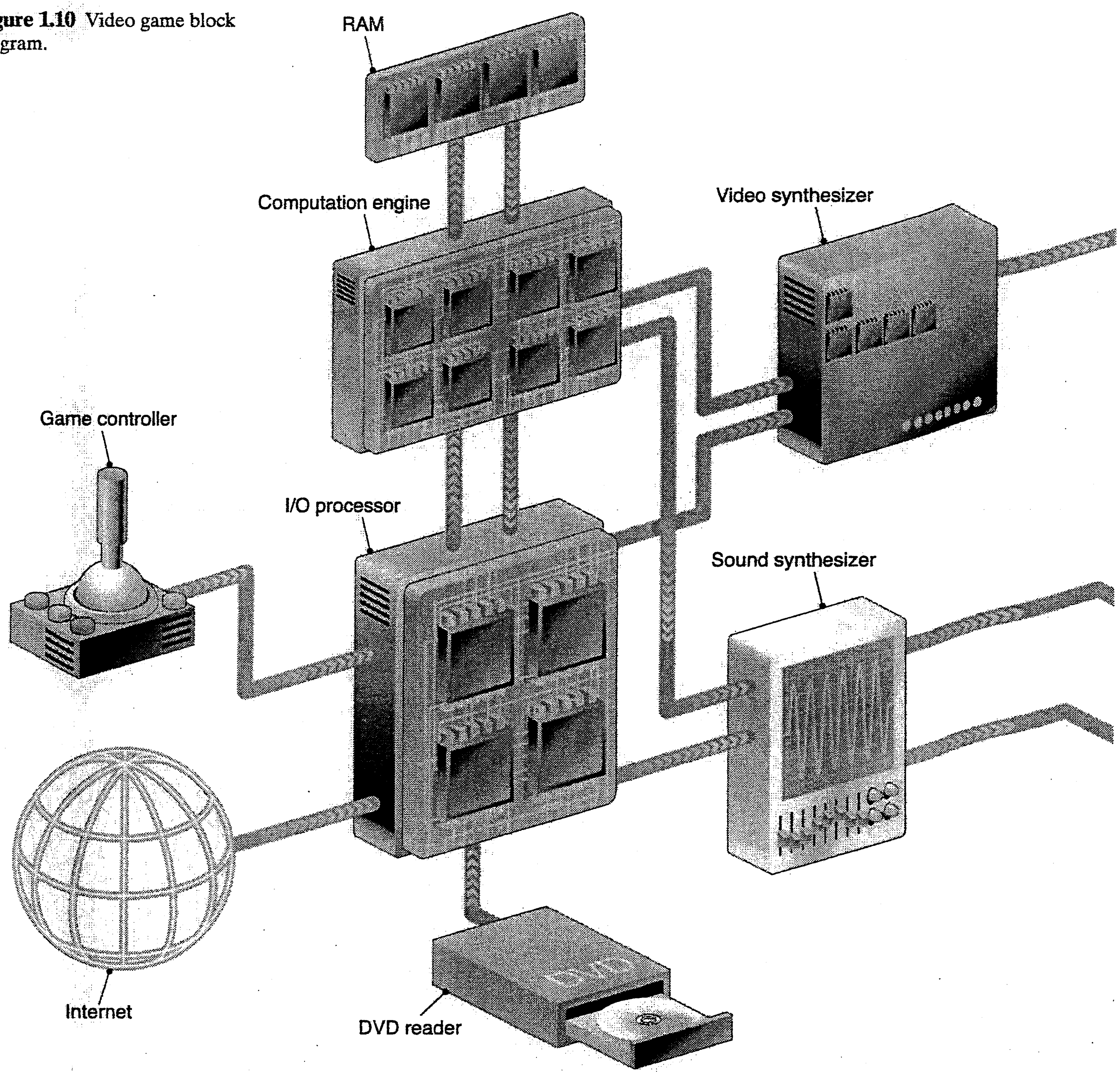
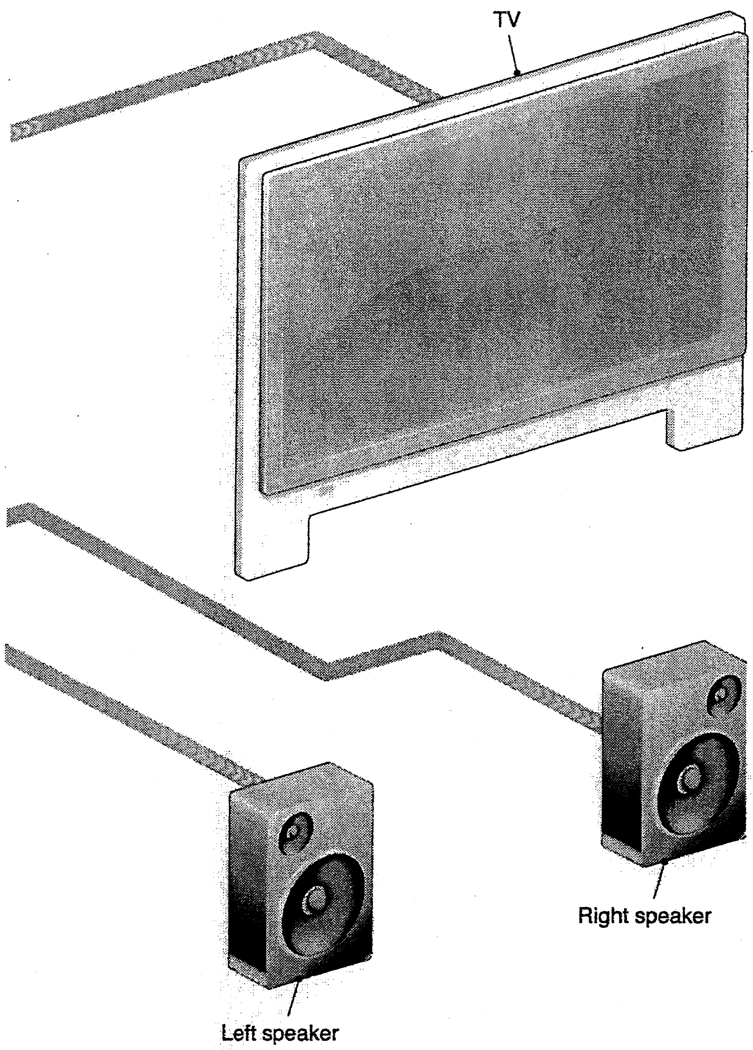


Figure 1.10 Video game block diagram.

2. The computation engine is the digital computer that determines where to place objects featured in the game, such as people, cars, and buildings, and determines how they are to move.
3. The video synthesizer takes the information from the computation engine and creates the corresponding digital images for the video display.



4. The sound synthesizer creates the sounds of the game.
5. The I/O processor controls the inputs and the outputs.
6. The DVD reader extracts game information from the DVD.

Throughout this book, you will have the opportunity to create your own high-tech designs and devices by following the engineering design process. During the actual design phase, you will create your designs by first constructing block diagrams of the overall system. These block diagrams will serve as a visual description of the total design and will allow you to clearly identify the inputs and outputs of the systems.

For example, when designing a system to create sound effects, you might use a microphone as the input to collect the original sound, a digital system to alter this sound in some desired way, and then a set of speakers to reproduce the sound. Alternatively, when creating a system to produce special effects for movies, you might use a video camera as the input, a digital system to create and add in the special effects, and a video display or monitor to show the effect. Both of these simple block diagrams are shown in Figure 1.11 and allow engineers to see clearly what the intended designs actually do.

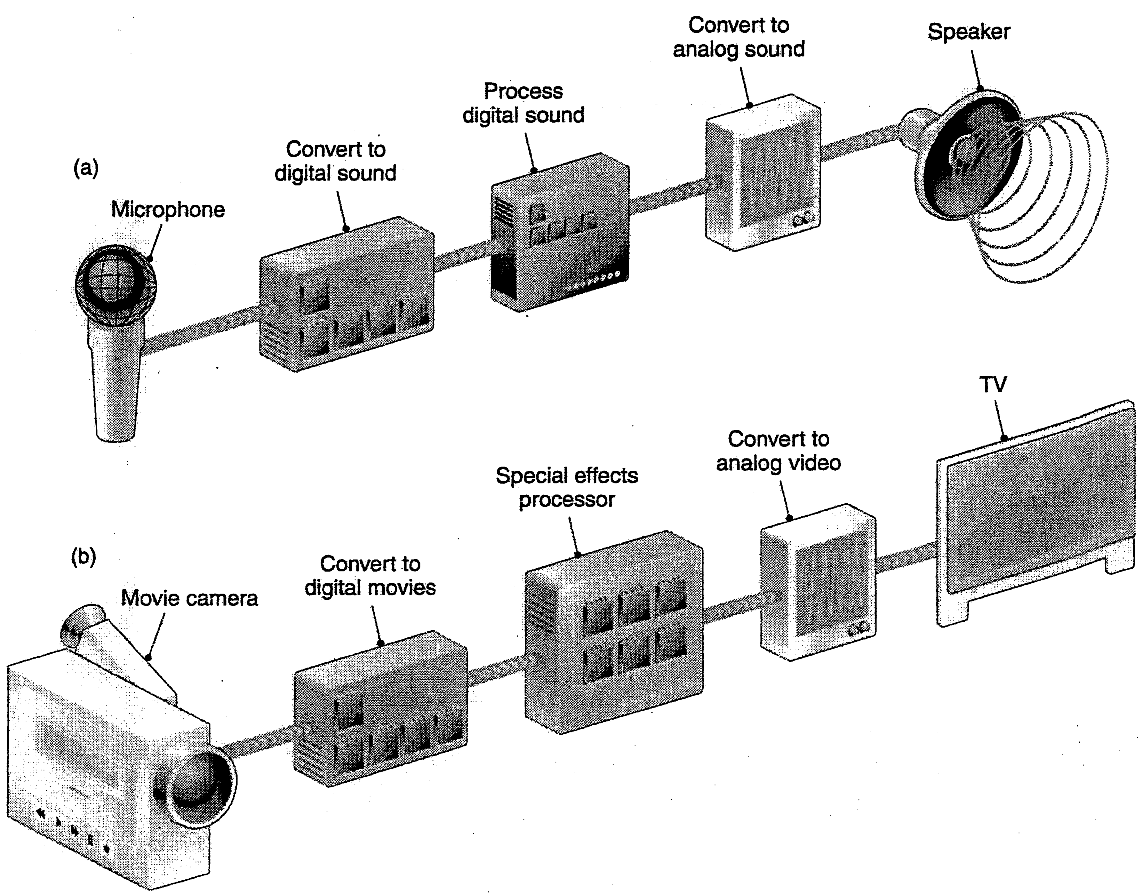


Figure 1.11 Block diagrams describing two systems: (a) one for creating sound effects and (b) one for creating special effects in movies.

Infinity Project Experiment: High-Tech Demos

Using block diagrams and modern technology, engineers can create prototypes of many different engineering designs quickly and easily. Some of these designs might include systems for creating sound or visual effects, for automatically counting the money in your pocket, or for tracking objects that are moving in space.

Explore these different designs, and ask yourself the following questions:

- What is the problem that they are each trying to solve?
- What are the constraints on the design?
- How effective are these prototypes in meeting the design objectives?
- How would you improve the design?
- How will Moore's law impact these designs in the future?

From Design Concept to Prototype

One of the many remarkable advances in digital technology that will become increasingly important in coming years is the ability for engineering manufacturers to produce a **prototype**, or first working system design, directly from the block diagram. What does this mean? Engineers can rapidly produce a working design to test and evaluate directly from the block diagram. So, in the near future, the block diagram will become the actual design itself.

Prototype: An original model of a design. Engineers use prototypes of systems to prove that the systems work.

EXERCISES 1.4

Try This

1. Construct a block-diagram description for the following activities:
   a. Getting dressed in the morning
   b. Cooking dinner at night
   c. Preparing for an exam

Back of the Envelope

2. Let's analyze a simple system: a portable CD player. Draw a block diagram that describes the functionality of this system.
   a. Describe the input and outputs of all the blocks.
   b. Imagine that it is your job to improve this system. Draw a block diagram of your new design.
3. Create a block diagram for an automobile braking system.
4. Create a block diagram describing a typical medical checkup in a doctor's office.

1.5 Summary

By now, it must be clear to you that engineers are creating our world of tomorrow with their know-how and ingenuity. This is what engineers have done over many centuries. Each generation has had new challenges to face and has developed new technology to deal with them. Today what we take for granted as normal in terms of living conditions—fresh food, travel, and entertainment—would have been beyond the dreams of the elite aristocracy 500 years ago. In the same way, the technology we create today that seems so amazing to us will be ordinary in the future as new technology is created.

During the remainder of this book, you will have the unique opportunity to participate in this remarkable endeavor by creating and inventing new technologies. You will be taught the skills and knowledge necessary to take your dreams and turn them into tomorrow's reality. As you move forward in this book, please remember the following statement made by Theodore Van Karman:

"Scientists explore what is; engineers create what never has been."

Master Design Problem

Now that we have learned about the world of engineering, it is time to apply our knowledge to a futuristic design problem. Most innovations begin with someone asking the question, "Is it possible to . . . ?" The engineer must determine not only whether the concept is feasible, but also how to actually create the design and then build and test the product.

In each chapter of this book, you will have the opportunity to assume the role of an engineer working on a Master Design Problem. While there is still much to learn, we can gain insight into the creative side of engineering by stepping through the design process for a futuristic design problem: **Create a digital system that can produce award-winning movies from scratch by simply using a few suggestive keywords typed in by a user.**

- *System Use:* An ideal design is easy to use. For example, selecting "Western, romance, comedy" would cause the system to automatically create the characters, plot, scenes, speech patterns of the digital actors, soundtracks, and any and all other components of this hypothetical Western romantic comedy.
- *First Step—Product Evaluation:* The first question that needs to be addressed when developing a new technology is simply, *Would anybody want this? Does it make any economical sense to even attempt to develop such a system?* This is not always an easy question to answer. Times change and with it, people's interests change. As an example, video rental stores continue to be popular in the face of other movie distribution alternatives, because people enjoy the communal experience of wandering the aisles of the store. Will this ever change? Only time will tell. Will our home movie production system be so desirable that it will change people's behavior? Before we get started, it is important that we attempt to answer these questions.
- *Engineering Design:* If your analysis shows that our new proposed technology to create individualized movies is wanted and needed, then we are off to begin the challenging and fun work of designing and building this system. Taking a good idea and turning it into a working product is an important dimension of being a successful prac-

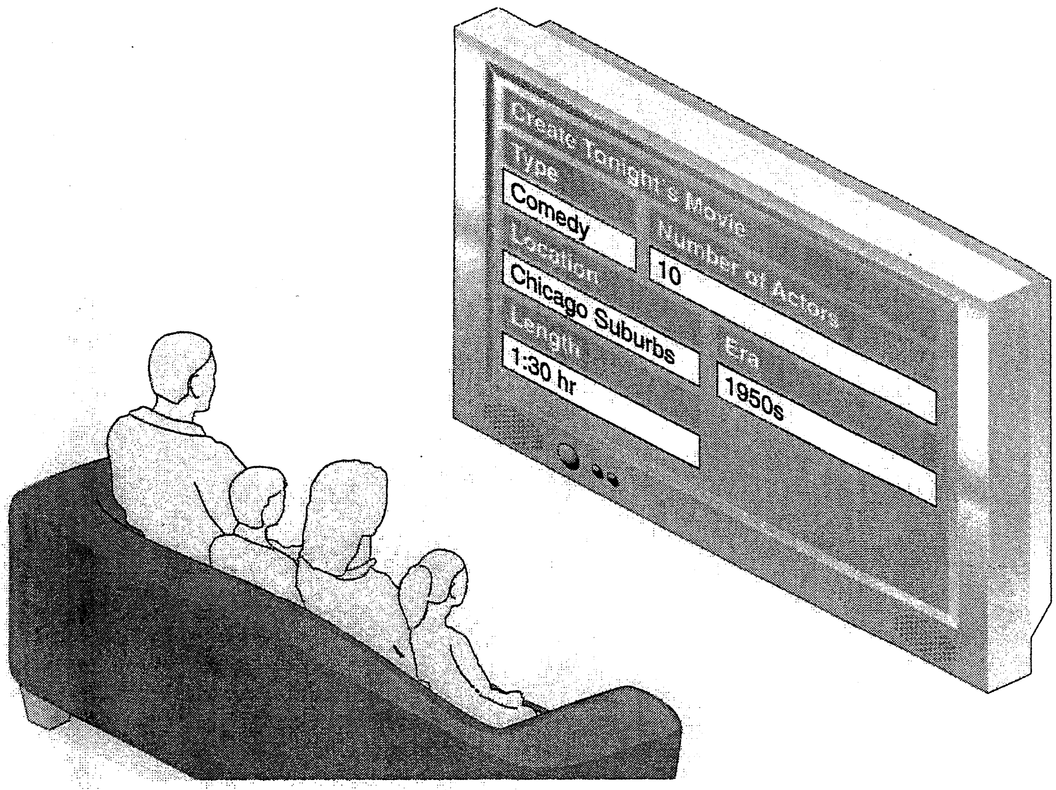


Figure 1.12 Family night in front of the "home movie production system."

ticing engineer. To accomplish this goal, we must determine whether it is even possible to create our proposed concept—and if it is not possible today, to assess the state of technology and predict the year when it will be possible. Let's consider a few of the key components of our futuristic design and attempt to estimate when the necessary technology will be mature enough for us to use to build this system.

- *Automated Story Creation:* As a critical component of the overall design, we need to develop a computer system that takes in a few suggestive keywords and then creates a text version of the complete plot, with a detailed description of all of the scenes and specific character lines. At first, this seems like a very difficult challenge. However, one simple, yet tedious, way to create such a system is to hire a large team of writers that would put together many, if not thousands, of small generic pieces of stories that could then be linked and edited together by a computer to produce a wide range of plots. Practically speaking, and in most cases, these stories would generally meet the interests of the users of the system. How often have you seen a movie with a misleading description in the newspaper that you still ended up enjoying? So long as the resulting movie is entertaining and loosely matches the keywords, the end users will be satisfied with the system. This approach, while somewhat primitive, might be an appropriate first version of the system that could be built to test the market interest. Future versions could involve more sophisticated approaches that will be available in future years.

- *Digital Character Creation:* Engineers and moviemakers have been making steady progress on developing the necessary systems and software to create lifelike, computer-generated characters. There are many good reasons for Hollywood to be doing this. For example, big stars today are commanding many millions of dollars in acting fees per movie, so it makes long-term economic sense to replace or supplement these real actors with digital facsimiles that cost far less to create and can be used in significantly more elaborate action scenes without any risk to the actor. Hollywood's first early efforts in this regard have been impressive and suggest that widescale use of this technology might be just around the corner.
- *Digital Speech and Music Creation:* Once you have the story with the individual character lines written, it will be necessary to have the system actually "speak" the lines, as well as create the background sound effects and music. Engineers have made a great deal of progress in this area already. You no doubt have played with toys and video games with computer-generated speech and audio, and you might even have a piece of software on your computer that converts typed text to "speech." As for the musical score and sound effects, most sound tracks for movies today are generated with the assistance of computers and other digital technologies. In the very near future, these systems will be able to automatically create the desired musical and sound effects without a human in the loop.
- *Editing:* The final step in producing a high-quality movie based on your keywords requires that we edit all these components together. As you may already know, nearly all movies today use computer-based digital editing systems. Extending their capabilities to edit together our computer-generated components will require some engineering, but it is conceivable that, with the right people working on the problem, engineers can achieve this goal within the next decade.

So, will people want to have digital systems create movies for them? Ask your friends and family. Can engineers do it? Yes, with enough creativity, determination, and time, this form of entertainment can be part of our future!

Is This Art?

Will these movies be any less works of art because they are created by engineers and computer scientists working with artists and psychologists rather than by producers, directors, and actors? This will be up to you and the marketplace to decide.

Big Ideas

Math and Science Concepts Learned

In this chapter, we discussed what makes engineers special, and we learned the basic processes by which engineers create the new technologies and inventions around us.

- The modern digital world began with the invention of the transistor in 1947.
- The mathematical foundation for the digital revolution is the engineer's ability to convert the physical, or analog, world into numbers to be collected, processed, and stored on digital technologies.
- High-speed, low-cost digital technologies were made possible by Jack Kilby's invention of the integrated circuit (IC) in 1958.
- Digital technologies, including computers, are accelerating in capability and performance at the rate predicted by Moore's law, doubling every two years.
- Bits and simple binary, or base-2, arithmetic are fundamental to the mathematics of all new digital technology.
- Engineers rely on block diagrams to visually describe processes and systems.

In the following chapters, we will apply these concepts to a variety of exciting design projects, including music, pictures, movies, and the Internet.

Important Equations

It is important for us to be able to predict the rate at which digital technology and engineering is accelerating. Moore's law allows us to predict the number of transistors used on future computer chips and integrated circuits (N_2), based on the number of transistors in computer chips today (N_1.)

Moore's law states the following: If you know that there are N_1 transistors on a computer chip in year Y_1, then in year Y_2 there will be N_2 transistors, where

$$N_2 = 2^{\left(\frac{Y_2 - Y_1}{2}\right)} \times N_1$$

Building Your Knowledge Library

Pearson, Greg, and A. Thomas Young, Editors, *Technically Speaking: Why All Americans Need to Know More about Technology*, National Academy of Engineering Press, 2002.

Technological literacy—a broad understanding of the human-designed world and our place in it—is an essential quality for all people who live in the increasingly technology-driven 21st century. This book explains what technological literacy is, why it's important, and what's being done to improve it.

Ambrose, Susan A., Kristin L. Dunkle, Barbara B. Lazarus, Indira Nair, and Deborah A. Harkus, *Journeys of Women in Science and Engineering: No Universal Constants*, Temple University Press, 1997.

Features short bios of 88 research scientists and engineers in areas from biochemistry to mathematics, from neuroscience to computer science, and from animal science to civil engineering. Includes those who have made careers in public service, such as Dr. Jocelyn Elders and Rhea L. Graham, as well as Nobel Prize winners, beginning assistant professors, division directors of corporations, and an engineering school dean. Each woman talks candidly about how she got into science or engineering, her work environment, and discrimination she may have encountered.

Uwe, Erb, and Harald Keller, *Scientific and Technical Acronyms, Symbols and Abbreviations*, John Wiley & Sons, Inc., 2001.

Never heard of a particular engineering and technology term before? This book has them all.

VIRGINIA DEPARTMENT OF EDUCATION

BRIEFING

STANDARDS FOR TECHNOLOGICAL LITERACY AND PROJECT LEAD THE WAY

PRESENTED TO

JOINT SUBCOMMITTEE STUDYING SCIENCE, MATHEMATICS, AND TECHNOLOGY EDUCATION

OCTOBER 10, 2006

GEORGE R. WILLCOX, COORDINATOR
OFFICE OF CAREER AND TECHNICAL EDUCATION
DIVISION OF INSTRUCTION
VIRGINIA DEPARTMENT OF EDUCATION

PART I: Standards for Technological Literacy

Development of the Standards

- The *Standards for Technological Literacy: Content for the Study of Technology* were developed as the result of both National Science Foundation (NSF) and National Aeronautics and Space Administration (NASA) grants administered by the International Technology Education Association (ITEA) and its Technology for All Americans Project.

- The standards were released in 2001 after rigorous evaluation by the National Research Council's Standards Review Committee, involving the National Academy of Engineering Special Review Committee.

- The standards define what students should know and be able to do in order to be technologically literate, enabling people to develop knowledge and abilities about human innovation in order to help our nation maintain and sustain economic progress.

- *Standards for Technological Literacy* establish requirements and benchmarks for all K-12 students, with 20 broadly stated standards that specify what every student should learn about technology. As a result, a technologically literate person understands what technology is, how it is created, how it shapes society, and is in turn shaped by society.

Listing of the Technology Content Standards

- <u>Nature of Technology</u> - Students will develop an understanding of:
  1. Characteristics and Scope of Technology
  2. The Core Concepts of Technology
  3. Relationships Among Technologies and the Connections Between Technology and Other Fields

- <u>Technology and Society</u> – Students will develop an understanding of:
  4. The Cultural, Social, Economic, and Political Effects of Technology

5. The Effects of Technology on the Environment
6. The Role of Society in the Development and Use of Technology
7. The Influence of Technology on History

- Design – Students will develop an understanding of:
  8. The Attributes of Design
  9. Engineering Design
  10. The Role of Troubleshooting, Research and Development, Invention and Innovation, and Experimentation in Problem Solving

- Abilities for a Technological World – Students will develop the abilities to:
  11. Apply Design Processes
  12. Use and Maintain Technological Products and Systems
  13. Assess the Impact of Products and Systems

- The Designed World – Students will develop an understanding of and be able to select and use:
  14. Medical Technologies
  15. Agriculture and Related Bio Technologies
  16. Energy and Power Technologies
  17. Information and Communication Technologies
  18. Transportation Technologies
  19. Manufacturing Technologies
  20. Construction Technologies

- Standards-based Technology Education is designed to engage student interest through hands-on/minds-on exploration of the designed world of the society in which they live. The value of design and modeling helps students develop spatial and visualization abilities critical to success.

- As students learn about the world around them, they discover relevance of other aspects of education as they use them to research, design, and implement solutions to technological challenges and issues.

- Students learn about the unique core concepts of technology; that technology involves resources, systems, processes, and controls, as well as optimization and trade-off as things are designed. They develop systems thinking as well as confidence in design, problem solving, and use of systems.

- As students study technology, they progress from awareness and understanding of interactions of the designed world to the development of abilities to apply the design process, and use, maintain, and assess the impacts of products and systems. Modeling, testing, evaluating, and modifying are used to transform ideas into practical solutions.

- Engaging in the process of learning about the pervasive nature of technology, its history, how it effects society and the environment, and in turn is driven by cultural, economic, and political issues, students are led to identify their own talents and interests. The result is a student who is well grounded in the technological nature of our world and ready to make decisions regarding further study in any field.

Innovation ??

Description of Standards-based Experiences by Grade Level:

- **Grades K-5 -** In the elementary school, students will:
  - Learn that people create technology as they create tools and products from materials. Technology and nature are different, both having systems. (The Nature of Technology)
  - Learn that technology can be helpful or harmful, the effects of technology on the environment, the importance of renewable resources, and the influence of technology on history as people expanded their needs from food, clothing, and protection to more advanced needs and wants of society. (Technology and Society)
  - Learn that design is a creative process that everyone can be involved in, with specific requirements and the engineering design process to guide them. They begin to troubleshoot and experiment as they learn about invention and innovation. (Design)

- Begin to communicate their thoughts about the challenges they are given through drawing, modeling, and words. (Abilities for a Technological World)

- Recognize that the designed world is all around them in the forms of medicine, agriculture, energy and power, information and communication, transportation, manufacturing, and construction technologies. (The Designed World)

- **Grades 6-8** – In the middle school, students will:

- Learn how people creatively use resources to develop systems and products that make things easier and increase the quality of life. They learn the parts of systems and about interaction among them, as well as the interrelations of technologies and knowledge of other fields of study. (The Nature of Technology)

- Learn about the impacts and consequences of technology including ethical issues and influences on economy, politics and culture such as environmental vs. economic concerns. They learn about specialization of labor, evolution of techniques, measurement and resources, and how technological and scientific advances enhance each other. (Technology and Society)

- Learn how design leads to useful products and systems, how brainstorming can increase the potential of a group, and how modeling, testing, and evaluating designs lead to modification. They learn how to troubleshoot systems to solve problems. (Design)

- Learn how to apply the design process, identify criteria and constraints, and make, test, and evaluate a product or system. They use information to understand how things work, while safely using tools to diagnose, adjust, and repair systems. They design and use instruments to collect and interpret data to identify trends, as well as evaluate and interpret the accuracy of information. (Abilities for a Technological World)

- Learn how inventions and innovations affect the areas of the designed world from medical and biotechnology through transportation, manufacturing, and construction systems by designing and producing systems. They learn about energy as the capacity to do work, how it is converted from one form to another, and how efficiency and conservation of energy affect systems. They learn how information and communication systems use energy to encode, transmit, and receive information as they use these systems to design messages. (The Designed World)

- **Grades 9-12** – In high school, students will:

  - Learn that technology's nature and development are functions of societal needs and wants, with the rate of development and diffusion increasing rapidly. They continue to explore by design and use of various systems while applying their academic skills to technological challenges. Invention and innovation are approached from the perspective of transfer of knowledge, patents, and protection of intellectual property. (The Nature of Technology)

  - Continue to study the effects of society on technology and that of technology on societies and the environment. The history of technology and its effects are explored in detail to help students learn to make appropriate decisions about development and consequences of introducing new technologies. (Technology and Society)

  - Continue to use the design process and principles, learning to clarify the issues and requirements involved in challenges, develop prototypes, and incorporate factors of engineering design. They apply the design process, documenting and communicating processes and procedures. They operate, troubleshoot, and maintain systems while synthesizing data to draw conclusions and utilize assessment techniques. (Design)

  - Begin to study various areas of the designed world that they find relevant and personally interesting. They may choose multiple aspects of the designed world in which to apply their prior knowledge and gain comprehension of factors that will lead to decisions for further study. (Abilities for a Technological World)

- **Standards Assessment:**

  - The *Standards for Technological Literacy* provide a systematic, multi-step process of collecting evidence on student learning, understanding, and abilities and requires measuring critical thinking and transfer of knowledge to real world situations.

  - Technology assessment of student achievement incorporates multiple standards to highlight interrelationships among technologies and the connections between technology and other disciplines. As a result, students are:

    - Required to perform complex tasks using what they have learned and appropriate technological resources
    - Assessed on their ability to use appropriate technology, science, and mathematics principles
    - Assessed on their ability to be creative in designing technological solutions
    - Assessed on the rigor of their methodology and the quality of the questions they pursue
    - Required to demonstrate their knowledge and abilities by creating a response or product that resembles practical experience

  - Student assessment must reflect the active, dynamic nature of the study of technology and the manner in which people draw upon and exercise knowledge and abilities acquired through experience.

Supporting Standards Documents

- In addition to the development of the *Standards for Technological Literary*, the following standards-based publications provide details for implementation and assessment of student performance:

  - Technological Literacy for All: A Rationale and Structure for the Study of Technology
  - Realizing Excellence: Structuring Technology Programs
  - Measuring Progress: Assessing Students for Technological Literacy
  - Planning Learning: Developing Technology Curricula
  - Developing Professionals: Preparing Technology Teachers

PART II: Project Lead The Way

- Project Lead The Way (PLTW) is a not-for-profit organization that partners with public schools, organizations in the private sector and higher education institutions to increase the number and quality of engineers graduating from the nation's education system.

- The PLTW curriculum is a four-year, flexible sequence of pre-engineering courses that, when combined with college preparatory mathematics and science courses in high school, introduces students to the scope, rigor and discipline of engineering and engineering technology prior to entering college.

- The courses are Principles of Engineering, Introduction to Engineering Design, Digital Electronics, Computer Integrated Manufacturing, Civil Engineering and Architecture, and Engineering Design and Development.

- Approximately 1,700 schools in 47 states and the District of Columbia have adopted PLTW's curriculum. Currently, 24 schools offer PLTW courses in Virginia.

- High school teachers in PLTW schools undergo an intensive two-week graduate level training program for each course.

- Ongoing professional development for both teachers and counselors is also an important component of the program.

- PLTW secondary school graduates are expected to:
    - Understand technology as a tool for problem solving
    - Have a broad-based understanding of the underlying methodology of science processes
    - Be well prepared for the rigorous college curriculum
    - Understand, apply, analyze and design technological systems
    - Select an appropriate technology system for a task and apply it
    - Understand the principles of mathematics
    - Demonstrate effective communication of information and solutions

  - Possess the skills necessary to work in teams effectively

- PLTW recommends that the program should be offered to the top 80 percent* of students in a school which includes students who are:

  - In the top 10 percent of their class
  - Good in mathematics and science
  - Interested in being engineers or technologists
  - Good in art and design
  - Underachievers who might get hooked by a high tech, hands-on class
  - Struggling students who learn best by "doing"

  * The 80 percent may vary from school to school. Students who would *not* be appropriately placed in the PLTW high school program are those who are taking certain mathematics courses such as General Mathematics and Consumer Mathematics, exhibiting weak mathematics skills, demonstrating little interest in science, or who are enrolling in alternative, remedial educational programs.

- College Credit: Once a high school in the PLTW Network of Schools is certified within two years of implementation, students are eligible to apply for the Exemplary Student Recognition Program, which offers transcripted college credit or other forms of recognition at over twenty national affiliate colleges and universities.

  - Students in certified schools who earn a "B" average or higher in their PLTW courses and score 70 percent or higher on the PLTW college credit exam are eligible to apply for college credit or recognition, depending on the requirements of the affiliates.

- PLTW requires that the school division sign a School Agreement affirming that all high schools will be certified by the second year in the program and re-certified every five years after.

  - This process requires schools to demonstrate that they meet PLTW's quality standards in professional development of teachers and counselors; the implementation of curriculum using required equipment and software; the formation of a Partnership Team, and several other requirements.

- School Divisions That Offer Project Lead The Way

Arlington County	Arlington Career Center Swanson Middle School Wakefield High School Washington & Lee High School
Clarke County	Clarke County High School
Fluvanna County	Fluvanna County High School
Gloucester County	Gloucester County High School Page Middle School Peasley Middle School
Hampton City	Phoebus High School Thomas Eaton Middle School
Henry County	Bassett High School Magna Vista High School
Madison County	Madison County High School
Montgomery County	Blacksburg High School
Pittsylvania County	Chatham High School
Prince William County	Woodbridge Senior High School
Richmond City	Chandler Middle School John F. Kennedy High School Martin Luther King, Jr. Middle School Fred D. Thompson Middle School
Russell County	Russell County Career & Technology Center
Smyth County	Smyth County Career & Technical Center
Williamsburg-James City County	Jamestown High School

- Old Dominion University serves as the Virginia PLTW university affiliate. As the state affiliate, ODU is responsible for providing in-depth graduate level summer training to prepare teachers to offer each approved PLTW course. Teachers may also attend other universities in the network of affiliate universities across the country.

- PLTW is currently developing two new instructional programs in the areas of Biotechnical Engineering and Aerospace Engineering.

Description of the Middle School Program (Gateway To Technology)

Gateway To Technology consists of five independent units that should be taught in conjunction with a rigorous academic curriculum. The units are designed to challenge and engage the exploratory minds of middle school students. Each nine–week unit contains performance objectives and suggested assessment methods. The five units are:

Design and Modeling - This unit uses solid modeling (a sophisticated mathematical technique for representing solid objects) to introduce students to the design process. Using this design approach, students understand how solid modeling has influenced their lives. Students also learn sketching techniques and use descriptive geometry as a component of design, measurement, and computer modeling. Using design briefs or abstracts, students create models and documentation to solve problems.

The Magic of Electrons - Through hands-on projects, students explore the science of electricity, the movement of atoms, circuit design, and sensing devices. Students acquire knowledge and skills in basic circuitry design and explore the impact of electricity on our lives.

The Science of Technology - This unit traces how science has affected technology throughout history. Students learn about the mechanics of motion, the conversion of energy, and the use of science to improve communication.

Automation and Robotics - Students trace the history and development of automation and robotics. They learn about structures, energy transfer, machine automation, and computer control systems. Students acquire knowledge and skills in engineering problem solving and explore requirements for careers in engineering.

Flight and Space - The purpose of this unit is to introduce the student to aeronautics, space, and the use of design used to help make aerospace engineering an important field. They learn about Newton's Laws of Motion, forces, rockets, propulsion, and what makes things fly. Students acquire and apply knowledge and skills in engineering problem solving and explore the many aspects of aerospace engineering.

Description of High School Courses (Pathway to Engineering)

- Principles of Engineering - A course that helps students understand the field of engineering/engineering technology. Exploring various technology systems and manufacturing processes helps students learn how engineers and technicians use mathematics, science and technology in an engineering problem solving process to benefit people. The course also includes concerns about social and political consequences of technological change.

  9th grade

- Digital Electronics - A course in applied logic that encompasses the application of electronic circuits and devices. Computer simulation software is used to design and test digital circuitry prior to the actual construction of circuits and devices.

  Junior yr option

- Introduction to Engineering Design - A course that teaches problem-solving skills using a design development process. Models of product solutions are created, analyzed and communicated using solid modeling computer design software. In New York State, the course is called Design and Drawing for Production and follows the syllabus developed by the State Education Department.

  10th grade

- Computer Integrated Manufacturing - A course that applies principles of robotics and automation. The course builds on computer solid modeling skills developed in Introduction to Engineering Design, and Design and Drawing for Production. Students use computer numerical control equipment to produce actual models of their three-dimensional designs. Fundamental concepts of robotics used in automated manufacturing, and design analysis are included.

  Junior yr option

- Civil Engineering and Architecture - This course provides an overview of the fields of Civil Engineering and Architecture, while emphasizing the interrelationship and dependence of both fields on each other. Students use state of the art software to solve real world problems and communicate solutions to hands-on projects and activities. This course covers topics such as: The Roles of Civil Engineers and Architects, Project Planning, Site Planning, Building Design, and Project Documentation and Presentation.

  Junior yr option

- Engineering Design and Development - An engineering research course in which students work in teams to research, design and construct a solution to an open-ended engineering problem. Students apply principles developed in the four preceding courses and are guided by a community mentor. They must present progress reports, submit a final written report and defend their solutions to a panel of outside reviewers at the end of the school year.

  CAPSTONE Design & Build Course – (Senior Yr)

- Aerospace Engineering - Through hands-on engineering projects developed with NASA, students learn about aerodynamics, astronautics, space-life sciences, and systems engineering (which includes the study of intelligent vehicles like the Mars rovers Spirit and Opportunity).

  – Junior year option

- Biotechnical Engineering - Relevant projects from the diverse fields of bio-technology, bio-engineering, bio-medical engineering, and bio-molecular engineering enable students to apply and concurrently develop secondary-level knowledge and skills in biology, physics, technology, and mathematics.

  – Junior yr option

Sample Student Schedule

English 9 Social Studies Mathematics Science Foreign Language **Principles of Engineering** Physical Education	English 10 Social Studies Mathematics Science Foreign Language **Principles of Engineering** Physical Education
English 11 Social Studies Mathematics Science **Digital Electronics (or one of the following: Computer Integrated Manufacturing, Civil Engineering and Architecture, Biotechnical Engineering, Aerospace Engineering)** Physical Education	English 12 Social Studies Mathematics Science **Engineering Design and Development** Health Physical Education

PLTW Program Evaluation

Initial research findings on the effectiveness of the Project Lead The Way program include:

A study by the Southern Regional Education Board (2005) where Project Lead The Way students:

- Achieved significantly higher in mathematics than students in comparable career and technical programs.
- Achieved significantly higher than all students in career and technical programs in mathematics, science and reading.
- Completed significantly more, higher level mathematics and science courses.

A study by True Outcomes of York, Pennsylvania (2005) showed that:

- 80 percent of seniors in Project Lead The Way planned on attending college or community college compared to 65 percent nationwide.
- 54 percent planned to enroll in engineering or engineering technology compared to 10 percent nationally.
- 19 percent planned on attending community college or Technical School.
- Overall schools offering PLTW were representative of their state's population.
- Minority student participation met or exceeded the proportion of Bachelor's Degrees awarded in Engineering in 2004 to minority students by race.
- The representation of Hispanics and African-Americans in PLTW courses was double their representation in post-secondary engineering programs nationwide.
- Female student participation in Project Lead The Way was comparable or exceeded the total proportion of females earning Bachelor's Degrees in Engineering in 2004, in the fields of Mechanical, Electrical and Computer Engineering, and in Engineering Technology, but less than the percentage in biomedical and environmental fields.

In October 2005, Project Lead The Way was cited in the report ***Rising Above the Gathering Storm: Energizing and Employing America for a Brighter Educational Future*** by the National Academy of Sciences, The National Academy of Engineering, and the Institute of Medicine of the National Academies. Among the report's recommendations was that K-12 curriculum materials for STEM education modeled on world class standards should foster "*high-quality teaching with world class curricula, standards and assessments of student learning.*" It further went on to say that *"The model for this recommendation is the Project Lead The Way pre-engineering courseware* (page 4)."

Community Partners:

PLTW has numerous partners throughout the country that support the initiative nationally and locally, including:

- 30 colleges and universities (support teacher professional development in their states)
- 40 State Departments of Education (collaborate with universities and schools which oversee program implementation in their states)
- Corporations like Intel and Rolls Royce (underwrite national and state initiatives for teacher training)
- Agencies like NASA (collaborate on curriculum development)
- Associations like the National Fluid Power Association and the Society of Manufacturing Engineers (collaborate on curriculum development and extra-curricular initiatives)
- Organizations like the National Action Council for Minorities in Engineering and the National Association for Partnerships in Equity (collaborate on the minority and female participation issues)
- Institutions like the National Academy of Engineering's Center for the Advancement of Scholarship in Engineering Education (recognizes PLTW as the top pre-college engineering education program)

Massachusetts Science and Technology/Engineering Curriculum Framework

Massachusetts

"We help children learn."

Department of Education

May 2001

The Commonwealth of Massachusetts
Department of Education

350 Main Street, Malden, Massachusetts 02148-5023 *Telephone: (781) 338-3000*

David P. Driscoll
Commissioner of Education

May 2001

Dear Colleagues,

I am pleased to present to you the 2001 Massachusetts Science and Technology/Engineering Curriculum Framework. This framework presents the revised statewide guidelines for learning, teaching, and assessment in science and technology/engineering for the Commonwealth's public schools. Based on scholarship, sound research, and effective practice, the framework will enable teachers and administrators to strengthen curriculum and instruction from prekindergarten through grade 12.

I am proud of the work that has been accomplished. The comments and suggestions received on the 1995 Science and Technology Curriculum Framework, as well as on working drafts of this version, have strengthened this framework. The major changes from the 1995 framework to the May 2001 document include the following:

- Standards are more specific, to enable teachers to design instruction and assessment more effectively. Grade spans have narrowed from PreK-4, 5-8, 9-10 to PreK-2, 3-5, 6-8, 9-10.
- The four strands in the 1995 document (Inquiry, Domains of Science, Technology and Science, and Technology and Human Affairs) are now four content strands (Earth and Space Science, Life Science, Physical Sciences, and Technology/ Engineering). "Inquiry" is now to be taught with the content of each domain of science.
- High school standards: The 2001 framework has a set of standards for comprehensive, full year courses in each of the four science domains, and in Technology/ Engineering. In each domain, a subset of these standards has been identified as core. Only core standards will be assessed by MCAS. In addition, a set of core standards has been identified for a two-year, grade 9 and 10 integrated science program. These standards are a subset of the core standards from each of the four science domains.

- Format: The revised document has a three-column grid for grades PreK-5 that shows the topic and the Learning Standards, Ideas for Developing Investigations and Learning Experiences, and Suggested Extensions to Learning in Technology/ Engineering.
- A glossary was added for selected terms and a topical outline was included.

From December 2000 to May 2001 the framework underwent an intensive review for scientific and technological accuracy. The wording was revised and specific examples were added to help clarify the learning standards. Changes at this final stage of review include the following:

- For grades PreK-2, students' sense of geologic time is strengthened in the earth science strand with the standard "Recognize that fossils provide us with information about living things that inhabited the earth years ago."
- Life science standards in the lower and middle grades were strengthened and made more specific to develop concepts of evolution, including adaptation, heredity, and comparison of organisms.
- Based on significant feedback from teachers, the focus on plants and animals in grades 6-8 was extended to include a standard that specified the human organism as a set of systems that interact with each other.
- The description of the taxonomic system was sharpened by including in the standards for grades 6-8 the classification of organisms into "the *currently recognized* kingdoms."
- At the high school level, we recognized the growing importance of molecular biology by adding the standard asking students to "Describe the processes of replication, transcription, and translation and how they relate to each other in molecular biology."
- In the physics standards, plasma was specified as the fourth state of matter.

We will continue to work with schools and districts to implement the 2001 Science and Technology/Engineering Curriculum Framework over the next several years, and we encourage you to send us your comments as you use it. All of the curriculum frameworks are subject to continuous review and improvement for the benefit of the students of the Commonwealth.

Thank you again for your ongoing support and for your commitment to achieving the goals of education reform.

Sincerely,

David P. Driscoll
Commissioner of Education

Acknowledgments

The 2001 Science and Technology/Engineering Curriculum Framework is the result of the contributions of many educators across the state. Because of the broad-based, participatory nature of the revision process, this document cannot reflect all of the professional views of every contributor. It reflects instead a balanced synthesis of their suggestions. The Department of Education wishes to thank all of the groups that contributed to the development of these science and technology/engineering standards: the Science and Technology/Engineering Revision Panel, the Mathematics/Science Advisory Council, the Technology/Engineering Advisory Council, grade-span teacher groups, professional educational associations and organizations, and all of the individual teachers, administrators, scientists, engineers, science education faculty, and parents who took the time to provide thoughtful comments during the public comment period.

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The Science and Technology/Engineering Curriculum Framework is available on-line at the Department's website (www.doe.mass.edu/frameworks/current.html). The Word and PDF files are the same as this printed version. The HTML file is a dynamic version that is continually being updated with new examples and vignettes that are linked directly to the learning standards. If you would like to contribute an example or vignette that has been successful in your classroom, please contact the Office of Mathematics, Science, and Technology/Engineering at (781) 338-3483.

Table of Contents

Introduction

The Massachusetts Science and Technology/Engineering Curriculum Framework is one of seven curriculum frameworks that advance Massachusetts's educational reform in learning, teaching, and assessment. It was created and has been revised by teachers and administrators of science and technology/engineering programs in prekindergarten through grade 12 school districts, by college and university professors, and by engineers and scientists in the various domains working with staff from the Department of Education. Its purpose is to guide teachers and curriculum coordinators about what content should be taught from PreK through high school.

Organization of the document

The guiding principles present a set of tenets about effective PreK–12 programs and instruction in science and technology/engineering. These principles articulate ideals of teaching, learning, assessing, and administering science and technology/engineering programs in Massachusetts. They show how educators may create educational environments characterized by curiosity, persistence, respect for evidence, open-mindedness balanced with skepticism, and a sense of responsibility.

The strands organize the content areas into earth and space science, life science (biology), the physical sciences (physics and chemistry), and technology/engineering. Each strand details the essential knowledge and skills that students should acquire through the grades. The learning standards within each strand are organized by grade span and grouped by subject area topics. Following the topics at the high school level are broad concepts to which the learning standards are related. The standards outline specifically what students should know and be able to do at the end of each grade span.

For grades PreK–5, the standards are accompanied by ideas for developing investigations and learning experiences in science and by extensions to learning in technology/engineering. These latter activities are coded to the PreK–5 technology/engineering standards. Additional activities to enhance the PreK–8 learning standards are found in Appendix III.

For grades 6–8, the science standards are accompanied by examples of sound science-based learning experiences. There are no extensions to technology/engineering associated with the science learning standards at this level because technology education is configured as a separate course in grades 6–8. Examples of learning activities for standards in the technology/engineering strand are included with the technology/engineering standards.

For grade 9 and higher, learning standards are listed for full first-year courses in earth and space science, biology, physics, chemistry, and technology/engineering. Core standards are in boldface type in each set of standards. From each set of core standards in the four sciences, a subset has been chosen for a two-year integrated science sequence in grades 9 and 10 (shown in Appendix II).

At the high school level, the Department will provide discipline-specific assessment options based on the core standards in earth and space science, biology, chemistry, physics, and technology/engineering. The Department will also offer an assessment for the two-year integrated science course sequence in grades 9 and 10 based on the subset of standards chosen for it. Districts will decide what assessment options to provide their students based on the courses they offer in grade 9 and higher.

Development of the standards

This framework derives from two reform initiatives in Massachusetts, the Education Reform Act of 1993 and Partnerships Advancing the Learning of Mathematics and Science (PALMS). Since 1992, the PALMS Statewide Systemic Initiative has been funded by the National Science Foundation in partnership with the state and the Noyce Foundation. Of the seven initial goals for this initiative, the first was to develop, disseminate, and implement curriculum frameworks in mathematics and in science and technology. The initial science and technology framework was approved in 1995, and was implemented in the field.

Because the Education Reform Act required that frameworks be reviewed and revised periodically, a revision panel was appointed by the Commissioner and the Board of Education in the summer of 1998. The panel examined the standards in the original framework, reviewed comments on them from the field, and reassessed their appropriateness in order to work out a more coherent organization of concepts and skills through the grade levels. The panel referred to the *Benchmarks for Science Literacy–Project 2061,* data from the Third International Mathematics and Science Study, the *National Research Council's National Science Education Standards,* the Technology for All Americans Project, results from the 1998 administration of the MCAS, and advances in science and technology/engineering.

The draft produced by the revision panel was released for public comment in August 1999. Based on comments on this draft from science and technology/engineering teachers and other educators, further revisions were made, particularly at the high school level. Groups of high school science teachers in each domain of science developed a comprehensive set of standards for a course in each domain from which core standards were chosen for discipline-specific assessments. Groups of technology/engineering educators also contributed to the development of a comprehensive set of standards and core standards for the technology/engineering course at the high school level.

Purpose and Nature of Science and Technology / Engineering

The purpose of science and technology/engineering education

Investigations in science and technology/engineering involve a range of skills, habits of mind, and subject matter knowledge. The purpose of science and technology/engineering education in Massachusetts is to enable students to draw on these skills, habits, and subject matter knowledge for informed participation in the intellectual and civic life of American society, and for further education in these areas if they seek it.

The nature of science

Science may be described as attempts to give good accounts of the patterns in nature. The result of scientific investigation is an understanding of natural processes. Scientific explanations are always subject to change in the face of new evidence. Ideas with the most durable explanatory power become established theories or are codified as laws of nature. Overall, the key criterion of science is that it provides a clear, rational, and succinct account of a pattern in nature. This account must be based on data gathering and analysis and other evidence obtained through direct observations or experiments, reflect inferences that are broadly shared and communicated, and be accompanied by a model that offers a naturalistic explanation expressed in conceptual, mathematical, and/or mechanical terms. Here are some everyday examples of patterns seen in nature:

- The sun appears to move each day from the eastern horizon to the western horizon.
- Virtually all objects released near the surface of the earth sooner or later fall to the ground.
- Parents and their offspring are similar, e.g., lobsters produce lobsters, not cats.
- Green is the predominant color of most plants.
- Some objects float while others sink.
- Fire yields heat.
- Weather in North America generally moves from west to east.
- Many organisms that once inhabited the earth no longer do so.

It is beyond the scope of this document to examine the scientific accounts of these patterns. Some are well known, such as that the rotation of the earth on its axis gives rise to the apparent travel of the sun across the sky, or that fire is a transfer of energy from one form to another. Others, like buoyancy or the cause of extinction, require subtle and sometimes complex accounts. These patterns, and many others, are the puzzles that scientists attempt to explain.

The nature of technology/engineering

Technology/engineering seeks different ends from those of science. Engineering strives to design and manufacture useful devices or materials, defined as technologies, whose purpose is to increase our efficacy in the world and/or our enjoyment of it. Can openers are technology, as are microwave ovens, microchips, steam engines, camcorders, safety glass, zippers, polyurethane, the Golden Gate Bridge, much of Disney World, and the "Big Dig" in Boston. Each of these, and innumerable other examples of technology/engineering, emerges from the scientific knowledge, imagination, persistence, talent, and ingenuity of its practitioners. Each technology represents a designed solution, usually created in response to a specific practical problem. As with science, direct engagement with the phenomena in question is central to the definition of these problems and their successful solution.

The relationship between science and technology/engineering

In spite of their different ends, science and technology have become closely, even inextricably, related in many fields. The instruments that scientists use, such as the microscope, balance, and chronometer, result from technology/engineering. Scientific ideas, such as the laws of motion, the relationship between electricity and magnetism, the atomic model, and the model of DNA, have contributed to improvement of the internal combustion engine, power transformers, nuclear power, and human gene therapy. In some of the most sophisticated efforts of scientists and engineers, the boundaries are so blurred that the designed device allows us to discern heretofore unnoticed natural patterns while the accounting for those patterns makes it possible to continue to develop the device. In these instances, scientists and engineers are engaged together in extending knowledge.

Inquiry and Experimentation

Asking and pursuing questions are keys to learning in all academic disciplines. There are multiple ways that students can ask and pursue questions in the science class. One way is to explore scientific phenomena in a classroom laboratory or around the school. Classroom investigation and experimentation can build essential scientific skills such as observing, measuring, replicating experiments, manipulating equipment, and collecting and reporting data. Students may sometimes choose what phenomenon to study, e.g., for a science fair project. More often, they conduct investigations and experiments that are selected and guided by the teacher.

Students can also examine the questions pursued by scientists in their investigations of natural phenomena and processes as reported or shown in textbooks, papers, videos, the internet, and other media. These sources are valuable because they efficiently organize and highlight the key concepts and supporting evidence that characterize the most important work in science. Such study can then be supported in the classroom by demonstrations, experiments, or simulations that deliberately manage features of a natural object or process. Whatever the instructional approach, science instruction should include both concrete and manipulable materials and explanatory diagrams and textbooks.

Scientific inquiry and experimentation should not be taught or tested as separate, stand-alone skills. Rather, opportunities for inquiry and experimentation should arise within a well-planned curriculum in the domains of science. They should be assessed through examples drawn from the life, physical, and earth and space science standards so that it is clear to students that in science, *what* is known does not stand separate from *how* it is known.

In the earliest grades, scientific investigations can center on student questions, observations, and communication about what they observe. For example, students might plant a bean seed following simple directions written on a chart. Then they would write down what happens over time in their own words.

In the later elementary years, students can plan and carry out investigations as a class, in small groups, or independently, often over a period of several class lessons. The teacher should first model the process of selecting a question that can be answered, formulating a hypothesis, planning the steps of an experiment, and determining the most objective way to test the hypothesis. Students should begin to incorporate the mathematical skills of measuring and graphing to communicate their findings.

In the middle school years, teacher guidance remains important but allows for more variations in student approach. Students at this level are ready to formalize their understanding of what an experiment requires by controlling variables to ensure a fair test. Their work becomes more quantitative, and they learn the importance of carrying out several measurements to minimize sources of error. Because students at this level use a greater range of tools and equipment, they must learn safe laboratory practices (see Appendix V). At the conclusion of their investigations, students at the middle school level can be expected to prepare formal reports of their questions, procedures, and conclusions.

In high school, students develop greater independence in designing and carrying out experiments, most often working alone or in small groups. They come up with questions and hypotheses that build on what they have learned from secondary sources. They learn to critique and defend their findings, and to revise their explanations of phenomena as new findings emerge. Their facility with using a variety of physical and conceptual models increases. Students in the final two years of high school can be encouraged to carry out extended independent experiments that explore a scientific hypothesis in depth, sometimes with the assistance of a scientific mentor from outside the school setting.

Skills of Inquiry

Grades PreK–2

- Ask questions about objects, organisms, and events in the environment.
- Tell about why and what would happen if?
- Make predictions based on observed patterns.
- Name and use simple equipment and tools (e.g., rulers, meter sticks, thermometers, hand lenses, and balances) to gather data and extend the senses.
- Record observations and data with pictures, numbers, or written statements.
- Discuss observations with others.

Grades 3–5

- Ask questions and make predictions that can be tested.
- Select and use appropriate tools and technology (e.g., calculators, computers, balances, scales, meter sticks, graduated cylinders) in order to extend observations.
- Keep accurate records while conducting simple investigations or experiments.
- Conduct multiple trials to test a prediction. Compare the result of an investigation or experiment with the prediction.
- Recognize simple patterns in data and use data to create a reasonable explanation for the results of an investigation or experiment.
- Record data and communicate findings to others using graphs, charts, maps, models, and oral and written reports.

Grades 6–8

- Formulate a testable hypothesis.
- Design and conduct an experiment specifying variables to be changed, controlled, and measured.
- Select appropriate tools and technology (e.g., calculators, computers, thermometers, meter sticks, balances, graduated cylinders, and microscopes), and make quantitative observations.
- Present and explain data and findings using multiple representations, including tables, graphs, mathematical and physical models, and demonstrations.
- Draw conclusions based on data or evidence presented in tables or graphs, and make inferences based on patterns or trends in the data.
- Communicate procedures and results using appropriate science and technology terminology.
- Offer explanations of procedures, and critique and revise them.

High School

- Pose questions and state hypotheses based on prior scientific observations, experiments, and knowledge.
- Distinguish between hypothesis and theory as scientific terms.
- Either individually or as part of a student team, design and complete a scientific experiment that extends over several days or weeks.
- Use mathematics to analyze and support findings and to model conclusions.
- Simulate physical processes or phenomena using different kinds of representations.
- Identify possible reasons for inconsistent results, such as sources of error or uncontrolled conditions.
- Revise scientific models.
- Communicate and defend a scientific argument.

Guiding Principles

GUIDING PRINCIPLE I

A comprehensive science and technology/engineering education program enrolls all students from PreK through grade 12.

Students benefit from studying science and technology/engineering throughout all their years of schooling. They should learn the fundamental concepts of each domain of science, as well as the connections across those domains and to technology/engineering. The purpose of this framework is to delineate what knowledge is essential if students are to attain understanding of basic scientific concepts before graduation from high school.

Students in grades PreK–5 should have science instruction on a regular basis every year. Approximately one-quarter of their science time in PreK–5 should be devoted to technology/engineering. In middle school, they should have a full year of science study every year. Within the grades 6–8 span, students should also have one year of technology/engineering education in addition to three years of science. Schools may choose to offer technology/engineering as a semester course in each of two years; as a full year course in grade 8; or in three units, one each year in grades 6, 7, and 8. In grades 9 and 10, all students should have full-year laboratory-based science courses, and in grades 11 and 12, they should take more science courses or pursue advanced study in science through advanced placement courses, independent research, or study of special topics. In technology/engineering at the high school level, students may take semester- or year-long coursework in this area to complement or extend their study of science and mathematics.

GUIDING PRINCIPLE II

An effective science and technology/engineering program builds students' understanding of the fundamental concepts of each domain of science and their understanding of the connections across these domains and to basic concepts in technology/engineering.

Each domain of science has its particular approach and area of concern. Taken together, they present a coherent view of the world. Students need to understand that much of the scientific work done in the world draws on multiple disciplines. Oceanographers, for instance, use their knowledge of physics, chemistry, biology, earth science, and technology to chart the course of ocean currents. Connecting the domains of natural science with mathematical study and with one another, and then to practical applications through technology and engineering, should be one goal of science education.

In the elementary grades, coursework should integrate all of the major domains of science and technology/engineering every year. In one approach, instruction can be organized around distinct but complementary units drawn from the earth, life, and physical sciences and from technology/engineering. In another approach, teachers working together and with outside help (e.g., museum personnel, scientists, or engineers) can organize activities around concepts or topics unifying all of the domains.

At the middle and high school level, science faculty may choose either a discipline-based or an integrated approach in science. In choosing an approach, faculty will want to consider the particular content expertise of teachers and the academic goals, abilities, and interests of students. In this document, the high school science standards are written to allow for choice in course organization and sequence.

GUIDING PRINCIPLE III

Science and technology/engineering are integrally related to mathematics.

Mathematics is an essential tool for scientists and engineers because it specifies in precise and abstract (general) terms many attributes of natural phenomena and manmade objects and the nature of relationships among them. Mathematics facilitates precise analysis and prediction.

Take, for example, the equation for one of Newton's Laws: $F = ma$ (force equals mass times acceleration). This remarkably succinct description states the invariable relationship among three fundamental features of our known universe. Its mathematical form permits all kinds of analysis and predictions.

Other insights come from simple geometric analysis applied to the living world. For example, volume increases by the cube of an object's fundamental dimension while area increases by the square. Thus, in an effort to maintain constant body temperature, most small mammals metabolize at much higher rates than larger ones. It is hard to imagine a more compelling and simple explanation than this for the relatively high heart rate of rodents versus antelopes.

Even more simple is the quantification of dimensions. How small is a bacterium, how large is a star, how dense is lead, how fast is sound, how hard is a diamond, how sturdy is the bridge, how safe is the plane? These questions can all be answered mathematically. And with these analyses, all kinds of intellectual and practical questions can be posed and solved.

Because of the importance of mathematics to science and technology/engineering, all teachers, curriculum coordinators, and others who help implement this framework must be aware of the level of mathematical knowledge needed for each science course at the high school level and ensure that the appropriate mathematical knowledge has already been taught or, at the least, is being taught concurrently.

GUIDING PRINCIPLE IV

An effective program in science and technology/engineering addresses students' prior knowledge and misconceptions.

Students are innately curious about the world and wonder how things work. They may make spontaneous, perceptive observations about natural objects and processes, and can often be found taking things apart and reassembling them. In many cases, they have developed mental models about how the world works. However, these mental models may be inaccurate even though they may make sense to the students, and the inaccuracies work against learning.

Research into misconceptions demonstrates that children can hold onto misconceptions even while reproducing what they have been taught are the "correct answers." For example, young children may repeat that the earth is round, as they have been told, while continuing to believe that the earth is flat, which is what they can see for themselves. They find a variety of ingenious ways of reconciling their knowledge, e.g., by concluding that we live on a flat plate inside the round globe.

Teachers must be skilled at uncovering inaccuracies in students' prior knowledge and observations, and in devising experiences that will challenge inaccurate beliefs and redirect student learning along more productive routes. The students' natural curiosity provides one entry point for learning experiences designed to remove students' misconceptions in science and technology/engineering.

GUIDING PRINCIPLE V

Investigation, experimentation, and problem solving are central to science and technology/engineering education.

Investigations introduce students to the nature of original research, increase students' understanding of scientific and technological concepts, promote skill development, and provide entry points for all learners. Teachers should establish the learning goals and context for an experiment, guide student activities, and help students focus on important ideas and concepts.

Puzzlement and uncertainty are common features in experimentation. Students need time to examine their ideas as they learn how to apply them to explaining a natural phenomenon or solving a design problem. Opportunities for students to reflect on their own ideas, collect evidence, make inferences and predictions, and discuss their findings are all crucial to growth in understanding.

When possible, students should also replicate in the classroom important experiments that have led to well-confirmed knowledge about the natural world, e.g., Archimedes' principle and the electric light bulb. By carefully following the thinking of experts, students can learn to improve their own problem-solving efforts.

GUIDING PRINCIPLE VI

Students learn best in an environment that conveys high academic expectations for all students.

A high quality education system simultaneously serves the goals of equity and excellence. At every level of the education system, teachers should act on the belief that young people from every background can learn rigorous science and solve tough engineering problems. Teachers and guidance personnel should advise students and parents that rigorous courses and advanced sequences in science and technology/engineering will prepare them for success in college and the workplace. After-school, weekend, and summer enrichment programs offered by school districts or communities may be especially valuable and should be open to all. Schools and districts should also invite role models from business and the community (including professional engineers and scientists) to visit classes, work with students, and contribute to instruction.

GUIDING PRINCIPLE VII

Assessment in science and technology/engineering serves to inform student learning, guide instruction, and evaluate student progress.

Assessment assists teachers in improving classroom practice, planning curricula, developing self-directed learners, and reporting student progress. It provides students with information about how their knowledge and skills are developing and what can be done to improve them. It lets parents know how well their children are doing and what needs to be done to help them do better. In essence, assessment reflects classroom expectations and shows the outcomes of student learning.

Assessments come in many forms. These include paper-and-pencil testing, performance testing, interviews, and portfolios, as well as less formal inventories such as regular observation of student responses to instruction. Diagnostic information gained from multiple forms of assessment enables teachers to adjust their day-to-day and week-to-week practices to foster greater student achievement.

The framework's learning standards are a key resource for setting knowledge and performance standards. In helping students achieve standards, teachers should use a variety of question formats: short answer, multiple choice, and open ended. They should also develop performance-based assessments that allow students to demonstrate what they have learned in the context of solving a complex problem. This kind of assessment requires students to refine a problem, devise a strategy to solve it, conduct sustained work, and deal with both complex concepts and discrete facts.

GUIDING PRINCIPLE VIII

An effective program in science and technology/engineering gives students opportunities to collaborate in scientific and technological endeavors and communicate their ideas.

Scientists and engineers work as members of their professional communities. Ideas are tested, modified, extended, and reevaluated by those professional communities over time. Thus, the ability to convey their ideas to others is essential for these advances to occur.

Students need opportunities to talk about their work in focused discussions with peers and with those who have more experience and expertise. This communication can occur informally, in the context of an ongoing student collaboration or on-line consultation with a scientist or engineer, or more formally, when a student presents findings from an individual or group investigation. Effective communication of scientific and technological ideas requires practice in making written and oral presentations, fielding questions, responding to critiques, and developing replies.

GUIDING PRINCIPLE IX

A coherent science and technology/engineering program requires district-wide planning.

An effective curriculum that addresses the learning standards of this framework needs to be planned as a unitary PreK–12 enterprise. Teachers need to work across grade levels and across schools to ensure that the curriculum is a coherent whole. There needs to be agreement among teachers in different classrooms and at different levels about what is to be taught in given grades. For example, middle school teachers should be able to expect that students coming from different elementary schools within a district share a common set of experiences and understandings in science and technology/engineering, and that the students they send on to high school will be well-prepared for what comes next. In order for this expectation to be met, middle school teachers will need to plan curricula in common with their elementary and high school colleagues and district staff. To facilitate planning, districts will need to provide their staff with adequate planning time and resources.

Guiding Principle X

Implementation of an effective science and technology/engineering program requires collaboration with experts, appropriate materials, support from parents and community, ongoing professional development, and quantitative and qualitative assessment.

Implementation of an effective science and technology/engineering curriculum aligned with these learning standards at every grade level is a multiyear process. The district coordinator should be involved in articulating, coordinating, and piloting a district-wide (PreK–12) science and technology/engineering curriculum. Districts may choose to pilot and systematically evaluate several different programs in multiple classrooms. Following the choice of a program, implementation may proceed one grade at a time or by introduction of a limited number of units at several grade levels each year.

School districts should select engaging, challenging, and accurate curriculum materials that are based on research on how children learn science and on how to overcome student misconceptions. To aid their selection, districts may want to consult the *Guidebook to Examine School Curricula* in the TIMSS Toolkit or Appendix VII in this framework, "Criteria for Evaluating Instructional Materials and Programs."

Implementation also requires extensive professional development. Teachers must have the content knowledge and the pedagogical expertise to use the materials in a way that enhances student learning. A well-planned program for professional development should provide for both content learning and content-based pedagogical training. Each area of science study should be taught by teachers who are certified in that area. Because of the nature of the technology/engineering environment, it is strongly recommended that it be taught in the middle and high school by teachers who are certified in technology education, and who are therefore very familiar with the safe use of tools and machines. Science and technology/engineering coordinators for the elementary grades could help to ensure that teachers in elementary schools are supported in their efforts to help students learn science and technology/engineering.

Introduction of a new science and technology/engineering program can be more effective when families and community members are brought into the selection and planning process. Parents who have a chance to examine and work with the materials in the context of a Family Science Night, Technology/Engineering Fair, or other occasion will better understand and support their children's learning. In addition, local members of the science and engineering community may be able to lend their own expertise to assist with the implementation of a new curriculum. Teachers and administrators should invite scientists, engineers, higher education faculty, representatives of local businesses, and museum personnel to help evaluate the planned curriculum and enrich it with community connections.

When planning for the introduction of a new curriculum, it is important to identify explicitly how success will be measured. Indicators need to be determined and should be communicated to all stakeholders. Supervisors should monitor whether the curriculum is actually being used and how instruction has changed, and make this information available to a broad range of participants. Teacher teams, working across grade levels, should look at student work and other forms of assessment to determine whether there is evidence for the sought-for gains in student understanding.

Science and Technology/Engineering Learning Standards, PreK–High School

STRAND 1: EARTH AND SPACE SCIENCE

In earth and space science, students study the origin, structure, and physical phenomena of the earth and the universe. Earth and space science studies include concepts in geology, meteorology, oceanography, and astronomy. These studies integrate previously or simultaneously gained understandings in physical and life science with the physical environment. Through a study of earth and space, students learn about the nature and interactions of oceans and the atmosphere, earth processes including plate tectonics, changes in topography over time, and the place of the earth in the universe.

In grades PreK–2, students are naturally interested in everything around them. This curiosity leads them to observe, collect, and record information about the earth and about objects visible in the sky. Teachers should encourage their students' observations without feeling compelled to offer the precise scientific reasons for these phenomena. Young children bring these experiences to school and learn to extend and focus their explorations. In the process, they learn to work with tools like magnifiers and simple measuring devices. The learning standards at this level fall under the topics of *Earth's Materials, Weather, Sun as a Source of Heat and Light,* and *Periodic Phenomena.*

In grades 3–5, students explore properties of earth materials and how they change. They conduct tests to classify materials by observed properties, make and record sequential observations, note patterns and variations, and look for factors that cause change. Students observe weather phenomena and describe them quantitatively using simple tools. They study the water cycle, including the forms and locations of water. The focus is on having students generate questions, investigate possible solutions, make predictions, and evaluate their conclusions. Learning standards fall under the topics of *Rocks and Their Properties, Soil, Weather, Water Cycle, Earth's History,* and *The Earth in the Solar System.*

In grades 6–8, students gain sophistication and experience in using models, satellite images, and maps to represent processes and features. In the early part of this grade span, students continue to investigate geological materials' properties and methods of origin. As their experiments become more quantitative, students should begin to recognize that many of the earth's natural events occur because of processes such as heat transfer.

At this level, students should recognize the interacting nature of the earth's four major systems: the geosphere, hydrosphere, atmosphere, and biosphere. They should begin to see how the earth's movement affects both the living and nonliving components of the world. Attention shifts from the properties of particular objects toward an understanding of the place of the earth in the solar system and changes in the earth's composition and topography over time. Middle school students grapple with the importance of and methods of obtaining direct and indirect evidence to support current thinking. They recognize that new technologies and observations change our explanations about how things in the natural world behave. Learning standards fall under the topics of *Mapping the Earth, Earth's Structure, Heat Transfer in the Earth System, Earth's History,* and *The Earth in the Solar System.*

The unifying theme of 9th and 10th grade earth and space science is the interaction of the Earth's various spheres and human activities. It falls into the following categories: *Matter and Energy in the Earth System, Earth's Sources of Energy, Earth's Processes and Cycles,* and *The Origin and Evolution of the Universe.* Students continue their studies to include the universe. As they review geological, meteorological, oceanographic, and astronomical data, they learn about direct and indirect evidence and consider how these might be used to test competing theories about the origin of stars and planets, including our own solar system. Through increasingly sophisticated investigations and measurements, students also learn about various geological processes, including plate tectonics, wind formation, the flow of water through the local watershed, and changes in the earth over time.

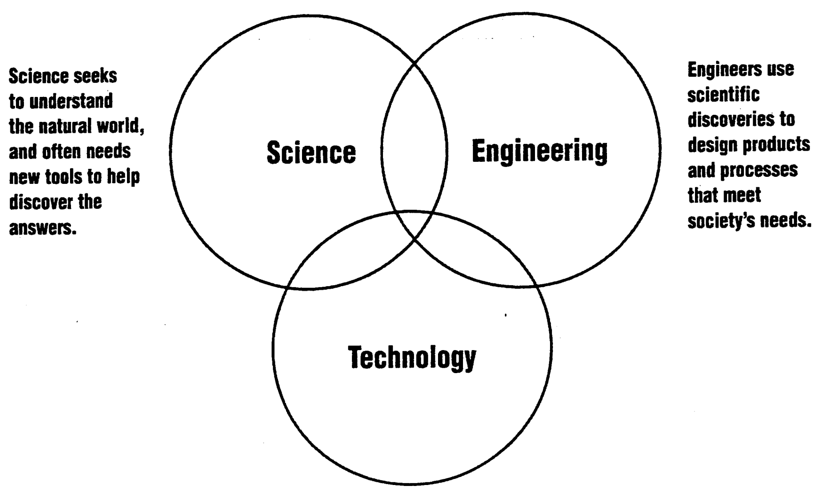
MASS

STRAND 4: TECHNOLOGY/ENGINEERING

Science tries to understand the natural world. Based on the knowledge that scientists develop, the goal of engineering is to solve practical problems through the development or use of technologies. For example, the planning, designing, and construction of the Central Artery Tunnel project in Boston (commonly referred to as the "Big Dig") is a complex and technologically challenging project that draws on knowledge of earth science, physics, and construction and transportation technologies.

Technology/engineering works in conjunction with science to expand our capacity to understand the world. For example, scientists and engineers apply scientific knowledge of light to develop lasers and fiber optic technologies and other technologies in medical imaging. They also apply this scientific knowledge to develop such modern communications technologies as telephones, fax machines, and electronic mail.

The Relationship Among Science, Engineering, and Technology



Technologies (products and processes) are the result of engineered designs. They are created by technicians to solve societal needs and wants.

Although the term technology is often used by itself to describe the educational application of computers in a classroom, instructional technology is a subset of the much broader field of technology. While important, computers and instructional tools that use computers are only a few of the many technological innovations in use today.

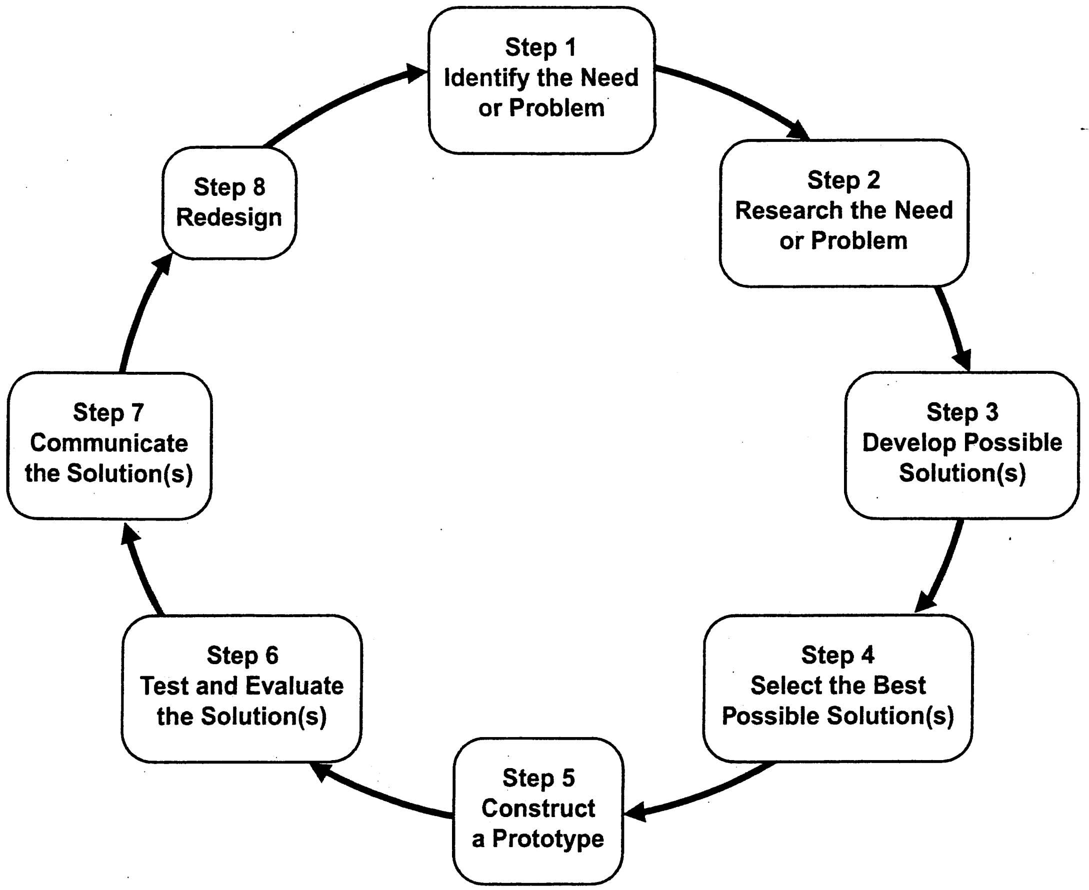
Technologies developed through engineering include the systems that provide our houses with water and heat; roads, bridges, tunnels, and the cars that we drive; airplanes and spacecraft; cellular phones, televisions, and computers; many of today's children's toys; and systems that create special effects in movies. Each of these came about as the result of recognizing a need or problem and creating a technological solution. Figure 1 on page 73 shows the steps of the engineering design process. Beginning in the early grades and continuing through high school, students carry out this design process in ever more sophisticated ways. As they gain more experience and knowledge, they are able to draw on other disciplines, especially mathematics and science, to understand and solve problems.

Students are experienced technology users before they enter school. Their natural curiosity about how things work is clear to any adult who has ever watched a child doggedly work to improve the design of a paper airplane, or to take apart a toy to explore its insides. They are also natural engineers and inventors, builders of sandcastles at the beach and forts under furniture. Most students in grades PreK–2 are fascinated with technology. While learning the safe use of tools and materials that underlie engineering solutions, they are encouraged to manipulate materials that enhance their three-dimensional visualization skills–an essential component of the ability to design. They identify and describe characteristics of natural and manmade materials and their possible uses and identify the use of basic tools and materials, e.g., glue, scissors, tape, ruler, paper, toothpicks, straws, and spools. In addition, students at this level learn to identify tools and simple machines used for a specific purpose (e.g., ramp, wheel, pulley, lever) and describe how human beings use parts of the body as tools.

Students in grades 3–5 learn how appropriate materials, tools, and machines extend our ability to solve problems and invent. They identify materials used to accomplish a design task based on a specific property and explain which materials and tools are appropriate to construct a given prototype. They achieve a higher level of engineering design skill by recognizing a need or problem, learn different ways that the problem can be represented, and work with a variety of materials and tools to create a product or system to address it.

In grades 6–8, students pursue engineering questions and technological solutions that emphasize research and problem solving. They identify and understand the five elements of a technology system (goal, inputs, processes, outputs, and feedback). They acquire basic skills in the safe use of hand tools, power tools, and machines. They explore engineering design; materials, tools, and machines; and communication, manufacturing, construction, transportation, and bioengineering technologies. Starting in these grades and extending through grade 10, the topics of power and energy are incorporated into the study of most areas of technology. Students integrate knowledge they acquired in their mathematics and science curricula to understand the links to engineering. They achieve a more advanced level of skill in engineering design by learning to conceptualize a problem, design prototypes in three dimensions, and use hand and power tools to construct their prototypes, test their prototypes, and make modifications as necessary. The culmination of the engineering design experience is the development and delivery of an engineering presentation.

Figure 1
Steps of the Engineering Design Process



1. Identify the need or problem
2. Research the need or problem
   - Examine current state of the issue and current solutions
   - Explore other options via the internet, library, interviews, etc.
3. Develop possible solution(s)
   - Brainstorm possible solutions
   - Draw on mathematics and science
   - Articulate the possible solutions in two and three dimensions
   - Refine the possible solutions
4. Select the best possible solution(s)
   - Determine which solution(s) best meet(s) the original requirements
5. Construct a prototype
   - Model the selected solution(s) in two and three dimensions
6. Test and evaluate the solution(s)
   - Does it work?
   - Does it meet the original design constraints?
7. Communicate the solution(s)
   - Make an engineering presentation that includes a discussion of how the solution(s) best meet(s) the needs of the initial problem, opportunity, or need
   - Discuss societal impact and tradeoffs of the solution(s)
8. Redesign
   - Overhaul the solution(s) based on information gathered during the tests and presentation

Students in grades 9 and 10 learn to apply scientific and mathematical knowledge in a full-year, comprehensive technology/engineering course. The topics addressed include engineering design; construction technologies; power and energy technologies in fluid, thermal, and electrical systems; communication technologies; and manufacturing technologies. Students engage in experiences that enhance their skills in designing, building, and testing prototypes. The culmination of this level of design experience is also the development and delivery of an engineering presentation.

Technology/engineering curricula in grades 11 and 12 follow the approaches used for the previous two grades but expand in a variety of areas based on available school expertise and student interest. Students may explore advanced technology/engineering curricula such as automation and robotics, multimedia, architecture and planning, biotechnology, and computer information systems. They may continue building on their background in engineering design by working on inventions. Course offerings in the high school grades should engage students who are interested in:

- expanding their studies in the area of engineering and technology because they are interested in a college-level engineering program,
- pursuing career pathways in relevant technology fields, or
- learning about certain areas of technology/engineering to expand their general educational background, but who will not necessarily follow a technical career.

All areas of study should be taught by teachers who are certified in that discipline. Because of the hands-on, active nature of the technology/engineering environment, it is strongly recommended that it be taught in the middle and high school by teachers who are certified in technology education, and who are very familiar with the safe use of tools and machines.

Technology/Engineering, Grades PreK–8

Please note: Suggested extensions to learning in technology/engineering for grades PreK–5 are listed with the science learning standards. See pages 21–26 (earth and space science), 39–44 (life science), and 55–59 (physical sciences).

Grades PreK–2

1. Materials and Tools

Broad Concept: Materials both natural and human-made have specific characteristics that determine how they will be used.

1.1 Identify and describe characteristics of natural materials (e.g., wood, cotton, fur, wool) and human-made materials (e.g., plastic, Styrofoam).

1.2 Identify and explain some possible uses for natural materials (e.g., wood, cotton, fur, wool) and human-made materials (e.g., plastic, Styrofoam).

1.3 Identify and describe the safe and proper use of tools and materials (e.g., glue, scissors, tape, ruler, paper, toothpicks, straws, spools) to construct simple structures.

2. Engineering Design

Broad Concept: Engineering design requires creative thinking and consideration of a variety of ideas to solve practical problems.

2.1 Identify tools and simple machines used for a specific purpose, e.g., ramp, wheel, pulley, lever.

2.2 Describe how human beings use parts of the body as tools (e.g., teeth for cutting, hands for grasping and catching), and compare their use with the ways in which animals use those parts of their bodies.

Grades 3–5

1. Materials and Tools

Broad Concept: Appropriate materials, tools, and machines extend our ability to solve problems and invent.

1.1 Identify materials used to accomplish a design task based on a specific property, i.e., weight, strength, hardness, and flexibility.

1.2 Identify and explain the appropriate materials and tools (e.g., hammer, screwdriver, pliers, tape measure, screws, nails, and other mechanical fasteners) to construct a given prototype safely.
1.3 Identify and explain the difference between simple and complex machines, e.g., hand can opener that includes multiple gears, wheel, wedge gear, and lever.

2. Engineering Design

Broad Concept: Engineering design requires creative thinking and strategies to solve practical problems generated by needs and wants.

2.1 Identify a problem that reflects the need for shelter, storage, or convenience.
2.2 Describe different ways in which a problem can be represented, e.g., sketches, diagrams, graphic organizers, and lists.
2.3 Identify relevant design features (e.g., size, shape, weight) for building a prototype of a solution to a given problem.
2.4 Compare natural systems with mechanical systems that are designed to serve similar purposes, e.g., a bird's wings as compared to an airplane's wings.

Grades 6–8

Please note: For grades 6–high school, there are suggested learning activities after each set of learning standards. The numbers in parentheses after each activity refer to the related technology/engineering learning standard(s).

1. Materials, Tools, and Machines

Broad Concept: Appropriate materials, tools, and machines enable us to solve problems, invent, and construct.

1.1 Given a design task, identify appropriate materials (e.g., wood, paper, plastic, aggregates, ceramics, metals, solvents, adhesives) based on specific properties and characteristics (e.g., weight, strength, hardness, and flexibility).
1.2 Identify and explain appropriate measuring tools, hand tools, and power tools used to hold, lift, carry, fasten, and separate, and explain their safe and proper use.
1.3 Identify and explain the safe and proper use of measuring tools, hand tools, and machines (e.g., band saw, drill press, sanders, hammer, screwdriver, pliers, tape measure, screws, nails, and other mechanical fasteners) needed to construct a prototype of an engineering design.

Suggested Learning Activities

- Conduct tests for weight, strength, hardness, and flexibility of various materials, e.g., wood, paper, plastic, ceramics, metals. (1.1)

- Design and build a catapult that will toss a marshmallow the farthest. (1.1, 1.2, 1.3)
- Use a variety of hand tools and machines to change materials into new forms through forming, separating, and combining processes, and processes that cause internal change to occur. (1.2)

2. Engineering Design

Broad Concept: Engineering design is an iterative process involving modeling and optimizing for developing technological solutions to problems within given constraints.

2.1 Identify and explain the steps of the engineering design process, i.e., identify the need or problem, research the problem, develop possible solutions, select the best possible solution(s), construct a prototype, test and evaluate, communicate the solution(s), and redesign.
2.2 Demonstrate methods of representing solutions to a design problem, e.g., sketches, orthographic projections, multiview drawings.
2.3 Describe and explain the purpose of a given prototype.
2.4 Identify appropriate materials, tools, and machines needed to construct a prototype of a given engineering design.
2.5 Explain how such design features as size, shape, weight, function, and cost limitations would affect the construction of a given prototype.
2.6 Identify the five elements of a universal systems model: goal, inputs, processes, outputs, and feedback.

Suggested Learning Activities

- Given a prototype, design a test to evaluate whether it meets the design specifications. (2.1)
- Using test results, modify the prototype to optimize the solution, i.e., bring the design closer to meeting the design constraints. (2.1)
- Communicate the results of an engineering design through a coherent written, oral, or visual presentation. (2.1)
- Develop plans, including drawings with measurements and details of construction, and construct a model of the solution, exhibiting a degree of craftsmanship. (2.2)

3. Communication Technologies

Broad Concept: Ideas can be communicated though engineering drawings, written reports, and pictures.

3.1 Identify and explain the components of a communication system, i.e., source, encoder, transmitter, receiver, decoder, storage, retrieval, and destination.
3.2 Identify and explain the appropriate tools, machines, and electronic devices (e.g., drawing tools, computer-aided design, and cameras) used to produce and/or reproduce design solutions (e.g., engineering drawings, prototypes, and reports).

3.3 Identify and compare communication technologies and systems, i.e., audio, visual, printed, and mass communication.
3.4 Identify and explain how symbols and icons (e.g., international symbols and graphics) are used to communicate a message.

4. Manufacturing Technologies

Broad Concept: Manufacturing is the process of converting raw materials (primary process) into physical goods (secondary process), involving multiple industrial processes, e.g., assembly, multiple stages of production, quality control.

4.1 Describe and explain the manufacturing systems of custom and mass production.
4.2 Explain and give examples of the impacts of interchangeable parts, components of mass-produced products, and the use of automation, e.g., robotics.
4.3 Describe a manufacturing organization, e.g., corporate structure, research and development, production, marketing, quality control, distribution.
4.4 Explain basic processes in manufacturing systems, e.g., cutting, shaping, assembling, joining, finishing, quality control, and safety.

5. Construction Technologies

Broad Concept: Construction technology involves building structures in order to contain, shelter, manufacture, transport, communicate, and provide recreation.

5.1 Describe and explain parts of a structure, e.g., foundation, flooring, decking, wall, roofing systems.
5.2 Identify and describe three major types of bridges (e.g., arch, beam, and suspension) and their appropriate uses (e.g., site, span, resources, and load).
5.3 Explain how the forces of tension, compression, torsion, bending, and shear affect the performance of bridges.
5.4 Describe and explain the effects of loads and structural shapes on bridges.

Suggested Learning Activities

- Design and construct a bridge following specified design criteria, e.g., size, materials used. Test the design for durability and structural stability. (5.3)

6. Transportation Technologies

Broad Concept: Transportation technologies are systems and devices that move goods and people from one place to another across or through land, air, water, or space.

6.1 Identify and compare examples of transportation systems and devices that operate on each of the following: land, air, water, and space.

6.2 Given a transportation problem, explain a possible solution using the universal systems model.
6.3 Identify and describe three subsystems of a transportation vehicle or device, i.e., structural, propulsion, guidance, suspension, control, and support.
6.4 Identify and explain lift, drag, friction, thrust, and gravity in a vehicle or device, e.g., cars, boats, airplanes, rockets.

Suggested Learning Activities

- Design a model vehicle (with a safety belt restraint system and crush zones to absorb impact) to carry a raw egg as a passenger. (6.1)
- Design and construct a magnetic levitation vehicle as used in the monorail system. Discuss the vehicle's benefits and trade-offs. (6.2)
- Conduct a group discussion of the major technologies in transportation. Divide the class into small groups and discuss how the major technologies might affect future design of a transportation mode. After the group discussions, the students draw a design of a future transportation mode (car, bus, train, plane, etc.). The students present their vehicle design to the class, including a discussion of the subsystems used. (6.1, 6.3)

7. Bioengineering Technologies

Broad Concept: Bioengineering technologies explore the production of mechanical devices, products, biological substances, and organisms to improve health and/or contribute improvement to our daily lives.

7.1 Explain examples of adaptive or assistive devices, e.g., prosthetic devices, wheelchairs, eyeglasses, grab bars, hearing aids, lifts, braces.
7.2 Describe and explain adaptive and assistive bioengineered products, e.g., food, bio-fuels, irradiation, integrated pest management.

Suggested Learning Activities

- Brainstorm and evaluate alternative ideas for an adaptive device that will make life easier for a person with a disability, such as a device to pick up objects from the floor. (7.1)

What It Looks Like in the Classroom

Local Wonders

Adapted from the Building Big Activity Guide, pp. 36—37

Technology/Engineering, Grades 6–8

Your community may not have an Eiffel Tower or a Hoover Dam, but you can choose any structure in your community that is significant because of its appearance, uniqueness, or historical or social impact. Consider local bridges, tunnels, skyscrapers or other buildings, domes, dams, and other constructions. You can e-mail the American Society of Civil Engineers at buildingbig@asce.org to connect with a volunteer civil engineer for this activity. To help select your local wonder, have the class brainstorm a list, take a bus tour around town for ideas, or collect some photographs for discussion.

After building newspaper towers and talking about structures and foundations, fifth and sixth graders at the Watertown, Massachusetts Boys and Girls Club brainstormed a list of interesting structures in their town. They selected St. Patrick's, an elaborate church across the street from the clubhouse. The children brainstormed questions about their local wonder. Those with an engineering focus included: When was it built? How long did the construction take? Who built it? What is it made of? Why did the builders choose that material? What is underneath the building? What holds it up? What keeps it from falling down? How was it built? Were there any problems during construction and how were they solved? Questions with a social/environmental focus included: Why was it built? What did the area look like before it was built?

Next, the students investigated their local wonder with some hands-on activities that explore basic engineering principles such as forces, compression, tension, shape, and torsion. They toured the structure, took photographs, researched the structure, interviewed long-time community members about their memories about the structure, and interviewed engineers, architects, and contractors who worked on the project. They conducted research at the library, the Historical Society, and the Watertown Building Inspector's office, where they acquired the building's plans and copies of various permits. They used this information to develop a timeline of the building's history.

Students can use the following method to estimate the size of a large structure. First, measure a friend's height. Have your friend stand next to the structure, while you stand a distance away (across the street, for instance). Close one eye and use your fingers to "stack" your friend's height until you reach the top of the structure. Multiply the number of times you stacked your friend by his/her height to find the total estimated height of the structure.

The outline of the final report may look like this:

I. Name of group submitting report

II. Name and description of structure (identify the type of structure, e.g., bridge, skyscraper, and describe and explain its parts)

III. Location

IV. Approximate date structure was completed

V. Approximate size

VI. Why we chose this particular local wonder

VII. What's important about our local wonder

VIII. Things we learned about our local wonder (include information such as type of construction, engineering design concepts, and forces acting on the structure)

IX. Interesting facts about our local wonder

Any group that completes this project can submit its investigation to pbs.org/building big. Send them your complete report, including photographs or original drawings of your local wonder. Students should be encouraged to draw the structure from a variety of different perspectives. Students can also share their reports with other classes in their school or at a local town meeting.

Assessment Strategies

- Share examples of other groups' completed investigations with the students at the beginning of the project. Discuss and develop criteria for effective write-ups, and identify what constitutes quality work.
- Students can record their learning in an engineering journal. Students can write down each day what they have learned, questions that they may have, resources they found helpful, and resources they need to find. The teacher should read the journals to monitor students' progress and level of participation, and to identify what topics the students have mastered and which areas of learning need to be reinforced by additional instruction.
- Post your local wonder report on your school district website, on the town website, or on a town agency's website, e.g., the Chamber of Commerce. Include an e-mail address and encourage feedback.
- At the end of the unit, provide the students with a photograph of a similar structure from another town or area. Ask them to write a final paper that compares this structure to the local wonder they just studied. How are they alike? Different? Compare the materials, design, and purpose of these structures.

Note: The applicable standards may vary depending upon the type of structure selected.

Engineering Design Learning Standards

2.2 Demonstrate methods of representing solutions to a design problem, e.g., sketches, orthographic projections, multi-view drawings.

2.5 Explain how such design features as size, shape, weight, function, and cost limitations would affect the construction of a given prototype.

Construction Technologies Learning Standards

5.1 Describe and explain parts of a structure, e.g., foundation, flooring, decking, wall, roofing systems.

5.2 Identify and describe three major types of bridges (e.g., arch, beam, and suspension) and their appropriate uses (e.g., site, span, resources, and load).

5.3 Explain how the forces of tension, compression, torsion, bending, and shear affect the performance of bridges.

5.4 Describe and explain the effects of loads and structural shapes on bridges.

Technology/Engineering, Grade 9 or 10

Learning Standards for a Full First-Year Course

1. Engineering Design

Broad Concept: Engineering design involves practical problem solving, research, development, and invention and requires designing, drawing, building, testing, and redesigning.

1.1 Identify and explain the steps of the engineering design process, i.e., identify the problem, research the problem, develop possible solutions, select the best possible solution(s), construct a prototype, test and evaluate, communicate the solution(s), and redesign.

1.2 Demonstrate knowledge of pictorial and multi-view drawings (e.g., orthographic projection, isometric, oblique, perspective) using proper techniques.

1.3 Demonstrate the use of drafting techniques with paper and pencil or computer-aided design (CAD) systems when available.

1.4 Apply scale and proportion to drawings, e.g., 1/4″ = 1′0″.

1.5 Interpret plans, diagrams, and working drawings in the construction of a prototype.

Suggested Learning Activities

- Create an engineering design presentation using multimedia, oral, and written communication. (1.1)
- Choose the optimal solution to a problem, clearly documenting ideas against design criteria and constraints, and explain how human values, economics, ergonomics, and environmental considerations have influenced the solution. (1.1)
- Visit a local industry in any area of technology and describe the research and development processes of the company. (1.1, 1.5)
- Have students utilize library resources/internet to research the patent process (1.1, 1.2, 1.5)
- Create pictorial and multi-view drawings that include scaling and dimensioning. (1.2, 1.3, 1.4, 1.5)
- Create plans, diagrams, and working drawings in the construction of a prototype. (1.2, 1.3, 1.4, 1.5)
- Create drawings that include scale and dimension. (1.2, 1.3)

2. Construction Technologies

Broad Concept: Various materials, processes, and systems are used to build structures.

2.1 Distinguish among tension, compression, shear, and torsion, and explain how they relate to the selection of materials in structures.

Boldface type indicates core standards for full-year courses.

Learning Standards for a Full First-Year Course

2.2 Identify and explain the purposes of common tools and measurement devices used in construction, e.g., spirit level, transit, framing square, plumb bob, spring scale, tape measure, strain gauge, venturi meter, pitot tube.
2.3 Describe how structures are constructed using a variety of processes and procedures, e.g., welds, bolts, and rivets are used to assemble metal framing materials.
2.4 Identify and explain the engineering properties of materials used in structures, e.g., elasticity, plasticity, thermal conductivity, density.
2.5 Differentiate the factors that affect the design and building of structures, such as zoning laws, building codes, and professional standards.
2.6 Calculate quantitatively the resultant forces for live loads and dead loads.

Suggested Learning Activities

- Demonstrate the transmission of loads for buildings and other structures. (2.1, 2.2, 2.6)
- Construct a truss and analyze to determine whether the members are in tension, compression, shear, and/or torsion. (2.1, 2.3, 2.4, 2.5)
- Given several types of measuring tools and testing tools, give students a challenge and have them evaluate the effectiveness of a tool for the given challenge. (2.2)
- Construct and test geometric shapes to determine their structural advantages depending on how they are loaded. (2.3, 2.5, 2.6, 2.6)
- Using a chart from the state building code, students should be able to correctly use the stress strain relationship to calculate the floor joist size needed. (2.4, 2.6)
- Design and conduct a test for building materials such as density, strength, thermal conductivity, specific heat, and moisture resistance. (2.4, 2.5)
- Calculate the live load for the second floor of a building and show how that load is distributed to the floor below. (2.5, 2.6, 2.6)
- Identify ways to protect a watershed, e.g., silt barriers, hay bales, maintenance of watershed areas. (2.5)

3. Energy and Power Technologies–Fluid Systems

Broad Concept: Fluid systems are made up of liquids or gases and allow force to be transferred from one location to another. They also provide water, gas, and oil, and remove waste. They can be moving or stationary and have associated pressures and velocities.

3.1 Differentiate between open (e.g., irrigation, forced hot air system) and closed (e.g., forced hot water system, hydroponics) fluid systems and their components such as valves, controlling devices, and metering devices.
3.2 Identify and explain sources of resistance (e.g., 45° elbow, 90° elbow, type of pipes, changes in diameter) for water moving through a pipe.
3.3 Explain Bernoulli's Principle and its effect on practical applications, i.e., airfoil design, spoiler design, carburetor.

Boldface type indicates core standards for full-year courses.

Learning Standards for a Full First-Year Course

3.4 **Differentiate between hydraulic and pneumatic systems and provide examples of appropriate applications of each as they relate to manufacturing and transportation systems.**
3.5 Explain the relationship between velocity and cross-sectional areas in the movement of a fluid.
3.6 Solve problems related to hydrostatic pressure and depth in fluid systems.

Suggested Learning Activities

- Demonstrate how the selection of piping materials, pumps and other materials is based on hydrostatic effects. (3.1, 3.5, 3.6)
- Demonstrate how a hydraulic brake system operates in an automobile. (3.1, 3.5, 3.6)
- Design a private septic system with consideration to the type of soil in the leach field. (3.1, 3.4)
- Identify the elements of a public sewer system and a private septic system. (3.1, 3.4)
- Explain engineering control volume concepts as applied to a domestic water system. Does the amount of water entering a residence equal the amount of water leaving the residence? (3.5)
- Design an airfoil or spoiler to examine Bernoulli's Principle. (3.5)
- Create a hydraulic arm powered by pistons that is capable of moving in three dimensions. (3.4, 3.6)
- Have students do a simple calculation with velocity and cross-sectional pipe size. Velocity times cross sectional area is a constant. As the pipe size changes the velocity will have to change as well. For example, if the pipe changes from a 2-inch diameter to a 1-inch diameter, the velocity will have to quadruple. (3.5, 3.6)

4. Energy and Power Technologies—Thermal Systems

Broad Concept: Thermal systems involve transfer of energy through conduction, convection, and radiation, and are used to control the environment.

4.1 **Differentiate among conduction, convection, and radiation in a thermal system, e.g., heating and cooling a house, cooking.**
4.2 **Give examples of how conduction, convection, and radiation are used in the selection of materials, e.g., home and vehicle thermostat designs, circuit breakers.**
4.3 Identify the differences between open and closed thermal systems, e.g., humidity control systems, heating systems, cooling systems.
4.4 **Explain how environmental conditions influence heating and cooling of buildings and automobiles.**
4.5 Identify and explain the tools, controls, and properties of materials used in a thermal system, e.g., thermostats, R Values, thermal conductivity, temperature sensors.

Boldface type indicates core standards for full-year courses.

Learning Standards for a Full First-Year Course

Suggested Learning Activities

- Create a model to test the concept of conduction and compute heat losses, e.g., through the multi-layer wall of a building. (4.1, 4.2, 4.4)
- Design and build a hot water solar energy system consisting of a collector, hoses, pump (optional), and storage tank. After it has been heated, calculate the heat gains achieved through solar heating. (4.1, 4.5)
- Design and build a model to test heat losses through various materials and plot the results. (4.2, 4.5)
- Design and build a solar cooker for various food substances. Each student should design their solar cooker for her or his specific food. (4.1, 4.2)
- Design an awning for a business based upon the seasonal changes in the angle of the sun. (4.2)

5. Energy and Power Technologies–Electrical Systems

Broad Concept: Electrical systems generate, transfer, and distribute electricity.

5.1 Describe the different instruments that can be used to measure voltage, e.g., voltmeter, multimeter.
5.2 Identify and explain the components of a circuit including a source, conductor, load, and controllers (controllers are switches, relays, diodes, transistors, integrated circuits).
5.3 Explain the relationship between resistance, voltage, and current (Ohm's Law).
5.4 Determine the voltages and currents in a series circuit and a parallel circuit.
5.5 Explain how to measure voltage, resistance, and current in electrical systems.
5.6 Describe the differences between Alternating Current (AC) and Direct Current (DC).

Suggested Learning Activities

- Design and create an electrical system containing a source, a switch, and multiple loads. Be able to measure the voltage and current at each load. (5.2)
- Design and create an electrical system with either motors or lights. All of the motors in the system will operate at different speeds, or the lamps will operate at different intensities. (5.2, 5.3)
- Create schematics for series, parallel, and combination (series-parallel) circuits, and construct them from the schematics. (5.4)

Boldface type indicates core standards for full-year courses.

Technology/Engineering, Grade 9 or 10

Learning Standards for a Full First-Year Course

6. Communication Technologies

Broad Concept: The application of technical processes to exchange information includes symbols, measurements, icons, and graphic images.

6.1 Identify and explain the applications of light in communications, e.g., reflection, refraction, additive, and subtractive color theory.

6.2 Explain how information travels through different media, e.g., electrical wire, optical fiber, air, space.

6.3 Compare the difference between digital and analog communication devices.

6.4 Explain the components of a communication system, i.e., source, encoder, transmitter, receiver, decoder, storage, retrieval, and destination.

6.5 Identify and explain the applications of laser and fiber optic technologies, e.g., telephone systems, cable television, medical technology, and photography.

Suggested Learning Activities

- Give an example of the following types of communication: human to human (talking), human to machine (telephone), machine to human (facsimile machine), and machine to machine (computer network). (6.4)
- Create specific types of communication: human to human (e.g., talking, telephone), human to machine (e.g., keyboard, cameras), machine to human (e.g., CRT screen, television, printed material), machine to machine (e.g., CNC, internetworking). (6.2, 6.3, 6.4)
- Explain what is meant by the size and focal length of a lens and its application for light theory. (6.5)
- Research a communication technology and the impact lasers or fiber optics have had on that technology. (6.4, 6.5)

7. Manufacturing Technologies

Broad Concept: Manufacturing processes can be classified into six groups: casting and molding, forming, separating, conditioning, assembling, and finishing.

7.1 Explain the manufacturing processes of casting and molding, forming, separating, conditioning, assembling, and finishing.

7.2 Differentiate the selection of tools and procedures used in the safe production of products in the manufacturing process, e.g., hand tools, power tools, computer-aided manufacturing, three-dimensional modeling.

7.3 Explain the process and the programming of robotic action utilizing three axes.

Suggested Learning Activities

- Design a system for mass producing a product. (7.1, 7.2)
- Design, build, and program a robotic device capable of moving through three axes. (7.3)

Boldface type indicates core standards for full-year courses.

What It Looks Like in the Classroom

A Look at Energy Efficient Homes

Adapted from Standards for Technological Literacy, p. 197

Technology/Engineering, Grades 9–10

The city of Westlake and the surrounding areas experienced an accelerated growth in the construction industry, especially in new home construction. The local high school technology teacher, Mr. Morales, thought it would be helpful for his students, as future consumers, to have an in-depth understanding of the housing industry and to know about the latest developments in home construction techniques, materials, and practices.

Mr. Morales decided to organize a lesson where students were invited to participate in designing an energy-efficient home for a family of four. He guided the students to consider all forms of energy and not to limit their imaginations. Students were instructed to consider costs of using energy-efficient designs and how those costs might affect the resale value of a home.

The students in the technology classes were challenged to design, draw, and build a scale model of a residential home using heating and cooling systems that were energy-efficient, aesthetically pleasing, functional, marketable, and innovative. The house also had to accommodate a family of four with a maximum size of 2100 square feet. The students had to work within a budget of $150,000, and they had nine weeks to complete the project.

The students began by researching homes in their area that already incorporated features that were required in their home. They conducted library and internet searches to learn about the latest materials and techniques available in the housing industry. Students also interviewed local architects and building contractors to learn about various practices and how they were integrating innovative features. For example, they learned about incorporating increased day lighting, which takes into account the home's orientation, into the design of the home. They also learned about designing and installing environmentally sound and energy-efficient systems and incorporating whole-home systems that are designed to provide maintenance, security, and indoor air-quality management.

The students then began the process of sketching their homes. Many students had to gather additional research as they realized they needed more information to complete their sketches. Using their sketches, the students built scale models of their homes out of mat board.

A group of building industry professionals from across the area was invited to evaluate students' work and provide feedback on their ideas in several categories, including design, planning and innovations, energy conservation features, drawing presentation, model presentation, and exterior design.

As a result of this experience, the students learned firsthand what it takes to design a home for the 21st century. Students also learned how to successfully plan and select the best possible solution from a variety of design ideas in order to meet criteria and constraints, as well as how to communicate their results using graphic means and three-dimensional models.

Assessment Strategies

- Students can research building codes and zoning laws in the community. Write a detailed report on the building codes and zoning laws.
- Students can compare construction efficiency of various house designs and evaluate the advantages and disadvantages of each design (e.g., ranch vs. colonial, lumber vs. steel framework). Create a chart illustrating the differences.

What It Looks Like in the Classroom

- Students can create an engineering presentation of the design, efficiency, and prototype using appropriate visual aids, e.g., charts, graphs, presentation software. Presentation may include any other factors that might impact the design of the house, e.g., the site, soil conditions, climate.
- Students will use a rubric to assess design specification, heat efficiency, and final prototype of the design challenge.

Engineering Design Learning Standards

1.1 Identify and explain the steps of the engineering design process, i.e., identify the problem, research the problem, develop possible solutions, select the best possible solution(s), construct a prototype, test and evaluate, communicate the solution(s), and redesign.

1.2 Demonstrate knowledge of pictorial and multi-view drawings (e.g. orthographic projection, isometric, oblique, perspective) using proper techniques.

1.3 Demonstrate the use of drafting techniques with paper and pencil or computer-aided design (CAD) systems when available.

1.4 Apply scale and proportion to drawings, e.g., 1⁄4″ = 1′0″.

1.5 Interpret plans, diagrams, and working drawings in the construction of a prototype.

Construction Technologies Learning Standards

2.1 Identify and explain the engineering properties of materials used in structures, e.g., elasticity, plasticity, thermal conductivity, density.

2.2 Differentiate the factors that affect the design and building of structures, such as zoning laws, building codes, and professional standards.

2.3 Calculate quantitatively the resultant forces for live loads and dead loads.

Energy and Power Technologies—Thermal Systems Learning Standards

4.1 Identify the differences between open and closed thermal systems, e.g., humidity control systems, heating systems, cooling systems.

4.4 Explain how environmental conditions influence heating and cooling of buildings and automobiles.

Appendices

Learning Standards by Grade Span, Grades PreK–8

GRADES PREK – 2

EARTH AND SPACE SCIENCE

- Recognize that water, rocks, soil, and living organisms are found on the earth's surface.
- Understand that air is a mixture of gases that is all around us and that wind is moving air.
- Describe the weather changes from day to day and over the seasons.
- Recognize that the sun supplies heat and light to the earth and is necessary for life.
- Identify some events around us that have repeating patterns, including the seasons of the year, day and night.

LIFE SCIENCE

- Recognize that animals (including humans) and plants are living things that grow, reproduce, and need food, air, and water.
- Differentiate between living and nonliving things. Group both living and nonliving things according to the characteristics that they share.
- Recognize that plants and animals have life cycles, and that life cycles vary for different living things.
- Describe ways in which many plants and animals closely resemble their parents in observed appearance.
- Recognize that fossils provide us with information about living things that inhabited the earth years ago.
- Recognize that people and other animals interact with the environment through their senses of sight, hearing, touch, smell, and taste.
- Recognize changes in appearance that animals and plants go through as the seasons change.

PHYSICAL SCIENCE

- Sort objects by observable properties such as size, shape, color, weight, and texture.
- Identify objects and materials as solid, liquid, or gas. Recognize that solids have a definite shape and that liquids and gases take the shape of their container.
- Describe the various ways that objects can move, such as in a straight line, zigzag, back-and-forth, round and round, fast, and slow.
- Demonstrate that the way to change the motion of an object is to apply a force (give it a push or a pull). The greater the force, the greater the change in the motion of the object.
- Recognize that under some conditions, objects can be balanced.

TECHNOLOGY/ENGINEERING

- Identify and describe characteristics of natural materials (e.g., wood, cotton, fur, wool) and human-made materials (e.g., plastic, Styrofoam).
- Identify and explain some possible uses for natural materials (e.g., wood, cotton, fur, wool) and human-made materials (e.g., plastic, Styrofoam).
- Identify and describe the safe and proper use of tools and materials (e.g., glue, scissors, tape, ruler, paper, toothpicks, straws, spools) to construct simple structures.
- Identify tools and simple machines used for a specific purpose, e.g., ramp, wheel, pulley, lever.
- Describe how human beings use parts of the body as tools (e.g., teeth for cutting, hands for grasping and catching), and compare their use with the ways in which animals use those parts of their bodies.

Comparing NAEP, TIMSS, and PISA in Mathematics and Science

The purpose of this document is to provide background information that will be useful in (1) interpreting the mathematics and science results from two key international assessments, which are being released in December 2004, and (2) comparing these results with recent findings from the U.S. National Assessment of Educational Progress in these subjects.

Background

Providing information to assist policymakers, researchers, educators, and the public obtain a comprehensive picture of how U.S. students perform in key subject areas is an important objective of the National Center for Education Statistics (NCES). In the United States, national-level data on student achievement comes primarily from two sources: the National Assessment of Educational Progress (NAEP)—also known as the "Nation's Report Card"—and the United States' participation and collaboration in international assessments, such as the Trends in International Mathematics and Science Study (TIMSS) and the Program for International Student Assessment (PISA).[1]

NAEP measures fourth-, eighth-, and twelfth-grade students' performance, most frequently in reading, mathematics, and science, with assessments designed specifically for national and state information needs. Alternatively, the international assessments allow the United States to benchmark its performance to that of other countries—in fourth- and eighth-grade mathematics and science in TIMSS and in 15-year-olds' reading, mathematical, and scientific literacy in PISA. All three assessments are conducted regularly to allow the monitoring of student outcomes over time.[2]

While these different assessments may appear to have significant similarities, such as the age or grade of students or content areas studied, each was designed to serve a different purpose and each is based on a separate and unique framework and set of items. Thus, not surprisingly, there may be differences in results for a given year or in trend estimates among the studies, each giving a slightly different view into U.S. students' performance in these subjects.

NCES released results from the 2003 administrations of TIMSS and PISA in December 2004. Results from the 2003 administration of NAEP Mathematics were released in late 2003; and results from the 2000 administration of NAEP Science also are available.[3] This document is intended to provide information that will help the press and others understand the mathematics and science results across three studies, grasp the similarities and differences in these results, and identify what each assessment contributes to the overall knowledge base on student performance.[4]

Comparing Features of the Assessments

NAEP, TIMSS, and PISA differ from one another on several key aspects of purpose, partners, population, and content.

Purpose and proximity to curriculum

The goals of the assessments have some subtle but important distinctions in regard to U.S. curricula.

NAEP is the U.S. source for information on mathematics and science achievement at key stages of education across the country using nationally established external benchmarks of performance (e.g., basic, proficient, advanced). The frameworks and benchmarks are established by the National Assessment Governing Board (NAGB) and are based on the collaborative input of a wide range of experts and participants in the United States from government, education, business and public sectors. Ultimately, they are intended to reflect the best thinking about the knowledge, skills, and competencies needed for students to have an in-depth understanding of these subjects at different grades.

TIMSS is the U.S. source for internationally comparative information on mathematics and science achievement in the primary and middle grades. Like NAEP, TIMSS assessments are based on collaboratively developed frameworks for the topics from curricula in mathematics and science to be assessed; but unlike NAEP, the framework and related consensus process involves content experts, education professionals, and measurement specialists from many different countries.

PISA is the U.S. source for internationally comparative information on the mathematical and scientific literacy of students in the upper grades at an age that, for most countries, is near the end of compulsory schooling. The objective of PISA is to measure the "yield" of education systems, or what skills and competencies students have acquired and can apply in these subjects to real-world contexts by age 15. The literacy concept emphasizes the mastery of processes, understanding of concepts, and application of knowledge and functioning in various situations within domains. By focusing on literacy, PISA draws not only from school curricula but also from learning that may occur outside of school.

The tailoring of NAEP to national practices distinguishes it from the other two assessments, the content of which is determined collaboratively with other countries and allows comparisons to international views of key content. The focus in PISA on yield and literacy distinguishes it from the other two assessments, which aim at measuring curricular attainment more closely.

Partners

For the international assessments, the groups of countries in the comparisons are different.

Around the world, TIMSS and PISA are well-subscribed programs. As shown in figure 1, some 46 countries participated in TIMSS 2003, and 41 countries participated in PISA 2003, though the composition of the groups is somewhat different.[5] PISA participants include all 30 OECD countries, and the international averages reported are based on only those countries. TIMSS participants include 13 industrialized countries, as well as middle-income and developing nations from around the world, and international averages reported are based on all participants. This should be kept in mind when interpreting results and is one of the reasons TIMSS and PISA scores should not be compared directly.

Figure 1. Participating countries in TIMSS 2003 and PISA 2003

Continent and country	TIMSS 4th grade	TIMSS 8th grade	PISA 15-year-olds
Africa			
Botswana		✓	
Egypt		✓	
Ghana		✓	
Morocco	✓	✓	
South Africa		✓	
Tunisia	✓	✓	✓
The Americas			
Brazil			✓
Canada			✓
Chile		✓	
Mexico			✓
United States	✓	✓	✓
Uruguay			✓
Asia			
Armenia	✓	✓	
Bahrain		✓	
Bulgaria		✓	
Chinese Taipei	✓	✓	
Hong Kong SAR	✓	✓	✓
Indonesia		✓	✓
Iran, Islamic Republic of	✓	✓	
Israel		✓	
Japan	✓	✓	✓
Jordan		✓	
Korea, Republic of		✓	✓
Lebanon		✓	
Macao-China			✓
Malaysia		✓	
Palestinian National Authority		✓	
Philippines	✓	✓	
Saudia Arabia		✓	
Singapore	✓	✓	
Thailand			✓
Australia/Oceania			
Australia	✓	✓	✓
New Zealand	✓	✓	✓

Continent and country	TIMSS 4th grade	TIMSS 8th grade	PISA 15-year-olds
Europe			
Austria			✓
Belgium[1]	✓	✓	✓
Cyprus	✓	✓	
Czech Republic			✓
Denmark			✓
England[2]	✓		
Estonia		✓	
Finland			✓
France			✓
Germany			✓
Greece			✓
Hungary	✓	✓	✓
Iceland			✓
Ireland			✓
Italy	✓	✓	✓
Latvia	✓	✓	✓
Liechtenstein			✓
Lithuania	✓	✓	
Luxembourg			✓
Macedonia, Republic of		✓	
Moldova, Republic of	✓	✓	
Netherlands	✓	✓	✓
Norway	✓	✓	✓
Poland			✓
Portugal			✓
Romania		✓	
Russian Federation	✓	✓	✓
Scotland[2]	✓	✓	
Serbia		✓	✓
Slovak Republic		✓	✓
Slovenia	✓	✓	
Spain			✓
Sweden		✓	✓
Switzerland			✓
Turkey			✓
United Kingdom[2]			✓

[1]Only Flemish Belgium participated in TIMSS 2003.

[2]Scotland and England participated separately in TIMSS 2003 at both grade levels but jointly as the United Kingdom (also including Northern Ireland) for PISA 2003. However, England did not meet response rate standards at grade 8 for TIMSS 2003 or for PISA 2003.

SOURCE: Organization for Economic Cooperation and Development (OECD), Program for International Student Assessment (PISA) 2003, and International Association for the Evaluation of Educational Achievement (IEA), Trends in International Mathematics and Science Study (TIMSS) 2003.

Population

The students being studied may represent different groups.

NAEP, TIMSS, and PISA are all sample-based assessments—that is, each administers the assessment to a subgroup of U.S. students in such a way that results can be generalized to the larger population. However, each assessment defines the population to which it is generalizing (and thus from which the sample is drawn) differently. One key distinction between NAEP and TIMSS, on the one hand, and PISA, on the other hand, is that NAEP and TIMSS use grade-based samples and PISA uses an age-based sample. These choices relate to the purposes of each program described earlier—NAEP and TIMSS to report on curricular achievement and PISA to describe the yield of systems toward the end of compulsory schooling.

- The NAEP target population is all students in fourth, eighth, and twelfth grades, and thus results reflect the performance of U.S. students in these grades—most recently for fourth, eighth, and twelfth grades in science in 2000; for fourth and eighth grades in mathematics in 2003; and for twelfth grade in mathematics in 2000.

- The TIMSS target population is all students from the upper of the two adjacent grades that contain the largest number of 9-year-olds and all students from the upper of the two adjacent grades that contain the largest number of 13-year-olds. For the United States (and many other countries), this population is all fourth-grade and all eighth-grade students. The most recent TIMSS results reflect the performance of U.S. students in these grades in 2003.

- The PISA target population is all 15-year-old students. Operationally, this included all students who were from 15 years and 3 months to 16 years and 2 months at the beginning of the testing period and who were enrolled in school, regardless of grade level or full- or part-time status. The most recent PISA results reflect the performance of U.S. 15-year-olds, who were in ninth, tenth, or another grade in 2003.

Thus, for mathematics, the most recent NAEP and TIMSS results are reporting on similar populations (fourth and eighth grades) in the same year—although NAEP is administered a few months prior to TIMSS in the school year. For science, however, NAEP reports on the population 3 years prior to the current TIMSS cohort. With regard to PISA, the population under study is uniformly older than the fourth- and eighth-graders in NAEP and TIMSS, and uniformly younger than the twelfth-graders in NAEP. Moreover, while most PISA students in the United States are in tenth grade, they are in other grades as well.

Content

The mathematics and science being assessed may be different in terms of content coverage and item format.

Also to be released in early 2005 are two technical reports describing the results of a content comparison of NAEP, TIMSS, and PISA in mathematics and of NAEP and TIMSS in science.[6] These studies show that, while there are similarities among the assessment programs, there are notable differences in terms of frameworks (more so in science), item content, and item format.

Frameworks

Each assessment is developed from a framework specifying the content and skills to be measured. The comparison of the NAEP 2003 and TIMSS 2003 mathematics frameworks reveals considerable agreement on the general boundaries and basic organization of mathematics content. For example, both assessments include five main content areas related to the major mathematical curricular areas of number, measurement, geometry, data, and algebra. Both frameworks also include dimensions that define a range of cognitive skills and processes, which overlap across the two assessments. However, closer examination at the item level (as in the two following sections) shows differences in operationalization of both the content (substantive focus) and item format.

PISA also specifies a range of content expectations, but the framework is organized around overarching ideas (e.g., space and shape) versus curricular-based areas like geometry or algebra and with emphasis on the contexts in which mathematics is applied (e.g., in school, in society). Closer examination of PISA items in comparison with NAEP items makes these differences apparent, though it also shows where content is similar despite its different organization in the frameworks.

The comparison of the NAEP 2000 and TIMSS 2003 science frameworks highlights more organizational differences than in mathematics. While the NAEP framework defines science content in terms of three broad fields of science (physical science, life science, and Earth science), the TIMSS framework is organized around five (also disciplinarily defined) content domains. Like NAEP, TIMSS identifies life science and Earth science as domains; however, it treats physical science differently (separating a physics domain from a chemistry domain) and also includes a separate domain for environmental science.

Because of the small number of scientific literacy items in PISA 2003, these items were not included in the comparison study and will not be reflected in the discussion on science in the following two sections. At the framework level, however, PISA's definition of the domain of science differs from NAEP and TIMSS in some of the same ways it did in the domain of mathematics. Content is defined in terms of themes (e.g., form and function, biodiversity) rather than disciplines, and the frameworks also specify, along with a process dimension, a context dimension (e.g., science in life and health, science in technology).

One additional feature of both the mathematics and science-frameworks for all three assessments is worth noting: they specify different item types (e.g., multiple choice or constructed response). In mathematics, about two-thirds of the NAEP and TIMSS assessments (in terms of percentages of items) are multiple choice, compared with one-third of the PISA assessment, which relies more heavily on constructed-response, or open-ended, items. In science, more differences are apparent between NAEP and TIMSS. NAEP is roughly balanced between multiple choice and constructed response, while TIMSS has more multiple-choice items (about two-thirds).

Item content

Because PISA treats mathematics as a major domain in 2003 and includes many more mathematics items with which to compare with NAEP and TIMSS, this section and the next focus on mathematics.

Comparisons of NAEP and TIMSS mathematics items show that at the level of broad content area, the assessments appear to be similar. Both NAEP and TIMSS have the highest proportion of items in the *number* content area; for both, the content area related to *data* reflects a relatively small proportion, particularly at the fourth grade. There also is a greater emphasis on *algebra* at the eighth grade than at the fourth grade in both assessments. Although the correspondence between NAEP and PISA content areas was not as strong as between NAEP and TIMSS, there was considerable overlap between the PISA overarching idea of *uncertainty* and the NAEP content area of *data analysis, statistics, and probability,* as well as between *space and shape* in PISA and *measurement* and *geometry and spatial sense* in NAEP. Overall, PISA has a greater focus on *data* (40 percent) and less focus on *algebra* (11 percent) than the eighth-grade assessments in NAEP (15 percent and 25 percent respectively) or TIMSS (11 percent and 23 percent respectively).

In the comparison studies, NAEP and TIMSS mathematics items were classified to each other's assessment frameworks in terms of content topics and subtopics in order to allow comparisons across the assessments. Differences emerge with a more detailed examination of the degree to which the items from one assessment map to the subtopics specified within content areas on the other assessment. About 20 percent of fourth-grade items and 15 percent of eighth-grade items from each assessment could not be classified to a subtopic in the other's framework. This indicates that both NAEP and TIMSS contain items that might not be included in the other assessment. The PISA items, on the other hand, have a higher level of content match with NAEP, with less than 10 percent not classified to subtopics in that framework.

Another analysis compared the grade level alignment of individual items, by examining which grade on the other assessment's framework the items were mapped to (grade match). In general, TIMSS items match to the corresponding grade level on the NAEP framework more often than NAEP items match to the corresponding grade in TIMSS: 90 percent or more for fourth- and eighth-grade TIMSS items compared to over 80 and 70 percent for fourth- and eighth-grade NAEP items, respectively. This differed greatly across the content areas, however. For example, the measurement and geometry content areas accounted for most of the TIMSS items classified at a different grade level on the NAEP framework. PISA items were found to correspond most closely with the NAEP eighth-grade framework.

Examining Results in the Context of the Distinctions Among the Assessments

Both NAEP and TIMSS provide a measure of fourth- and eighth-grade mathematics and science performance, and NAEP, TIMSS, and PISA provide a measure of the mathematics and science performance of older students (grades 8-12). It is natural to compare them, but the distinctions described previously need to be kept in mind in understanding converging or diverging results. Two examples follow.

Comparing select results from the international assessments

Results from TIMSS 2003 showed that U.S. fourth- and eighth-grade students perform above the international average for all participating countries in both mathematics and science. The PISA 2003 results showed that U.S. 15-year-olds performed below the international (Organization for Economic Cooperation and Development [OECD]) average in mathematical literacy and scientific literacy. Both results are informative.

The TIMSS results indicate that, on the curricular matter that is being assessed, U.S. students at these two grade levels fare better than a "world" average. With TIMSS, however, it is informative to also look at how the United States fared compared specifically with other industrialized countries, which form a small subset of the participating countries. In eighth-grade mathematics, for example, U.S. students' performance was not measurably different from that of students in Australia, New Zealand, Scotland, Slovak Republic, and Sweden; was higher than that of students in Italy and Norway; and was lower than that of students in Belgium (Flemish), Hungary, Japan, Korea, and the Netherlands. These and similar comparisons of OECD countries to the U.S. mean (for both TIMSS and PISA) are summarized in figure 2.

The PISA results indicate that, on literacy measures, U.S. 15-year-olds do not perform as well as their international counterparts in mathematics and science. Characterizing these relative standings as a "decline" from TIMSS performance would be incorrect—the lack of comparability of grade- and aged-based samples, methods of sampling, goals of the assessments, and other elements of content preclude this type of statement. At the same time, some of the reasons TIMSS and PISA give a slightly different story for students close in age/grade and may relate to the emphases on different content areas within the assessments (as described earlier), item design, different sets of countries participating in each study, and other study features.

Figure 2. Average mathematics performance of fourth-graders, eighth-graders, and 15-year-olds for all OECD participating countries, relative to the U.S. average (2003)

	TIMSS		PISA
Country	4th grade	8th grade	15-year-olds
Australia	▼	•	▲
Austria	†	†	▲
Belgium[1]	†	†	▲
Canada	†	†	▲
Czech Republic	†	†	▲
Denmark	†	†	▲
England	▲	*	*
Finland	†	†	▲
France	†	†	▲
Germany	†	†	▲
Iceland	†	†	▲
Ireland	†	†	▲
Japan	▲	▲	▲
Korea, Republic of	†	▲	▲
Luxembourg	†	†	▲
Netherlands	▲	▲	▲
New Zealand	▼	•	▲
Norway	▼	▼	▲
Slovak Republic	†	•	▲
Sweden	†	•	▲
Switzerland	†	†	▲
Hungary	▲	▲	•
Poland	†	†	•
Scotland	▼	•	*
Spain	†	†	•
Greece	†	†	▼
Italy	▼	▼	▼
Mexico	†	†	▼
Portugal	†	†	▼
Turkey	†	†	▼

† Not applicable. Did not participate in this assessment.

[1]Only Flemish Belgium participated in TIMSS 2003. Scores for Flemish Belgium were higher than the United States at grades 4 and 8 in TIMSS 2003.

*Scotland and England participated separately in TIMSS 2003 at both grade levels but jointly as the United Kingdom (including Northern Ireland) in PISA 2003. However, England did not meet response rate standards for grade 8 in TIMSS 2003 or for PISA 2003, so no comparisons are reported with the United States for England for grade 8 in TIMSS 2003 or for the United Kingdom for PISA 2003.

NOTE: Countries are ordered according to their performance relative to the United States in PISA and then alphabetized, except for England and Scotland, which did not participate in PISA separately.

SOURCE: Organization for Economic Cooperation and Development (OECD) Program for International Student Assessment (PISA) 2003, and International Association for the Evaluation of Educational Achievement (IEA) Trends in International Mathematics and Science Survey (TIMSS) 2003.

Key:

▲ Average score is higher than U.S. average score

• Average score is not measurably different from U.S. average score

▼ Average score is lower than U.S. average score

Comparing select results from NAEP and TIMSS

The most recent results from both NAEP and TIMSS include information on trends over time in the United States: between 1996 and 2003 for mathematics in NAEP; between 1996 and 2000 in science for NAEP; and between 1995 and 2003 in mathematics and science for TIMSS—with intervening assessments in NAEP mathematics and TIMSS as well.

In mathematics, TIMSS 2003 shows that statistically there is no change in U.S. fourth-grade students' average scores between 1995 and 2003. This contrasts with NAEP results, which show an improvement in the average mathematics scores of fourth-grade students over roughly the same period (1996 to 2003). However, although the populations in NAEP and TIMSS are the same, as the previous section highlighted, there are some differences in the content of the assessments: about one-fifth of items from each assessment do not correspond well to the other assessment's framework, which could explain these differences in part. Perhaps also the nature of NAEP as a national instrument may make it somewhat more sensitive to picking up changes in the performance of U.S. students early in their school careers and over relatively short time periods. At the eighth-grade level, both NAEP and TIMSS identify an improvement in the performance of U.S. students over the respective periods. In the eighth-grade, there is more overlap in the content of the two assessments—which may explain the similarities in the results, with U.S. eighth-graders doing better in mathematics in 2003 than in the mid-1990s.

In science, both TIMSS and NAEP show no change in fourth-grade students' average scores over the two periods. Though there are differences in content between the two assessments at this grade level, these results show that U.S. students performed consistently in each assessment. At the eighth-grade level, TIMSS 2003 reports an increase in U.S. students' science scores since 1995. The NAEP trend line, from 1996 to 2000, shows no change. However, a closer examination of the TIMSS trend line, which also has a data point for 1999, shows that the two assessments' results are actually not dissimilar when considering similar periods. The change in U.S. students' performance since 1995 reported in TIMSS is largely from improvements from 1999 to 2003, as TIMSS showed no change in science performance between 1995 and 1999.

Conclusions

In sum, there appears to be an advantage in capitalizing on the complementary information presented in national and international assessments. The NAEP assessment measures in detail the mathematics and science knowledge of U.S. students as a whole. NAEP also can provide information for different geographic regions and demographic population groups. The international assessments, PISA and TIMSS, provide a method for comparing our performance in the United States to the performance of students in other nations. Because of their international cooperative nature, they provide information on additional and different facets of mathematics and science performance than NAEP. Considering NAEP results in the context of TIMSS and PISA provides an important international perspective and allows us to reflect both on how well our students know what we believe they should know *and* on where we stand among other nations.

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Useful websites

NAEP http://nces.ed.gov/nationsreportcard

TIMSS http://isc.bc.edu (international)
http://nces.ed.gov/timss (national)

PISA http://www.pisa.oecd.org (international)
http://nces.ed.gov/surveys/pisa (national)

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[1] TIMSS is conducted under the auspices of the International Association for the Evaluation of Educational Achievement (IEA). PISA is sponsored by the Organization for Economic Cooperation and Development (OECD).

[2] All statements about NAEP in this paper refer to national NAEP (versus state or long-term trend NAEP). NAEP currently assesses fourth- and eighth-grade mathematics on a 2-year cycle and twelfth-grade mathematics on a 4-/5-year cycle. It assesses all three grades of science on a 4-/5-year cycle. TIMSS is on a 4-year cycle and PISA is on a 3-year cycle.

[3] See

(a) For results from TIMSS: Gonzales, P., Guzmán, J.C., Partelow, L., Pahlke, E., Jocelyn, L., Kastberg, D., and Williams, T. (2004). *Highlights From the Trends in International Mathematics and Science Study (TIMSS) 2003* (NCES 2005-005). U.S. Department of Education. Washington, DC: National Center for Education Statistics.

(b) For results from PISA: Lemke, M., Sen, A., Pahlke, E., Partelow, L., Miller, D., Williams, T., Kastberg, D., and Jocelyn, L. (2004). *International Outcomes of Learning in Mathematics Literacy and Problem Solving: PISA 2003 Results From the U.S. Perspective* (NCES 2005-003). U.S. Department of Education. Washington, DC: National Center for Education Statistics.

(c) For results from fourth- and eighth-grade NAEP mathematics: Braswell, J., Daane, M., and Grigg, W. (2004). *The Nation's Report Card: Mathematics Highlights 2003* (NCES 2004-451). U.S. Department of Education. Washington, DC: National Center for Education Statistics.

(d) For results from twelfth-grade NAEP mathematics: Santapau, S.L. (2001). *The Nation's Report Card: Mathematics Highlights 2000* (NCES 2001-518). U.S. Department of Education. Washington, DC: National Center for Education Statistics

(e) For results from NAEP science: National Center for Education Statistics (2002). *The Nation's Report Card: Science 2000* (NCES 2002-452). U.S. Department of Education. Washington, DC: National Center for Education Statistics.

[4] A separate analysis comparing the reading assessments of NAEP 2003 and PISA 2000 is forthcoming and is not discussed in this paper.

[5] The 46 countries will have publishable results for TIMSS 2003. In PISA 2003, although 41 countries participated, because 1 country did not meet the international requirements for response rates, comparisons are available for 40 countries.

[6] See

(a) Neidorf, T.S., Binkley, M., Gattis, K. and Nohara, D. (forthcoming). *A Content Comparison of the National Assessment of Educational Progress (NAEP), Trends in International Mathematics and Science Study (TIMSS), and Program for International Student Assessment (PISA) 2003 Mathematics Assessments* (NCES 2005-112). U.S. Department of Education. Washington, DC: National Center for Education Statistics.

(b) Neidorf, T.S., Binkley, M., and Stephens, M. (forthcoming). *A Content Comparison of the National Assessment of Educational Progress (NAEP) 2000 and Trends in International Mathematics and Science Study (TIMSS) 2003 Science Assessments* (NCES 2005-106). U.S. Department of Education. Washington, DC: National Center for Education Statistics.