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

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Contents

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Dr. Joel Faircloth	Virginia Tech Agricultural Research Station
Dr. Gus Gerrans	University of Virginia
Dr. Rob Hinkle	College of William & Mary
Mr. Chris Hodge	Naval Surface Warfare Center - Dahlgren
Dr. Henry McGee	Virginia Commonwealth University
Dr. Jim Murday	Naval Research Laboratory/Univ of Southern California
Mr. Lennie Routten	Northrop-Grumman
Dr. Mia Siochi	NASA Langley Research Center
Mr. Tom Wavering	LUNA Innovations

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 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 an 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?**

This is the final report of the Panel on *Chemistry* which met at the National Institute of Aerospace in Hampton, Virginia, May 30-31, 2007.

Four weeks prior to the meeting, panel members were provided materials on proposed national science standards, outlines of the Advanced Placement Chemistry, and International Baccalaureate Chemistry courses, Virginia's Science SOL and Chemistry Curriculum Framework, and copies of Chemistry SOL from several other states whose SOL were ranked high by the Fordham Institute.

After working in facilitated sessions as subgroups and a committee of the whole, the Chemistry Panel developed the following findings and recommendations in four main categories regarding the current Virginia SOL in Chemistry:

General:

- The traditional science disciplines are becoming increasingly outmoded as an appropriate taxonomy for secondary school education. A key illustration of this point is modern biology, increasingly molecular in content and thereby critically dependent on knowledge of chemistry. Further, learning occurs best when content is reiterated with increasing levels of sophistication – rather than the single year "bites" of biology, chemistry and physics. The growing technological manifestations of science need to be rooted in a greater appreciation of engineering principles and approaches. Virginia should begin serious exploration of restructuring its curriculum and Standards of Learning in an integrated mode such as that advocated by Lederman, e.g., Science and Engineering 1, 2, 3, 4.

- Chemistry relates real-world phenomena to fundamental abstract principles that are discovered through observation and laboratory methodology and then expressed quantitatively in the language of mathematics and qualitatively in the written word.
- To better motivate the importance and usefulness of chemistry, the order of teaching chemistry should be from physical world observed phenomena (macroscopic) to fundamental building blocks (microscopic). (Macroscopic Properties -> Chemical Structures -> Chemical and Physical Interactions). This new approach may require new intellectual agility from chemistry teachers to move back and forth between these layers of understanding.

<u>Laboratories</u>:

- Laboratories should comprise about 20% of class time throughout the year and teachers should have freedom to choose which topics they complement/integrate with laboratories.
- Laboratories must integrate into the chemistry topics, make use of state-of-the-practice equipment and methodologies (eg: modeling and simulation, lab on a chip), ensure good data handling, and must include written lab reports to communicate the process and results. Laboratory principles and practice must be included in the assessed content.
- Teachers should partner with universities and work-world laboratories to develop laboratory modules – particularly in contemporary research areas.

<u>Contemporary Applications and Emerging Technologies</u>:

- Chemistry applications, including contemporary uses of chemistry in the physical world and emerging technologies, must be integrated into the chemistry content and included in assessed content.

<u>Open Source Courseware</u>:

- The Virginia Department of Education should support a website (such as a wiki) to which teachers can add laboratory modules and contemporary applications as they develop and use them. A collaborative effort with other states and/or NSF would accelerate progress in this effort.

Introduction and Background

In the Fall of 2006, NASA engaged in discussion 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 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.

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[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* 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:

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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 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).

- "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, and 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 is a bit more broadly defined in terms of what K-12 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) wing of the Department of Education. Thus the panel could not look at an SOL content set for engineering, but did look 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 is on ALL students in laying out a safety net of science (physics/chemistry) 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.

[6] In Virginia, approximately 10% of students in grades 9-12 are taking one or more advanced placement courses; 1% are in Governor's Schools, and 0.25% are in International Baccalaureate (IB) programs. The College Boards are working on aligning AP courses and the American Institute of Physics and NRC have develop reports on advanced needs in physics and chemistry respectively. The Chemistry Report is in the Appendix B of this report.

Philosophy for Selecting Team Membership

Because many previous SOL content development teams were made up with a preponderance of K-12 science educators with a few practicing scientists as advisors or reviewers, this team was designed to complement and supplement the content-area expertise of those teams. The Chemistry Team was designed to have subject matter expertise on the full range of chemistry technology readiness levels from basic research through technology and development to operations and production. To this end, members were solicited from university chemistry departments, government research laboratories, and industry. One of the team members had recently taught high school chemistry as adjunct faculty.

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

Dr. Joel Faircloth	Virginia Tech Agricultural Research Station
Dr. Gus Gerrans	University of Virginia
Dr. Rob Hinkle	College of William & Mary
Mr. Chris Hodge	Naval Surface Warfare Center - Dahlgren
Dr. Henry McGee	Virginia Commonwealth University
Dr. Jim Murday	Naval Research Laboratory / Univ Southern California
Mr. Lennie Routten	Northrop-Grumman
Dr. Mia Siochi	NASA Langley Research Center
Mr. Tom Wavering	LUNA Innovations

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

- They were a team of content-centric practitioners – not education specialists.
- They had available the current range of standards developed and implemented over the past decade as benchmarks – that is they had the advantage of standing back and evaluating what's been created there.
- They brought a range of technical 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 chemistry 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 chemistry 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 both the Virginia Science SOL and a copy of the Virginia Curriculum Framework for Chemistry. The Curriculum Framework serves as a guide for teachers by providing the next deeper level of specificity for the SOL. The Framework enumerates the essential understandings and the essential knowledge and skills that students should develop for each of the standards in the SOL. In addition to the current Virginia Standards and Curriculum Framework, the Chemistry Team had available to them: sets of standards from other states that have been judged as "leaders" in the development of quality standards[8], the College Board Advanced Placement (AP) Chemistry course outline, 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 Nobel Laureate Leon Lederman on sequencing and content of science courses. Dr. Lederman suggests that because the nature of biology has changed so radically from mostly an exercise in classification (1930's) to almost completely molecular biology in the 21st century, that chemistry (and in particular organic chemistry) should precede biology rather than the traditional order in which biology precedes chemistry in K-12 curricula. He also proposes that Physics precede Chemistry, ending with atomic and nuclear physics. Some 250 to 300 schools across the United States are experimenting with this new approach

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 percent of these teachers were aware of "nanotechnology", but only 18% said that they understood it, and 7% replied that they taught it. Thirty-eight per-cent 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 team were also given copies of the NRC's *National Science Education Standards*, the AAAS Project 2061 *"Science for All Americans"* and *"Benchmarks"*, and the thinking of the National Research Council on an advanced high school Chemistry course – *Learning and Understanding: Improving Advanced Study of Mathematics and Science in U.S. High Schools: Report of the Content Panel for Chemistry (2002).*

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

Meeting Place and Process (Agenda)

The Chemistry Team met on May 30 - 31, 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 chemistry 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 three smaller homogeneous breakout groups to consider (brainstorm) the main question before them: **What are the chemistry essential content to reach 80% – 90% of all high school students to help them become productive citizens[9] in the 21st Century?** The three homogeneous groups were broken out as:

- University representatives
- Government laboratory representatives
- Industry representatives

The three 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 one member from each of industry, university, and government lab representatives. The three mixed groups were each 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.

The result of this work was then a final result which had three components:

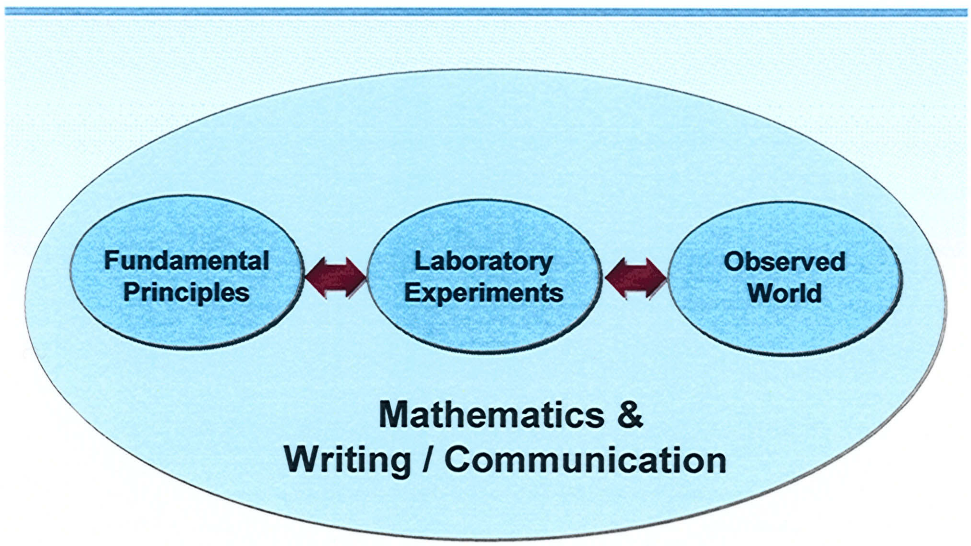
- Cross-cutting essential content that supports all of chemistry
- Required (essential) chemistry topics for all students
- Elective chemistry topics from which a subset would be chosen each year by the teacher

[9] What is the essential 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, and 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 chemistry expertise, and their thoughts based on their expertise and preparatory reading material. During this introductory discussion, there was a strong direction that laboratories, through which students *engage* in the scientific method, be a strong component of the program (Figure 1).

Figure 1. Chemistry Describes the Observed World



The panel then went into breakout sessions with three homogeneous groups: university, government labs, industry.

Two main themes developed from these breakout sessions (homogeneous groups):

- Experiments and demonstrations mediate between the observed world and basic chemistry principles and there are certain "cross-cutting essentials" that are foundational to the chemistry content *per se*.
- While many things are "good and interesting chemistry", they do not all fit into one academic year, so choices of "core" or "essential" content had to be made.

The cross cutting essentials are listed below as section "A" and are shown graphically in Figure 2. These cross-cutting essentials include safety, laboratory skills and appropriate use of the scientific method. Students integrate the use of state-of-the-practice equipment for data acquisition, data handling, and data analysis. The writing of reports to clearly record and communicate results is also included in this section.

In the second set of breakout sessions, mixed groups (membership of each group was mix of university, government lab, and industry) worked on these two themes and presented their ideas on what was core. As the groups formed back into a committee of the whole, the idea that there was not a simple fix to the current Virginia SOL emerged. The fundamental nature of Virginia's chemistry course must be changed and thus individual deletions and additions or modifications to the SOL were inadequate[10]. The major philosophical change that emerged was that chemistry should be taught from the macroscopic to the microscopic. Applications and observations of the real world must be woven throughout the tapestry of the course by the teacher and not reserved as anecdotes at the end of a unit or worse, the end of the term. Rather than start with the structure of the atom and build up to real-word macroscopic behaviors of matter, chemistry should begin with the behaviors of matter at dimensions that are observable by humans. These macroscopic properties and behaviors (please see section "B" in the outline below) start the student thinking about why chemistry is useful and important. It should create some curiosity and motivate further exploration to understand these observed behaviors. Gross chemical and physical properties such as gas compressibility (SCUBA diving/bends), phase changes (boiling/solidification), viscosity (automobile oil/belly flop on water), and interaction phenomena (cleaning agents/salt to melt ice on sidewalks) would be investigated. Next, the microscopic world of chemical structure would be investigated (section "C" in the outline below). Here we would begin the atomic structure of the elements and their periodic properties, move to "beyond elements" with molecules and nanostructures and "formulas and nomenclature". Another name for these topics combined might be "common chemicals and their properties". We would look at different atmospheric gases, hydrocarbons, sugars, and salts. We would then move on to acids and their properties; how we use acids and their different strengths (pH). The student learns that vinegar is not particularly worrisome, oxalic acid is useful to clean/etch concrete but requires care in its use, while sulfuric acid in your car battery is very useful but requires extreme care in handling. Continuing down the list below, we would extend a hand across disciplines to biology with the introduction of sugars, amino acids (proteins), nucleic acids, (DNA and RNA) from a chemical standpoint. This would give the student an introduction to the role of organic chemistry in molecular biology.

After dealing with the microscopic *structures*, we next explain microscopic chemical and physical *interactions*. In section "D" below we include intermolecular forces, Avogadro's Number, the Ideal Gas Law, and kinetic theory completing this section with electrochemistry and interfaces such as adhesion and lubricants.

All of these sections comprise the essential or core content of the course. The final component of the course (Section "E" – italic typeface) is made up of a series of subjects from which a number should be chosen by the teacher each year. These elective subjects are all applications of chemistry. They should be integrated appropriately into the course and include human chemistry and emerging technologies. The overall scheme of these sections, the cross-cutting essentials, and the elective subjects crosscut relationship are shown graphically in Figure 2 and listed in total on the following pages.

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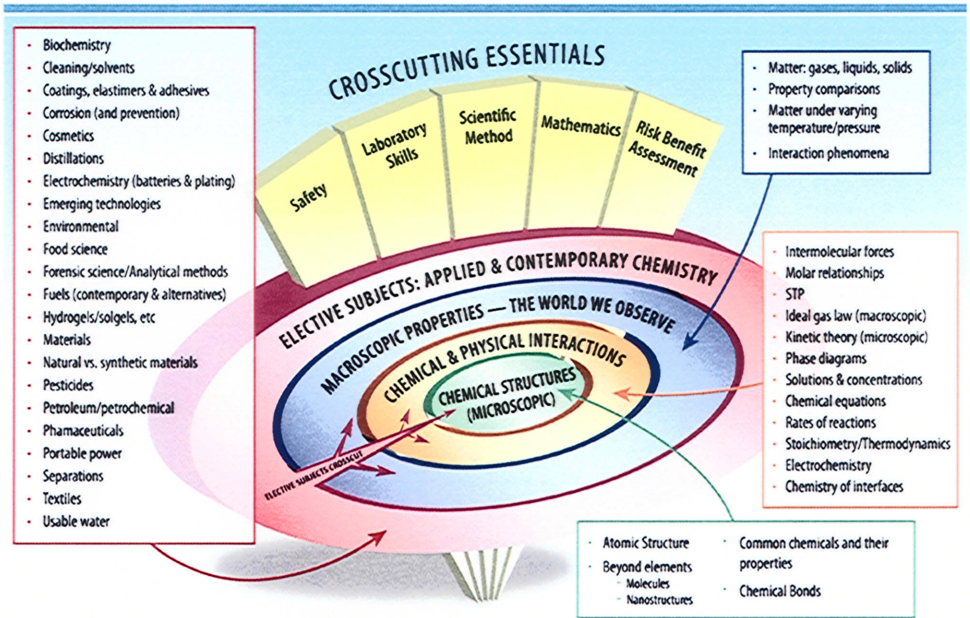
[10] However, lest the reader believe that the panel has produced an all or nothing set of recommendations, the final recommendations will include improvements to the current program that do not require a total rewrite of the Chemistry course.

Figure 2. A Hierarchy of Chemistry Content



A. *Crosscutting Essentials*

1. Safety: Personal Protective Equipment, fire extinguishers, etc.
   Wikipedia (chemical data resource), MSDS, LD_{50}
2. Laboratory skills – measurement, graphing, uncertainty, handling/disposal of chemicals,…
3. The Scientific Method
   a. Data Handling: SI Units and conversions (physics, biology, math), real life examples of mistakes originating from improper conversion of units, such as Mars Landing, airplane incidents and accidents.
   b. Planning, Recording and Reporting (Writing Lab reports!)
   c. Data Acquisition using state-of-the-practice methodology: "Probeware", computers, graphing calculators, lab-on-a chip, etc
   d. Modeling and simulation (web-based or computer-based)—e. g., nano-hub
4. Risk Benefit Assessment
5. Mathematics as the mechanism to quantify results

B. Macroscopic Properties – why is Chemistry Useful and Important

1. Matter – illustrate via the periodic table
   - Elements and atoms (not subatomic structure)
   - Three phases of matter (ordinary terrestrial conditions): gas, liquid, solid.
     - Gases – compressible fluid – He, Ne, N_2, earth's atmosphere, steam
     - Liquids – incompressible fluid – Hg, Ga, LN_2, liquid water
     - Solids – resist deformation and change in volume – Si, Fe, diamond, graphite, ice
   - Introduce phase changes (boiling, solidification, sublimation)
   - What influences phase: intermolecular attractions,

2. Comparisons of properties found in various phases - Use the elements C, He, Rn, Si, Al, Fe, Hg at STP and relate to periodic table

Property	Real world applications
-density	(He balloon rises, Radon gas safety in basement, weight of Hg vs Fe vs Al)
-compressibility	(iron wheel/auto tire, tennis ball/golf ball)
-viscosity	(automobile oil, molasses, belly flop on water to illustrate importance of timescale)
-heat capacity	(necessary to continuously heat a warm-air balloon compared with heat stored in a Fe frying pan; water as a coolant in car radiators)
-thermal conductivity	(insulation effectiveness – gas versus condensed phase, He in thermal windows)
-electrical conductivity	(metal (Al, Fe, Hg), semiconductor (Si, graphite), non-metal (He, Rn, diamond))

3. Matter under varying temperature/pressure conditions
   - Phase diagrams – water (ice, liquid, steam), CO_2 (solid, gas), He, Al, Fe
   - Plasmas (occurring at much higher temperatures, examples of sun, arc cutters, flat panel displays)

4. Interaction Phenomena between phases
   - concentration as prerequisite for following discussion (molarity; ppm)
   - solubility/miscibility (solutions vs. mixtures; cleaning)
   - colligative properties (salt for ice melting on walkways, home ice cream)
   - surfactants (soaps/detergents - oil vs. water salad dressing; cleaning)

C. Chemical Structures (Microscopic)

1. Atomic structure
   - -isotopes
   - -atomic mass
   - -1/2 life

2. Beyond Elements – an introductory, motivating look at more complex building blocks: molecules, nanostructures.
   - Nitrogen, Oxygen, Water, Carbon dioxide, Nitrogen oxides – simple atmospheric molecules
   - Carbon (C) Diamond (gem, grit), graphite (lubricant), amorphous (carbon black tire filler), fullerenes and nanotubes (allotropes of carbon, bridging the various size scales from molecules to nanostructures to bulk)
   - CdSe color change as function of nanocrystal size to highlight size effect
   - Hydrocarbons (example of C and H) - methane (natural gas), propane (fuel gas), octane (gasoline)

- Sugars (example of C, H, and O - glucose, fructose, sucrose,…) – illustrating richness of carbon chemistry and coming attraction to the complexity of biomolecules

3. Common Chemicals and their Properties
   - Formulas and nomenclature as a pre-requisite to the following:
   - Acids(hydrochloric [HCl, stomach acid], nitric [HNO_3, reagent for explosives, fertilizers], sulfuric [H_2SO_4, auto battery], phosphoric [H_2PO_4, coca cola], acetic [H_3CCO_2H, vinegar], oxalic [HO_2CCO_2H, concrete prep], ascorbic [vitamin C],..)
   - Bases (NaOH [lye], Ca(OH)2 [slaked lime, lawn "sweetner"], Mg(OH)2 [milk of magnesia],...)
   - Binary salts (e.g., NaCl [table salt], CaCl2 [drying agent], BCl3 [synthetic reagent], CCl4 [dry cleaning solvent], etc.)
   - Complex salts (e.g., sulfates, carbonates, phosphates,..)
   - Saturated hydrocarbons (methane [natural gas], ethane, propane [fuel gas], butane [fuel gas], isobutane . . . octane [gasolene paradigm], …polyethylene)
   - Unsaturated hydrocarbons (acetylene [fuel for high temperature torches], propylene, butylene,…)
   - Alcohols (methanol, ethanol, isopropanol, butanol,..; solvents, antiseptics)
   - Ketones (acetone,…; polar solvent, nail polish remover)
   - Aromatics (benzene, toluene, xylene, …; non-polar solvents)
   - Polymers (polyethylene, polytetrafluoroethylene [teflon], polypropylene, polyester, polystyrene, etc.)
   - Polysaccharides (carbohydrates from sugars [monosaccharides] - starch, cellulose)
   - Polypeptides (example of C, H, O, and N - proteins from amino acids)
   - Polynucleic acids (example of C, H, O, N, and P - DNA/RNA)
4. Chemical Bonds
   -Periodic Properties (use observed periodicity and trends to establish families and the periodic table)
   - "Combining capacity"
   - Valence electrons
   - Degree of electron sharing - covalent, ionic, metallic
   - Bond orientations – ionic radial, covalent directional, metallic complex mix

D. Chemical and Physical Interactions (Microscopic)

1. Intermolecular forces (cause liquification, solidification, e.g., mp, bp of molecular materials; critical to many biological processes)--provide "scale" of forces vs. type of bond
   - dipoles (permanent moments), induced dipoles (dispersion)
   - H-bonding*, a particularly important variant of dipole/dipole [critical to water properties and protein folding]
   - bond scale construct to illustrate different types, strengths, distance dependence
2. Molar Relationships and Avogadro's number (Avogadro Constant)
3. STP (need establish standard temperature (Kelvin) and pressure)
4. Ideal Gas Law ($PV = nRT$)

- Boyle's, Charles's and Avogadro's Laws
- Dalton's Law (relate to SCUBA diving rules)
- molecular collisions,
- pressure (vacuum systems, hot air balloons, tires, air bags, etc.), examples of unit conversions

5. Kinetic Theory
   - pressure, temperature, volume
   - vapor pressure
   - specific heat capacity
   - colligative properties
6. Phase diagram
   - phase changes
   - molar heats of fusion and vaporization
   - phase boundary / coexistence – relative humidity
   - matter under extreme conditions-supercritical point (decaf coffee)
7. Solutions and concentrations (Molarity)
   -parts per million (ppm)
   -pH and acid/base (Bronsted)
   -titrations
   -electrolytic strength
   -solubilities / partitioning (coefficient)
8. Chemical equations and stoichiometry
   -types of equations/reactions (e.g., acid-base, redox, substitution, etc.)
   -balancing equations
9. Rates of reactions
   - activation energy (barrier)
   - collisions (attempt frequency - pre exponential factor)
   - catalysts
10. Thermodynamics
   - equilibrium
   -(1^{st} and 2^{nd} Laws related to endo- and exothermic)
11. Electrochemistry (redox)
   - batteries
   - electroplating
12. Interfaces
   - adhesion
   - lubricants (i.e., friction reduction)
   - corrosion
   - adsorbants
   - surfactants/micelles (i.e., phase-transfer agents)
   - lipid bilayers vs. vesicles/micelles
   - colloid

E. Applications of Chemistry: Elective Subjects (and outer circle in diagram)

Adhesives / Sealers / Lubricants
Biochemistry
Cleaning/solvents
Coatings, elastimers, & adhesives (includes paint)

Corrosion and Aging (prevention)
Cosmetics
Distillations
Electrochemistry (batteries & plating)
Emerging Technologies (molecular electronics, printable electronics, tissue engineering, genetic engineering, laboratory on a chip, smart textiles, ...)
Environmental (ozone depletion, global warning gases, algae blooms, asbestos, radon, ... monitoring, remediation, nuclear waste disposal, biodegradability, recycling,...)
Food Science (sweeteners, additives, colors, fragrances, flavors, cooking/baking)
Forensic science / analytical methods
Fuels (contemporary: wood – "cellulose", gasoline – "octane", propane, alternatives: hydrogen, biomass, ethanol, ...)
Horticulture (pesticides, fertilization, genetic modification)
Human chemistry (genomics, proteomics, cellular processes, toxicity, digestion, metabolism, ...)
Hydrogels / solgels, etc
Natural vs synthetic materials (polymers/plastics, ceramics, composites, alloys)
Petroleum / petrochemical
Pharmaceuticals
Portable Power - batteries, fuel cells
Separations
Textiles
Usable water (hard water, potable water, sewage treatment)

Because there are so many new approaches, new interfaces, and new content in the team's recommendation, and because new technology and knowledge continues to grow exponentially with time[11], there was one final recommendation: to use a 21st Century technology (invented at the closing of the 20th Century) for teachers to share information and promote continuous learning in a timely way. This technology is the electronic bulletin board, sometimes referred to as a "wiki" and is an example of open-source courseware. A "wiki" can be set up to allow many users to contribute their own information and comment on others contributions. An excellent example is the on-line "Wikipedia"[12]. In addition to allowing the timely dissemination of discoveries and information that would take years to appear in a textbook, the wiki allows teachers and professional scientists to form a "network" to efficaciously grow and mature ideas, lesson plans, and laboratory modules.

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[11] Please see chapters 1-3 of Ray Kurzweil's book, "The Singularity is Near". Viking Press (2005)

[12] For a nice summary of the founding and operation of the Wikipedia, please see the article "All he News That's Fit to Print Out" by Jonathon Dee in the New York Times Magazine, Sunday, July 1, 2007, pp 34-39 or simply Google "wikipedia" on-line to investigate first hand.

A summary of results from the panel fell into four main areas as follows:

General:

- The traditional science disciplines are becoming increasingly outmoded as an appropriate taxonomy for secondary school education. A key illustration of this point is modern biology, increasingly molecular in content and thereby critically dependent on knowledge of chemistry. Further, learning occurs best when content is reiterated with increasing levels of sophistication – rather than the single year "bites" of biology, chemistry and physics. The growing technological manifestations of science need to be rooted in a greater appreciation of engineering principles and approaches. Virginia should begin serious exploration of restructuring its curriculum and Standards of Learning in an integrated mode such as that advocated by Lederman, e.g., Science and Engineering 1, 2, 3, 4.
- Chemistry relates real-world phenomena to fundamental abstract principles that are discovered through observation and laboratory methodology and then expressed quantitatively in the language of mathematics and qualitatively in the written word.
- To better motivate the importance and usefulness of chemistry, the order of teaching Chemistry should be from physical world observed phenomena (macroscopic) to fundamental building blocks (microscopic). (Macroscopic Properties -> Chemical Structures -> Chemical and Physical Interactions). This new approach may require new intellectual agility from Chemistry teachers to move back and forth between these layers of understanding.

Laboratories:

- Laboratories should comprise about 20% of class time throughout the year and teachers should have freedom to choose which topics they complement/integrate with laboratories.
- Laboratories must integrate into the chemistry topics, make use of state of the practice equipment and methodologies (eg: modeling and simulation, lab on a chip), ensure good data handling, and must include written lab reports to communicate the process and results. Laboratory principles and practice must be included in the assessed content.
- Teachers should partner with universities and work-world laboratories to develop laboratory modules – particularly in contemporary research areas.

Contemporary Applications and Emerging Technologies:

- Chemistry applications, including contemporary uses of chemistry in the physical world and emerging technologies, must be integrated into the chemistry content and included in assessed content.

Open Source Courseware:

- The Virginia Department of Education should support a website (a wiki perhaps) to which teachers can add laboratory modules and contemporary applications as they develop and use them. A collaborative effort with other states and/or NSF would accelerate progress in this effort.

A

APPENDIX A

Short Biographies of Chemistry Team Members:

Dr. Joel Faircloth – Assistant Professor, Department of Crop and Environmental Sciences, Tidewater Agricultural Research and Extension Center, Virginia Polytechnic Institute and State University. BS (Wildlife and Fisheries) NC State; MS (Entomology) NC State; Ph.D. (Crop Science) NC State. Dr. Faircloth has had previous appointments at NC State Urban Entomology Lab and Department of Agronomy Macon Ridge Research Station, LSU.

Dr. Gus Gerrans - Professor of Chemistry, University of Virginia. B.Sc (Chemistry Honors) Rhodes University, Grahamstown S.A.; Ph.D. (Chemistry) Cambridge University, U.K. Dr. Gerrans previously worked in industry at Fry's Metals and Seravac Laboratories and taught for 30 years at University of Witwatersond, Johannesburg, S.A. He has also served as Director for Education and Information Resources at Chemical and Allied Industries Association, S.A..

Dr. Rob Hinkle - Associate Professor of Chemistry, College of William & Mary. AB (Summa Cum Laude, Chemistry) Bowdoin College; Ph.D (Organic Chemistry) University of Utah. Dr. Hinkle previously held positions as Visiting Scholar at Indiana University and Research Scientist and NIH Postdoctoral Fellow at the University of California, Irvine. His current research is in catalytic use of Bi(III) compounds for the synthesis of ethers and the chemistry of iodonium salts.

Mr. Chris Hodge - Chemist, CBR (Chemical, Biological, and Radiological) Concepts & Experimentation Branch, Naval Surface Warfare Center, Dahlgren. BS (Chemistry) Tennessee Technological University, MS (Bioorganic Chemistry) University of South Carolina. Mr. Hodge works primarily on formulation and development of chemical and biological decontamination systems and subsequent efficacy and materials compatibility testing. He previously worked as a process chemist in industry.

Dr. Henry McGee - Founding Dean *Emeritus*, Virginia Commonwealth University. Ph.D. (Chemical Engineering) Georgia Tech. Prior to founding the School of Engineering at VCU, Dr. McGee served as Head of the Chemical Engineering Department at Virginia Tech for 10 years and as Director of the Chemical and Transport Systems Division at NSF where he developed the research area now known as "green chemistry and engineering". He began his career working on fuels and propulsion at NASA Marshall Space Flight Center and is perhaps most well-known for his 1991 book, "Molecular Engineering".

Dr. Jim Murday – Director of Physical Sciences, University of Southern California, Research Advancement Office. BS (Physics) Case Western Reserve University; Ph.D. (Solid State Physics) Cornell. Dr. Murday previously served for 20 years as Superintendent of the Chemistry Division at the Naval Research Laboratory (MD) after working as a bench scientist and as leader of the Surface Chemistry effort there. He has also served as Acting Director of Research for DoD Research and Engineering, Chief Scientist for the Office of Naval Research (ONR), and as Director, National Nanotechnology Coordination Office.

Mr. Lennie Routten - Laboratory Supervisor, Northrop-Grumman Newport News. BS (Biochemistry) Virginia Tech. Mr. Routten has more than 30 years industry experience in analytical and environmental chemistry. He is currently chairman of the Hampton City School Board.

Dr. Mia Siochi - Assistant Head, Advanced Materials & Processing Branch, NASA Langley Research Center. BS (Chemistry) Ateneo de Manila University, Philippines; MS (Chemistry) Virginia Tech; Ph.D. (Materials Engineering Science) Virginia Tech. Dr. Siochi's current research areas of interest are polymer physics and nanomaterials development. She previously carried out research in the area of bionanotechnology and biologically inspired materials.

Mr. Tom Wavering – Vice President, Technologies Development Division, Luna Innovations Incorporated. BS (Electrical Engineering), Virginia Tech; MS (Electrical Engineering) Virginia Tech. His main areas of interest include polymers, coatings, biomaterials, nanomaterials, elastomers, composites, alloys, and gels. Mr. Wavering previously worked for Computer Sciences Corporation and as a research scientist on advanced sensors for Luna where he helped found Luna's Charlottesville Office in Health and Materials Science. He serves as a reviewer for several journals including Microlithography and Microfabrication.

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. Mr. Batterson most recently served as Deputy Director for Strategic Development. He 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). Dr. Sapp previously served as a pilot in the Navy, retiring as a Captain. He 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 (2 Excerpts)

National Science Education Standards (Excerpts)

A "Critique" of the National Science Education Standards

Leon Lederman on Science Reform

Fordham Institute Rankings of State Science Standards

Advanced Chemistry Course Content Panel Standards

International Baccalaureate (IB) Chemistry Syllabus

College Boards Advanced Placement (AP) Chemistry Outline

Thomas Jefferson Governor's School (Fairfax) Courses

Virginia Science Standards of Learning (SOL)

Virginia SOL Chemistry Curriculum Framework

California Standards of Learning – Physics/Chemistry/Earth Science

Massachusetts Standards of Learning – Physical Sciences

South Carolina Standards of Learning – Chemistry

Blooms Taxonomy

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.

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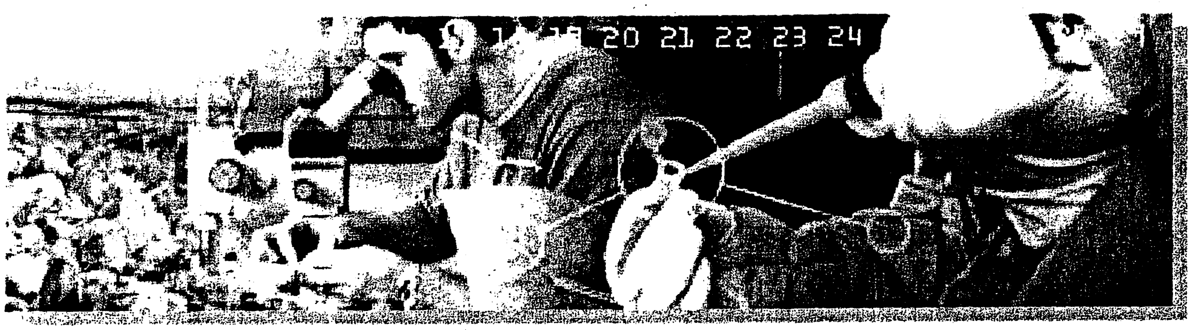
[5] Paul R. Gross: The State of State SCIENCE Standards. Thomas B. Fordham Institute (2005).

KENTUCKY SURVEY OF CRITICAL TECHNOLOGIES: Highlights



Sponsored by: Kentucky Science and Engineering Foundation

An initiative of: KSTC

Prepared by: HORIZON RESEARCH international

Supported with State Funds through: Kentucky Council on Postsecondary Education

ONE MISSION, BETTER LIVES

June 2004

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.

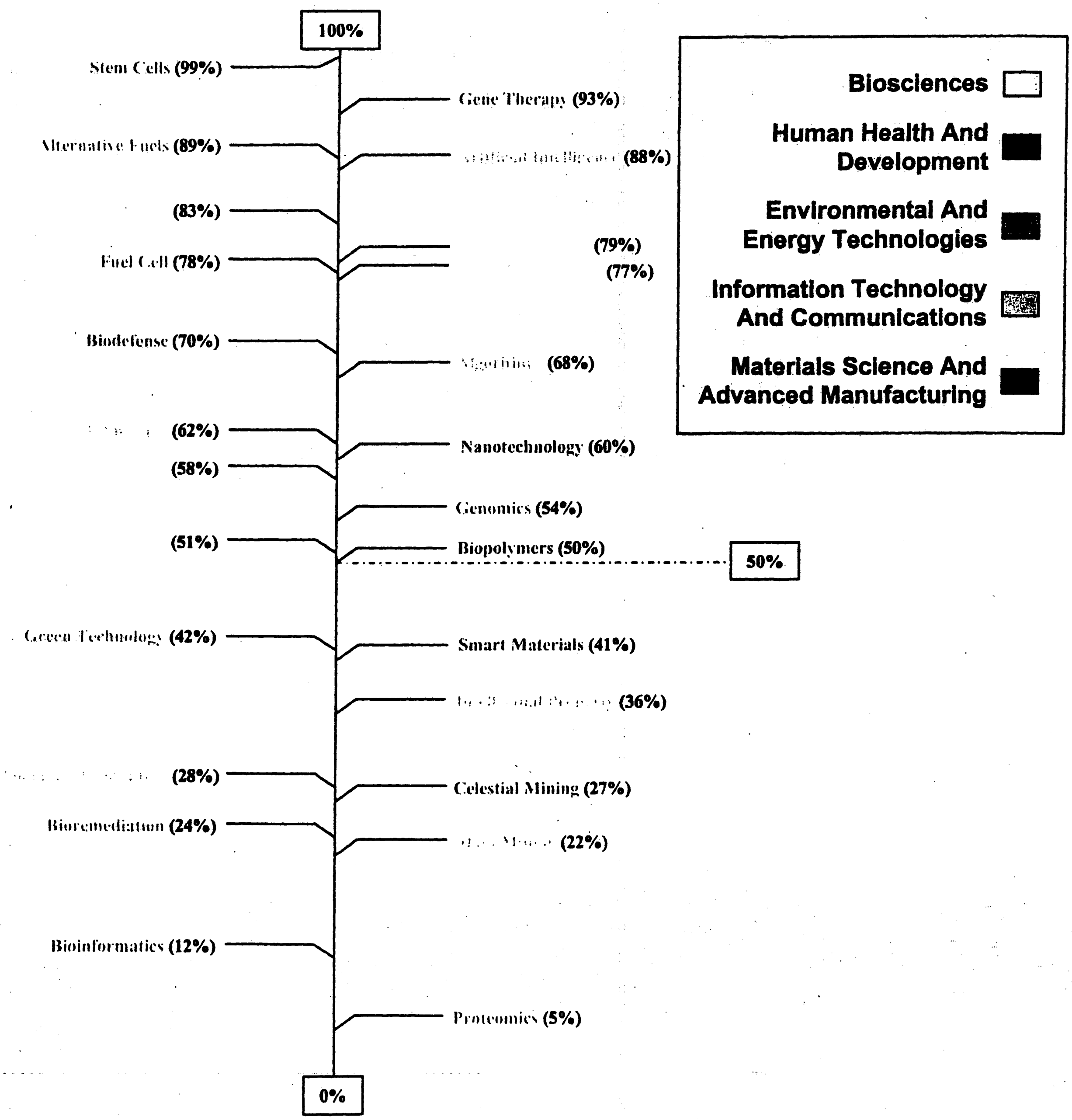
Horizon Research International then emailed each school contact requesting the email addresses of all science teachers. Those contacts not responding to the initial email request were sent at least two reminder emails requesting the information again. Contacts from 121 schools provided email addresses 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.

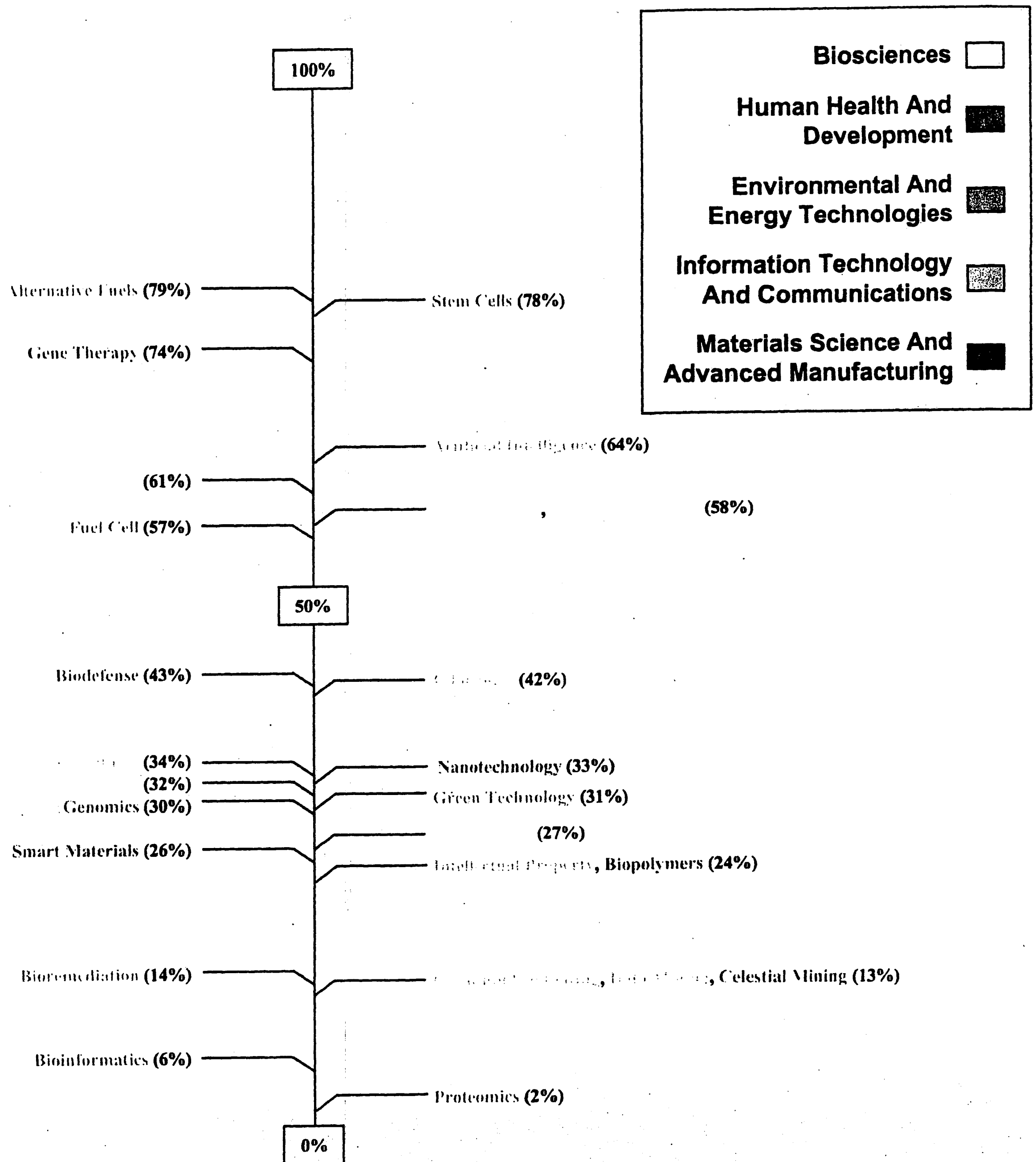
SUMMARY TABLES (TOTAL RESULTS)

Percent Of Teachers Aware Of Concept



Base = (241)

Percent Of Teachers Familiar With Concept*



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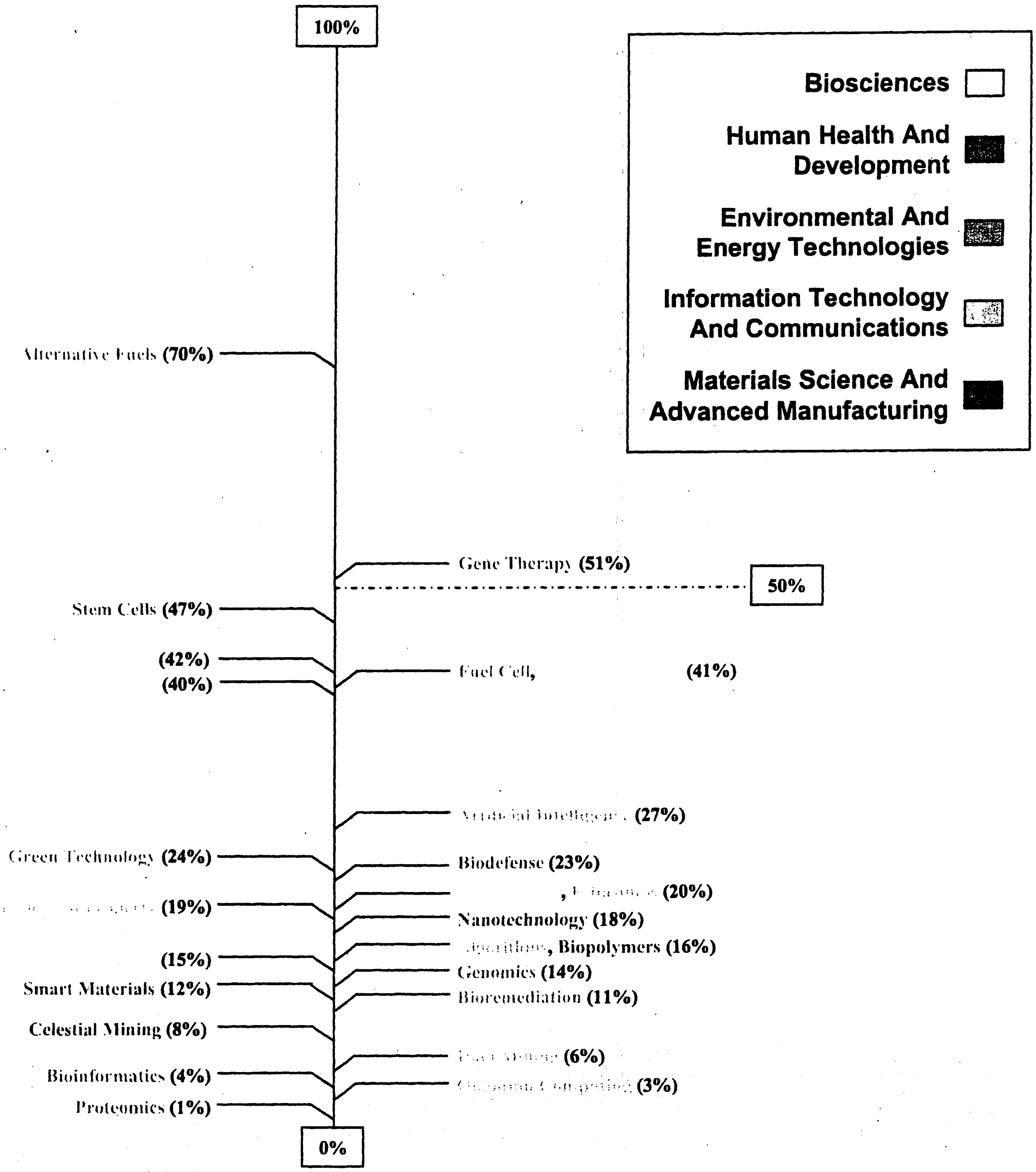
*** Summary of "extremely/very/somewhat familiar" with concept.***

Percent Of Teachers That Understand Concept



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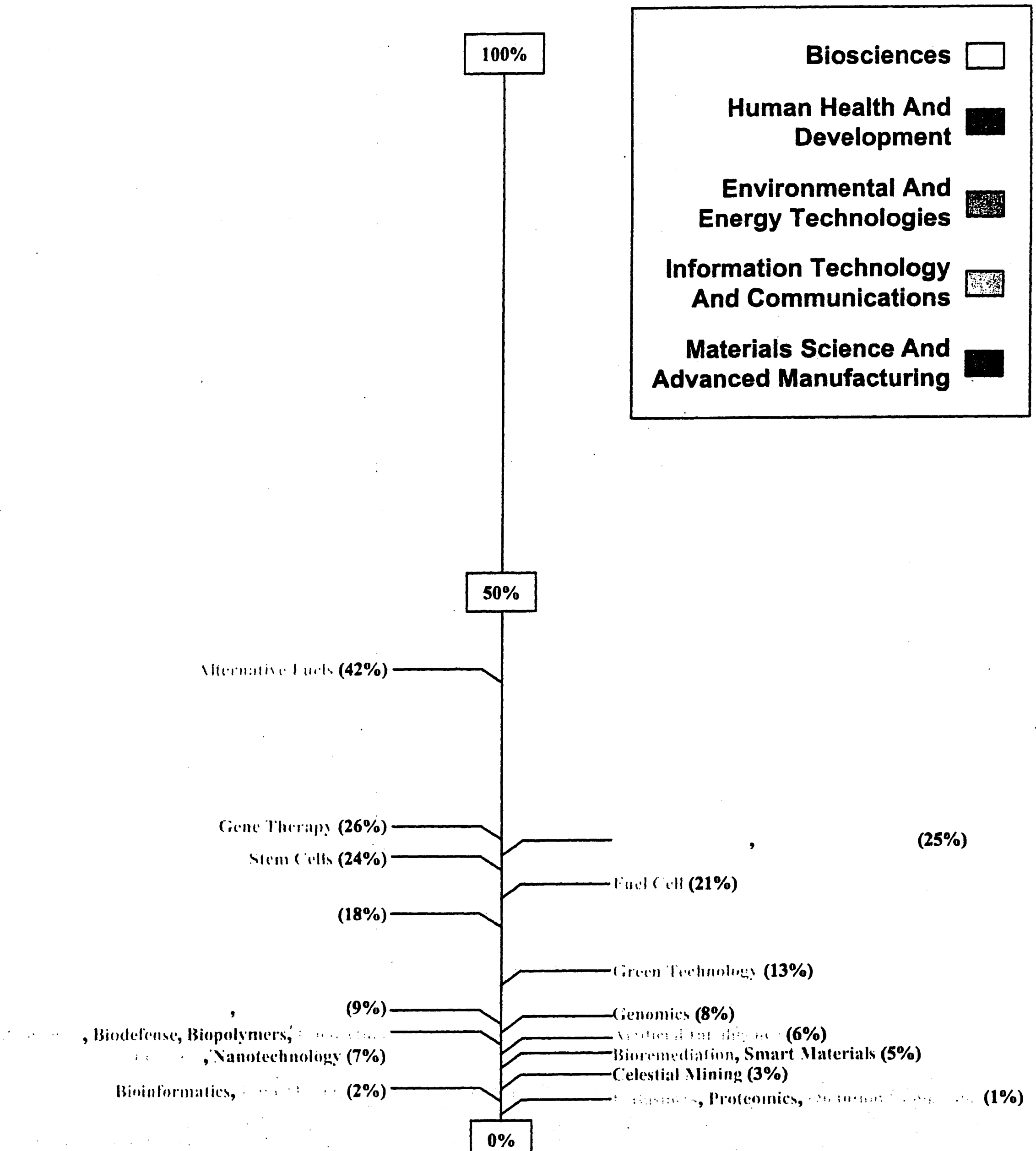
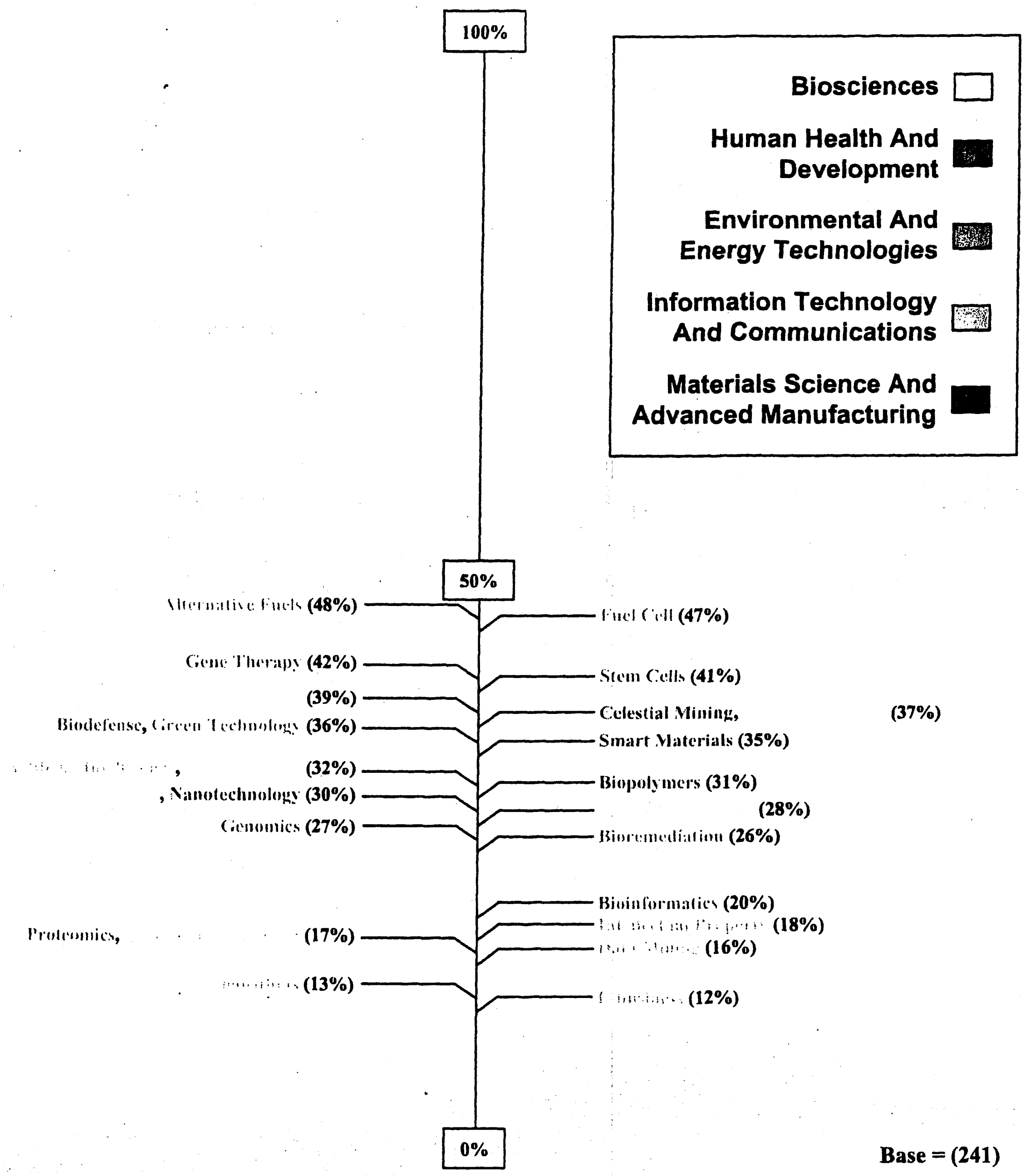
Percent Of Teachers Currently Teaching Concept

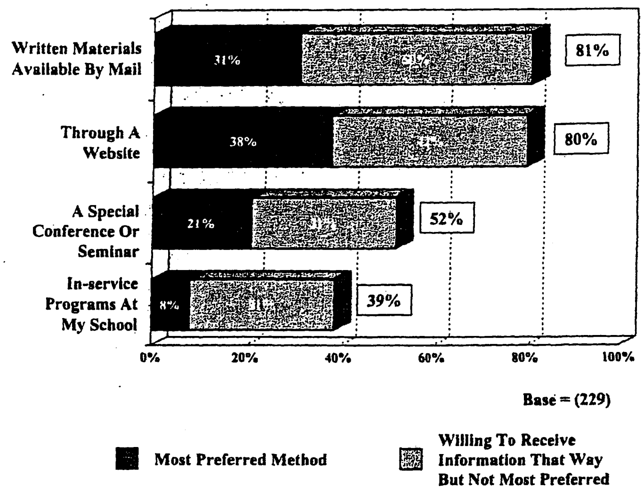


Base = (241)

Percent Of Teachers Who Want To Learn More About Concept

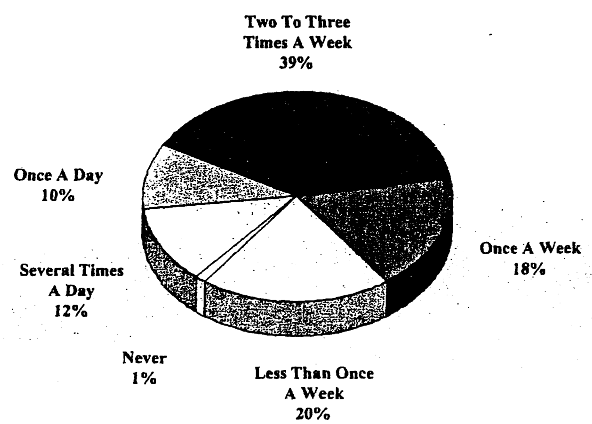


PREFERRED METHODS OF CONTACT FOR INFORMATION ON EMERGING CONCEPTS AND NEW TECHNOLOGIES TOP RESPONSES*



**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)

4. THE PHYSICAL SETTING

View Research

Humans have never lost interest in trying to find out how the universe is put together how it works, and where they fit in the cosmic scheme of things. The development of our understanding of the architecture of the universe is surely not complete, but we have made great progress. Given a universe that is made up of distances too vast to reach and of particles too small to see and too numerous to count, it is a tribute to human intelligence that we have made as

much progress as we have in accounting for how things fit together. All humans should participate in the pleasure of coming to know their universe better.

Science for All Americans

One of the grand success stories of science is the unification of the physical universe. It turns out that all natural objects, events, and processes are connected to each other in such a way that only a relatively few concepts are needed to make sense of them.

In a way, this fact complicates efforts to delineate what students should know about the makeup and structure of the universe. Any one arrangement of topics inevitably neglects many cross-connections among topics. In the arrangement used here (and also in Science for All Americans), benchmarks dealing with gravity, electromagnetism, and scale appear in several different sections. For example, 4A: The Universe, 4B: The Earth, 4F: Motion, and 4G: Forces of Nature are intimately linked by ideas of gravitational attraction and immense scales of distance, mass, and time. And 4D: Structure of Matter, 4E: Energy Transformations, and 4G: Forces of Nature are linked by ideas of electromagnetism and minute scales of distance, mass, and energy. Benchmarks for any section are connected to others and should be read in the context of the others.

The physical universe is a subject in which many ideas make high demands on students' comprehension and imagination. Students in elementary school can only begin to form notions of stars and matter. The drastically different scales of astronomical and atomic phenomena can be learned only over many years. But it is important that all students develop a sense of the context of place, time, and physical interactions in which their lives occur. Students in the early years are especially curious about how the world works.

Consequently, there is a dilemma about when to introduce ideas into the curriculum. On the one hand, rushing to teach elementary students about atoms or galaxies is not likely to be productive. Most students will only learn to recite facts about them, with little comprehension.

On the other hand, discussion and images about such imponderables are common in the popular media, and avoiding them seems unreasonable. The curriculum can focus on experiences and ideas that are accessible to children-for example, how different other planets are from the earth, or the different kinds of materials found in nature. And it can build in precursors to eventual understanding, such as observable motions in the sky and observable changes in materials.

A. The Universe Chapter Contents View Research Also See...

In earlier times, people everywhere were much more aware of the stars and were familiar with them in ways that few people today are. Back then, people knew the patterns of stars in the night sky, the regularity of the motions of the stars, and how those motions related to the seasons. They used their knowledge to plan the planting of crops and to navigate boats. The constellations, along with the sun, the moon, and the "wanderers"-the planets-have always figured in the efforts of people to explain themselves and their world through stories, myths, religions, and philosophies.

For all of that, and for the sheer wonder the stars provoke on a clear, moonless night far from city lights-awe that has inspired the expressive powers of poets, musicians, and artists-science is not needed. Why, then, insist that everyone become familiar with the heavens as portrayed by science? Consider that in cities the night sky is no longer a familiar part of a person's neighborhood. Many people today live in circumstances that deprive them of the chance to see the sky often enough to become personally familiar with it. Fortunately, telescopes, photography, computers, and space probes make up the difference by revealing more of the cosmos in greater detail than ever before. Thus, science education can bring back the sky-not the same sky, but one that is richer and more varied than people's eyes alone had ever led them to imagine.

Finding our place in the cosmic scheme of things and how we got here is a task for the ages-past, present, and future. The scientific effort to understand the universe is part of that enduring human imperative, and its successes are a tribute to human curiosity, resourcefulness, intelligence, and doggedness. If being educated means having an informed sense of time and place, then it is essential for a person to be familiar with the scientific aspects of the universe and know something of its origin and structure.

In thinking about what students should learn about the heavens, at least three aspects of the current scientific view ought to be taken into account: (1) the composition of the cosmos and its scale of space and time; (2) the principles on which the universe seems to operate; and (3) how the modern view of the universe emerged. The benchmarks in this section deal primarily with composition and scale; principles are dealt with in subsequent sections of the chapter, and some rudiments of the history of the scientific picture appear in Chapter 10: Historical Perspectives.

Kindergarten through Grade 2

Chapter Contents

During these years, learning about objects in the sky should be entirely observational and qualitative, for the children are far from ready to understand the magnitudes involved or to make sense out of explanations. The priority is to get the students noticing and describing what the sky looks like to them at different times. They should, for example, observe how the moon appears to change its shape. But it is too soon to name all the moon's phases and much too soon to explain them.

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

- **There are more stars in the sky than anyone can easily count, but they are not scattered evenly, and they are not all the same in brightness or color.**
- **The sun can be seen only in the daytime, but the moon can be seen sometimes at night and sometimes during the day. The sun, moon, and stars all appear to move slowly across the sky.**
- **The moon looks a little different every day, but looks the same again about every four weeks.**

Grades 3 through 5

Chapter Contents

Students should begin to develop an inventory of the variety of things in the universe. Planets can be shown to be different from stars in two essential ways-their appearance and their motion. When a modest telescope or pair of binoculars is used instead of the naked eyes, stars only look brighter-and more of them can be seen. The brighter planets, however, clearly are disks. (Not very large disks except in good-sized telescopes, but impressive enough after seeing a lot of stars.) The fixed patterns of stars should be made more explicit, although learning the constellation names is not important in itself. When students know that the star patterns stay the same as they move across the sky (and gradually shift with the seasons), they can then observe that the planets change their position against the pattern of stars.

Once students have looked directly at the stars, moon, and planets, use can be made of photographs of planets and their moons and of various collections of stars to point out their variety of size, appearance, and motion. No particular educational value comes from memorizing their names or counting them, although some students will enjoy doing so. Nor should students invest much time in trying to get the scale of distances firmly in mind. As to numbers of stars in the universe, few children will have much of an idea of what a billion is; thousands are enough of a challenge. (At this stage, a billion means more than a person could ever count one-at-a-time in an entire lifetime.)

Students' grasp of many of the ideas of the composition and magnitude of the universe has to grow slowly over time. Moreover, in spite of its common depiction, the sun-centered system seriously conflicts with common intuition. Students may need compelling reasons to really abandon their earth-centered views. Unfortunately, some of the best reasons are subtle and make sense only at a fairly high level of sophistication.

Some ideas about light and sight are prerequisite to understanding astronomical phenomena. Children should learn early that a large light source at a great distance looks like a small light source that is much closer. This phenomenon should be observed directly (and, if possible, photographically) outside at night. How things are seen by their reflected light is a difficult concept for children at this age, but is probably necessary for them to learn before phases of the moon will make sense.

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

- **The patterns of stars in the sky stay the same, although they appear to move across the sky nightly, and different stars can be seen in different seasons.**
- **Telescopes magnify the appearance of some distant objects in the sky, including the moon and the planets. The number of stars that can be seen through telescopes is dramatically greater than can be seen by the unaided eye.**
- **Planets change their positions against the background of stars.**
- **The earth is one of several planets that orbit the sun, and the moon orbits around the earth.**
- **Stars are like the sun, some being smaller and some larger, but so far away that they look like points of light.**

Grades 6 through 8 Chapter Contents

Students should add more detail to their picture of the universe, pay increasing attention to matters of scale, and back up their understanding with activities using a variety of astronomical tools. Student access to star finders, telescopes, computer simulations of planetary orbits, or a planetarium can be useful at this level. Figuring out and constructing models of size and distance-for example, of the planets within the solar system-is probably the most effective activity. Models with three dimensions are preferable to pictures and diagrams. Everyone should experience trying to fashion a physical model of the solar system in which the same scale is used for the sizes of the objects and the distances between them (as distinct from most illustrations, in which distances are underrepresented by a factor of 10 or more).

Some experiences with how apparent positions of objects differ from different points of observation will make plausible the estimation of distances to the moon and sun. Finding distances by triangulation and scale drawings will help students to understand how the distances to the moon and sun were estimated and why the stars must be very much farther away. (The dependence of apparent size on distance can be used to pose the historically important puzzle that star patterns do not appear any larger from one season to the next, even though the earth swings a hundred million miles closer to them.)

Using light years to express astronomical distances is not as straightforward as it seems. (Many adults think of light years as a measure of time.) Beginning with analogs such as "automobile hours" may help.

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

- **The sun is a medium-sized star located near the edge of a disk-shaped galaxy of stars, part of which can be seen as a glowing band of light that spans the sky on a very clear night. The universe contains many billions of galaxies, and each galaxy contains many billions of stars. To the naked eye, even the closest of these galaxies is no more than a dim, fuzzy spot.**
- **The sun is many thousands of times closer to the earth than any other star. Light from the sun takes a few minutes to reach the earth, but light from the next nearest star takes a few years to arrive. The trip to that star would take the fastest rocket thousands of years. Some distant galaxies are so far away that their light takes several billion years to reach the earth. People on earth, therefore, see them as they were that long ago in the past.**
- **Nine planets of very different size, composition, and surface features move around the sun in nearly circular orbits. Some planets have a great variety of moons and even flat rings of rock and ice particles orbiting around them. Some of these planets and moons show evidence of geologic activity. The earth is orbited by one moon, many artificial satellites, and debris.**
- **Large numbers of chunks of rock orbit the sun. Some of those that the earth meets in its yearly orbit around the sun glow and disintegrate from friction as they plunge through the atmosphere-and sometimes impact the ground. Other chunks of rocks mixed with ice have long, off-center orbits that carry them close to the sun, where the sun's radiation (of light and particles) boils off frozen material from their surfaces and pushes it into a long, illuminated tail.**

Grades 9 through 12

Chapter Contents

This is the time for all of the pieces to come together. Concepts from physics and chemistry, insights from history, mathematical ways of thinking, and ideas about the role of technology in exploring the universe all contribute to a grasp of the character of the cosmos. In particular, the role of gravity in forming and maintaining planets, stars, and the solar system should become clear. The scale of billions will make better sense, and the speed of light can be used to express relative distances conveniently.

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

- **The stars differ from each other in size, temperature, and age, but they appear to be made up of the same elements that are found on the earth and to behave according to the same physical principles. Unlike the sun, most stars are in systems of two or more stars orbiting around one another.**
- **On the basis of scientific evidence, the universe is estimated to be over ten billion years old. The current theory is that its entire contents expanded explosively from a hot, dense, chaotic mass. Stars condensed by gravity out of clouds of molecules of the lightest elements until nuclear fusion of the light elements into heavier ones began to occur. Fusion released great amounts of energy over millions of years. Eventually, some stars exploded, producing clouds of heavy elements from which other stars and planets could later condense. The process of star formation and destruction continues.**
- **Increasingly sophisticated technology is used to learn about the universe. Visual, radio, and x-ray telescopes collect information from across the entire spectrum of electromagnetic waves; computers handle an avalanche of data and increasingly complicated computations to interpret them; space probes send back data and materials from the remote parts of the solar system; and accelerators give subatomic particles energies that simulate conditions in the stars and in the early history of the universe before stars formed.**
- **Mathematical models and computer simulations are used in studying evidence from many sources in order to form a scientific account of the universe.**

B. The Earth

Chapter Contents View Research Also See...

An integrated picture of the earth has to develop over many years, with some concepts being visited over and over again in new contexts and greater detail. Some aspects can be learned in science, others in geography; some parts can be purely descriptive, others must draw on physical principles. The benchmarks in this section complement those of the previous section that locate the earth in the cosmos and those of the following section that focus on the surface of the earth. This arrangement does not imply any particular order of teaching. Often, teaching near-at-hand phenomena before teaching the far-distant ones makes sense; on the other hand, sometimes the near-to-far progression that makes sense cognitively may not correspond to what interests children.

Perhaps the most important reason for students to study the earth repeatedly is that they take years to acquire the knowledge that they need to complete the picture. The full picture requires the introduction of such concepts as temperature, the water cycle, gravitation, states of matter, chemical concentration, and energy transfer. Understanding of these concepts grows slowly as children mature and encounter them in different contexts.

The benchmarks here call for students to be able to explain two phenomena-the seasons and the phases of the moon-that are usually not learned well. Most adults are unable to give even approximately correct explanations for them. Most students are told by teachers what causes the seasons and the phases of the moon, and they read about them without understanding. Moon phases are difficult because of students' unfamiliarity with the geometry of light and "seeing." To help figure out the geometry, students can act out the sun-earth-moon relationships and make physical models. In trying to understand the seasons, students have difficulties regarding geometry and solar radiation. Students need direct experience with light and surfaces-shadows, reflection, and warming effects at different angles.

Kindergarten through Grade 2

Chapter Contents

There are many ways to acquaint children with earth-related phenomena that they will only come to understand later as being cyclic. For instance, students can start to keep daily records of temperature (hot, cold, pleasant) and precipitation (none, some, lots), and plot them by week, month, and years. It is enough for students to spot the pattern of ups and downs, without getting deeply into the nature of climate. They should become familiar with the freezing of water and melting of ice (with no change in weight), the disappearance of wetness into the air, and the appearance of water on cold surfaces. Evaporation and condensation will mean nothing different from disappearance and appearance, perhaps for several years, until students begin to understand that the evaporated water is still present in the form of invisibly small molecules.

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

- **Some events in nature have a repeating pattern. The weather changes some from day to day, but things such as temperature and rain (or snow) tend to be high, low, or medium in the same months every year.**
- **Water can be a liquid or a solid and can go back and forth from one form to the other. If water is turned into ice and then the ice is allowed to melt, the amount of water is the same as it was before freezing.**
- **Water left in an open container disappears, but water in a closed container does not disappear.**

Grades 3 through 5

Chapter Contents

During this period, students can begin to learn some of the surface features of the earth and also the earth's relation to the sun, moon, and other planets. Films, computer simulations, a planetarium, and telescopic observations will help, but it is essential that all students, sometimes working together in small groups, make physical models and explain what the models show. At the same time, students can begin learning about scale (counting, comparative distances, volumes, times, etc.) in interesting, readily understood activities and readings. However, scale factors larger than thousands, and even the idea of ratios, may be difficult before early adolescence.

An important point to be made along the way is that one cannot determine how the solar system is put together just by looking at it. Diagrams show what the system would look like if people could see it from far away, a feat that cannot be accomplished. Telescopes and other instruments do provide information, but a model is really needed to make sense out of the information. (The realization that people are not able to see, from the outside, how the solar system is constructed will help students understand the basis for the Copernican Revolution when the topic arises later.)

In making diagrams to show, say, the relative sizes of the planets and the distances of the planets from the sun, students may try to combine them using a single scale-and quickly become frustrated. Perhaps this can lead to a discussion of the general limits of graphic methods (including photographs) for showing reality. In any case, at this stage a rough picture of the organization of the solar system is enough.

Water offers another important set of experiences for students at this level. Students can conduct investigations that go beyond the observations made in the earlier grades to learn the connection between liquid and solid forms, but recognizing that water can also be a gas, while much more difficult, is still probably accessible. Perhaps the main thrust there is to try to figure out where water in an open container goes. This is neither self-evident nor easy to detect. But the water cycle is of such profound importance to life on earth that students should certainly have experiences that will in time contribute to their understanding of evaporation, condensation, and the conservation of matter.

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

- **Things on or near the earth are pulled toward it by the earth's gravity.**
- **Like all planets and stars, the earth is approximately spherical in shape. The rotation of the earth on its axis every 24 hours produces the night-and-day cycle. To people on earth, this turning of the planet makes it seem as though the sun, moon, planets, and stars are orbiting the earth once a day.**
- **When liquid water disappears, it turns into a gas (vapor) in the air and can reappear as a liquid when cooled, or as a solid if cooled below the freezing point of water. Clouds and fog are made of tiny droplets of water.**
- **Air is a substance that surrounds us, takes up space, and whose movement we feel as wind.**

Grades 6 through 8

Chapter Contents

Students can now consolidate their prior knowledge of the earth (as a planet) by adding more details (especially about climate), getting a firmer grasp of the geometry involved in explaining the seasons and phases of the moon, improving their ability to handle scale, and shifting their frame of reference away from the earth when needed. An inevitable paradox of the large scales involved is that an ocean that is difficult to imagine being 7 miles deep also can be considered a "relatively thin" layer on the earth's surface. Students should exercise their understanding of the paradox, perhaps by debating provocative questions such as "Is the ocean amazingly deep or amazingly shallow?"

Gravity, earlier thought of as acting toward the ground, can by now be thought of as acting toward the center of the spherical earth and reaching indefinitely into space. It is also time for students to begin to look at the planet's role in sustaining life-a complex subject that involves many different issues and benchmarks. In this section, the emphasis is on water and air as essential resources.

The cause of the seasons is a subtle combination of global and orbital geometry and of the effects of radiation at different angles. Students can learn part of the story at this grade level, but a complete picture cannot be expected until later.

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

- **We live on a relatively small planet, the third from the sun in the only system of planets definitely known to exist (although other, similar systems may be discovered in the universe).**
- **The earth is mostly rock. Three-fourths of its surface is covered by a relatively thin layer of water (some of it frozen), and the entire planet is surrounded by a relatively thin blanket of air. It is the only body in the solar system that appears able to support life. The other planets have compositions and conditions very different from the earth's.**
- **Everything on or anywhere near the earth is pulled toward the earth's center by gravitational force.**
- **Because the earth turns daily on an axis that is tilted relative to the plane of the earth's yearly orbit around the sun, sunlight falls more intensely on different parts of the earth during the year. The difference in heating of the earth's surface produces the planet's seasons and weather patterns.**
- **The moon's orbit around the earth once in about 28 days changes what part of the moon is lighted by the sun and how much of that part can be seen from the earth-the phases of the moon.**
- **Climates have sometimes changed abruptly in the past as a result of changes in the earth's crust, such as volcanic eruptions or impacts of huge rocks from space. Even relatively small changes in atmospheric or ocean content can have widespread effects on climate if the change lasts long enough.**
- **The cycling of water in and out of the atmosphere plays an important role in determining climatic patterns. Water evaporates from the surface of the earth, rises and cools, condenses into rain or snow, and falls again to the surface. The water falling on land collects in rivers and lakes, soil, and porous layers of rock, and much of it flows back into the ocean.**
- **Fresh water, limited in supply, is essential for life and also for most industrial processes. Rivers, lakes, and groundwater can be depleted or polluted, becoming unavailable or unsuitable for life.**

- **Heat energy carried by ocean currents has a strong influence on climate around the world.**
- **Some minerals are very rare and some exist in great quantities, but-for practical purposes-the ability to recover them is just as important as their abundance. As minerals are depleted, obtaining them becomes more difficult. Recycling and the development of substitutes can reduce the rate of depletion but may also be costly.**
- **The benefits of the earth's resources-such as fresh water, air, soil, and trees-can be reduced by using them wastefully or by deliberately or inadvertently destroying them. The atmosphere and the oceans have a limited capacity to absorb wastes and recycle materials naturally. Cleaning up polluted air, water, or soil or restoring depleted soil, forests, or fishing grounds can be very difficult and costly.**

Grades 9 through 12

Chapter Contents

Two important strands of understanding can now be pulled together to enrich students' views of the physical setting. One strand connects such physical concepts and principles as energy, gravitation, conservation, and radiation to the descriptive picture that students have built in their minds about the operation of the planets. The other strand consists of the Copernican Revolution, which illustrates the place of technology, mathematics, experimentation, and theory in scientific breakthroughs. In the context of thinking about how the solar system is put together, this historical event unites physics and astronomy, involves colorful personalities, and raises deep philosophical and political issues.

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

- **Life is adapted to conditions on the earth, including the force of gravity that enables the planet to retain an adequate atmosphere, and an intensity of radiation from the sun that allows water to cycle between liquid and vapor.**
- **Weather (in the short run) and climate (in the long run) involve the transfer of energy in and out of the atmosphere. Solar radiation heats the land masses, oceans, and air. Transfer of heat energy at the boundaries between the atmosphere, the land masses, and the oceans results in layers of different temperatures and densities in both the ocean and atmosphere. The action of gravitational force on regions of different densities causes them to rise or fall-and such circulation, influenced by the rotation of the earth, produces winds and ocean currents.**

C. Processes that Shape the Earth

Chapter Contents View Research Also See...

Students should learn what causes earthquakes, volcanos, and floods and how those events shape the surface of the earth. Students, however, may show more interest in the phenomena than in the role the phenomena play in sculpting the earth. So teachers should start with students' immediate interests and work toward the science. Students may find it harder to take seriously the less-obvious, less-dramatic, long-term effects of erosion by wind and water, annual deposits of sediment, the creep of continents, and the rise of mountains. Students' recognition of those effects will depend on an improving sense of long time periods and familiarity with the effect of multiplying tiny fractions by very large numbers (in this case, slow rates by long times).

Students can start in the early grades with the ways in which organisms, themselves included, modify their surroundings. As people have used earth resources, they have altered some earth systems. Students can gradually come to recognize how human behavior affects the earth's capacity to sustain life. Questions of environmental policy should be pursued when students become interested in them, usually in the middle grades or later, but care should be taken not to bypass science for advocacy. Critical thinking based on scientific concepts and understanding is the primary goal for science education.

Kindergarten through Grade 2

Chapter Contents

Teaching geological facts about how the face of the earth changes serves little purpose in these early years. Students should start becoming familiar with all aspects of their immediate surroundings, including what things change and what seems to cause change. Perhaps "changing things" can be a category in a class portfolio of things students observe and read about. At some point, students can start thinking up and trying out safe and helpful ways to change parts of their environment.

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

- **Chunks of rocks come in many sizes and shapes, from boulders to grains of sand and even smaller.**
- **Change is something that happens to many things.**
- **Animals and plants sometimes cause changes in their surroundings.**

Grades 3 through 5

Chapter Contents

In these years, students should accumulate more information about the physical environment, becoming familiar with the details of geological features, observing and mapping locations of hills, valleys, rivers, etc., but without elaborate classification. Students should also become adept at using magnifiers to inspect a variety of rocks and soils. The point is not to classify rigorously but to notice the variety of components.

Students should now observe elementary processes of the rock cycle-erosion, transport, and deposit. Water and sand boxes and rock tumblers can provide them with some firsthand examples. Later, they can connect the features to the processes and follow explanations of how the features came to be and still are changing. Students can build devices for demonstrating how wind and water shape the land and how forces on materials can make wrinkles, folds, and faults. Films of volcanic magma and ash ejection dramatize another source of buildup.

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

- **Waves, wind, water, and ice shape and reshape the earth's land surface by eroding rock and soil in some areas and depositing them in other areas, sometimes in seasonal layers.**
- **Rock is composed of different combinations of minerals. Smaller rocks come from the breakage and weathering of bedrock and larger rocks. Soil is made partly from weathered rock, partly from plant remains-and also contains many living organisms.**

Grades 6 through 8

Chapter Contents

At this level, students are able to complete most of their understanding of the main features of the physical and biological factors that shape the face of the earth. This understanding will still be descriptive because the theory of plate tectonics will not be encountered formally until high school. Of course, students should see as great a variety of landforms and soils as possible.

It is especially important that students come to understand how sedimentary rock is formed periodically, embedding plant and animal remains and leaving a record of the sequence in which the plants and animals appeared and disappeared. Besides the relative age of the rock layers, the absolute age of those remains is central to the argument that there has been enough time for evolution of species. The process of sedimentation is understandable and observable. But imagining the span of geologic time will be difficult for students.

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

- **The interior of the earth is hot. Heat flow and movement of material within the earth cause earthquakes and volcanic eruptions and create mountains and ocean basins. Gas and dust from large volcanoes can change the atmosphere.**
- **Some changes in the earth's surface are abrupt (such as earthquakes and volcanic eruptions) while other changes happen very slowly (such as uplift and wearing down of mountains). The earth's surface is shaped in part by the motion of water and wind over very long times, which act to level mountain ranges.**
- **Sediments of sand and smaller particles (sometimes containing the remains of organisms) are gradually buried and are cemented together by dissolved minerals to form solid rock again.**
- **Sedimentary rock buried deep enough may be reformed by pressure and heat, perhaps melting and recrystallizing into different kinds of rock. These re-formed rock layers may be forced up again to become land surface and even mountains. Subsequently, this new rock too will erode. Rock bears evidence of the minerals, temperatures, and forces that created it.**
- **Thousands of layers of sedimentary rock confirm the long history of the changing surface of the earth and the changing life forms whose remains are found in successive layers. The youngest layers are not always found on top, because of folding, breaking, and uplift of layers.**

- **Although weathered rock is the basic component of soil, the composition and texture of soil and its fertility and resistance to erosion are greatly influenced by plant roots and debris, bacteria, fungi, worms, insects, rodents, and other organisms.**
- **Human activities, such as reducing the amount of forest cover, increasing the amount and variety of chemicals released into the atmosphere, and intensive farming, have changed the earth's land, oceans, and atmosphere. Some of these changes have decreased the capacity of the environment to support some life forms.**

Grades 9 through 12

Chapter Contents

The thrust of study should now turn to modern explanations for the phenomena the students have learned descriptively and to consideration of the effects that human activities have on the earth's surface. Knowledge of radioactivity helps them understand how rocks can be dated, which helps them appreciate the scale of geologic time.

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

- **Plants alter the earth's atmosphere by removing carbon dioxide from it, using the carbon to make sugars and releasing oxygen. This process is responsible for the oxygen content of the air.**
- **The formation, weathering, sedimentation, and reformation of rock constitute a continuing "rock cycle" in which the total amount of material stays the same as its forms change.**
- **The slow movement of material within the earth results from heat flowing out from the deep interior and the action of gravitational forces on regions of different density.**
- **The solid crust of the earth-including both the continents and the ocean basins-consists of separate plates that ride on a denser, hot, gradually deformable layer of the earth. The crust sections move very slowly, pressing against one another in some places, pulling apart in other places. Ocean-floor plates may slide under continental plates, sinking deep into the earth. The surface layers of these plates may fold, forming mountain ranges.**
- **Earthquakes often occur along the boundaries between colliding plates, and molten rock from below creates pressure that is released by volcanic eruptions, helping to build up mountains. Under the ocean basins, molten rock may well up between separating plates to create new ocean floor. Volcanic activity along the ocean floor may form undersea mountains, which can thrust above the ocean's surface to become islands.**

D. The Structure of Matter

Chapter Contents View Research Also See...

This section may have the most implications for students' eventual understanding of the picture that science paints of how the world works. And it may offer great challenges too. Atomic theory powerfully explains many phenomena, but it demands imagination and the joining of several lines of evidence. Students must know about the properties of materials and their combinations, changes of state, effects of temperature, behavior of large collections of pieces, the construction of items from parts, and even about the desirability of nice, simple explanations. All of these elements should be introduced in middle school so the unifying idea of atoms can begin by the end of the 8th grade.

The scientific understanding of atoms and molecules requires combining two closely related ideas: All substances are composed of invisible particles, and all substances are made up of a limited number of basic ingredients, or "elements." These two merge into the idea that combining the particles of the basic ingredients differently leads to millions of materials with different properties.

Students often get the idea that atoms somehow just fill matter up rather than the correct idea that the atoms are the matter. Middle-school students also have trouble with the idea that atoms are in continual motion. Coming to terms with these concepts is necessary for students to make sense of atomic theory and its explanatory power.

The strategy here is to describe the complexity of atoms gradually, using evidence and explanations from several connected story lines. Students first learn the notion that atoms make up objects, not merely occupy space inside them; then they are introduced to crystal arrays and molecules. With this understanding, they can imagine how molecules and crystals lead to visible, tangible matter. Only then should the study of the internal structure of atoms be taken up.

Bringing atomic and molecular theory into the earlier grades is a great temptation, but most students are not ready to understand atomic theory before adolescence. The theory is certainly essential to much of modern scientific explanation, but moving atomic/molecular theory forward to the earlier grades should be resisted. The tiny size and huge number of atoms in even a sand grain are vastly beyond even adult experience. Having students memorize the names of invisible things and their parts gets things backward and wastes time. Concrete perceptions must come before abstract explanations. Students need to become familiar with the physical and chemical properties of many different kinds of materials through firsthand experience before they can be expected to consider theories that explain them.

There seems to be no tidy and consistent way to relate the terms atom, molecule, ion, polymer, and crystal. A facility in discussing these terms will grow slowly over time. Students should also not rush into discussions of nuclear theory. The abstractions are too formidable. The emptiness of the atom and its electrical balance, isotopes, decay, and radiation challenge the human mind. The preparations for these concepts should be developed carefully over several years so they can converge in high school.

Kindergarten through Grade 2 Chapter Contents

Students should examine and use a wide variety of objects, categorizing them according to their various observable properties. They should subject materials to such treatments as mixing, heating, freezing, cutting, wetting, dissolving, bending, and exposing to light to see how they change. Even though it is too early to expect precise reports or even consistent results from the students, they should be encouraged to describe what they did and how materials responded.

Students should also get a lot of experience in constructing things from a few kinds of small parts ("Tinkertoys" and "Legos"), then taking them apart and rearranging them. They should begin to consider how the properties of objects may differ from properties of the materials they are made of. And they should begin to inspect things with a magnifying glass to discover features not visible without it.

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

- **Objects can be described in terms of the materials they are made of (clay, cloth, paper, etc.) and their physical properties (color, size, shape, weight, texture, flexibility, etc.).**
- **Things can be done to materials to change some of their properties, but not all materials respond the same way to what is done to them.**

Grades 3 through 5

Chapter Contents

The study of materials should continue and become more systematic and quantitative. Students should design and build objects that require different properties of materials. They should write clear descriptions of their designs and experiments, present their findings whenever possible in tables and graphs (designed by the students, not the teacher), and enter their data and results in a computer database.

Objects and materials can be described by more sophisticated properties-conduction of heat and electricity, buoyancy, response to magnets, solubility, and transparency. Students should measure, estimate, and calculate sizes, capacities, and weights. If young children can't feel the weight of something, they may believe it to have no weight at all. Many experiences of weighing (if possible on increasingly sensitive balances)-including weighing piles of small things and dividing to find the weight of each-will help. It is not obvious to elementary students that wholes weigh the same as the sum of their parts. That idea is preliminary to, but far short of, the conservation principle to be learned later that weight doesn't change in spite of striking changes in other properties as long as all the parts (including invisible gases) are accounted for.

With magnifiers, students should inspect substances composed of large collections of particles, such as salt and talcum powder, to discover the unexpected details at smaller scales. They should also observe and describe the behavior of large collections of pieces-powders, marbles, sugar cubes, or wooden blocks (which can, for example, be "poured" out of a container) and consider that the collections may have new properties that the pieces do not.

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

- **Heating and cooling cause changes in the properties of materials. Many kinds of changes occur faster under hotter conditions.**
- **No matter how parts of an object are assembled, the weight of the whole object**

made is always the same as the sum of the parts; and when a thing is broken into parts, the parts have the same total weight as the original thing.

- **Materials may be composed of parts that are too small to be seen without magnification.**
- **When a new material is made by combining two or more materials, it has properties that are different from the original materials. For that reason, a lot of different materials can be made from a small number of basic kinds of materials.**

Grades 6 through 8

Chapter Contents

The structure of matter is difficult for this grade span. Historically, much of the evidence and reasoning used in developing atomic/molecular theory was complicated and abstract. In traditional curricula too, very difficult ideas have been offered to children before most of them had any chance of understanding. The law of definite proportions in chemical combinations, so obvious when atoms (and proportions) are well understood, is not likely to be helpful at this level. The behavior of gases-such as their compressibility and their expansion with temperature-may be investigated for qualitative explanation; but the mathematics of quantitative gas laws is likely to be more confusing than helpful to most students. When students first begin to understand atoms, they cannot confidently make the distinction between atoms and molecules or make distinctions that depend upon it-among elements, mixtures, and compounds, or between "chemical" and "physical" changes. An understanding of how things happen on the atomic level-making and breaking bonds-is more important than memorizing the official definitions (which are not so clear in modern chemistry anyway). Definitions can, of course, be memorized with no understanding at all.

Going into details of the structure of the atom is unnecessary at this level, and holding back makes sense. By the end of the 8th grade, students should have sufficient grasp of the general idea that a wide variety of phenomena can be explained by alternative arrangements of vast numbers of invisibly tiny, moving parts. Possible differences in atoms of the same element should be avoided at this stage. Historically, the identical nature of atoms of the same element was an assumption of atomic theory for a very long time.

When isotopes are introduced later, to explain subsequent observations, they can be a surprise and a lesson in the nature of progress in science. The alternative-teaching atoms' variety at the same time as the notion of their identity-seems likely to be prohibitively confusing to most students.

To that end, students should become familiar with characteristics of different states of matter-now including gases-and transitions between them. Most important, students should see a great many examples of reactions between substances that produce new substances very different from the reactants. Then they can begin to absorb the rudiments of atomic/molecular theory, being helped to see that the value of the notion of atoms lies in the explanations it provides for a wide variety of behavior of matter. Each new aspect of the theory should be developed as an explanation for some observed phenomenon and grasped fairly well before going on to the next.

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

- **All matter is made up of atoms, which are far too small to see directly through a microscope. The atoms of any element are alike but are different from atoms of other elements. Atoms may stick together in well-defined molecules or may be packed together in large arrays. Different arrangements of atoms into groups compose all substances.**
- **Equal volumes of different substances usually have different weights.**
- **Atoms and molecules are perpetually in motion. Increased temperature means greater average energy of motion, so most substances expand when heated. In solids, the atoms are closely locked in position and can only vibrate. In liquids, the atoms or molecules have higher energy, are more loosely connected, and can slide past one another; some molecules may get enough energy to escape into a gas. In gases, the atoms or molecules have still more energy and are free of one another except during occasional collisions.**
- **The temperature and acidity of a solution influence reaction rates. Many substances dissolve in water, which may greatly facilitate reactions between them.**
- **Scientific ideas about elements were borrowed from some Greek philosophers of 2,000 years earlier, who believed that everything was made from four basic substances: air, earth, fire, and water. It was the combinations of these "elements" in different proportions that gave other substances their observable properties. The Greeks were wrong about those four, but now over 100 different elements have been identified, some rare and some plentiful, out of which everything is made. Because most elements tend to combine with others, few elements are found in their pure form.**
- **There are groups of elements that have similar properties, including highly reactive metals, less-reactive metals, highly reactive nonmetals (such as chlorine, fluorine, and oxygen), and some almost completely nonreactive gases (such as helium and neon). An especially important kind of reaction between substances involves combination of oxygen with something else-as in burning or rusting. Some elements don't fit into any of the categories; among them are carbon and hydrogen, essential elements of living matter.**
- **No matter how substances within a closed system interact with one another, or how they combine or break apart, the total weight of the system remains the same. The idea of atoms explains the conservation of matter: If the number of atoms stays the same no matter how they are rearranged, then their total mass stays the same.**

Grades 9 through 12

Chapter Contents

Understanding the general architecture of the atom and the roles played by the main constituents of the atom in determining the properties of materials now becomes relevant. Having learned earlier that all the atoms of an element are identical and are different from those of all other elements, students now come up against the idea that, on the contrary, atoms of the same element can differ in important ways. This revelation is an opportunity as well as a complication-scientific knowledge grows by modifications, sometimes radical, of previous theories. Sometimes advances have been made by neglecting small inconsistencies, and then further advances have been made later by attending closely to those inconsistencies.

Students may at first take isotopes to be something in addition to atoms or as only the unusual, unstable nuclides. The most important features of isotopes (with respect to general scientific literacy) are their nearly identical chemical behavior and their different nuclear stabilities. Insisting on the rigorous use of isotope and nuclide is probably not worthwhile, and the latter term can be ignored.

The idea of half-life requires that students understand ratios and the multiplication of fractions, and be somewhat comfortable with probability. Games with manipulative or computer simulations should help them in getting the idea of how a constant proportional rate of decay is consistent with declining measures that only gradually approach zero. The mathematics of inferring backwards from measurements to age is not appropriate for most students. They need only know that such calculations are possible.

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

- **Atoms are made of a positive nucleus surrounded by negative electrons. An atom's electron configuration, particularly the outermost electrons, determines how the atom can interact with other atoms. Atoms form bonds to other atoms by transferring or sharing electrons.**
- **The nucleus, a tiny fraction of the volume of an atom, is composed of protons and neutrons, each almost two thousand times heavier than an electron. The number of positive protons in the nucleus determines what an atom's electron configuration can be and so defines the element. In a neutral atom, the number of electrons equals the number of protons. But an atom may acquire an unbalanced charge by gaining or losing electrons.**
- **Neutrons have a mass that is nearly identical to that of protons, but neutrons have no electric charge. Although neutrons have little effect on how an atom interacts with others, they do affect the mass and stability of the nucleus. Isotopes of the same element have the same number of protons (and therefore of electrons) but differ in the number of neutrons.**
- **The nucleus of radioactive isotopes is unstable and spontaneously decays, emitting particles and/or wavelike radiation. It cannot be predicted exactly when, if ever, an unstable nucleus will decay, but a large group of identical nuclei decay at a predictable rate. This predictability of decay rate allows radioactivity to be used for estimating the age of materials that contain radioactive substances.**
- **Scientists continue to investigate atoms and have discovered even smaller constituents of which neutrons and protons are made.**
- **When elements are listed in order by the masses of their atoms, the same sequence of properties appears over and over again in the list.**
- **Atoms often join with one another in various combinations in distinct molecules or in repeating three-dimensional crystal patterns. An enormous variety of biological, chemical, and physical phenomena can be explained by changes in the arrangement and motion of atoms and molecules.**

- **The configuration of atoms in a molecule determines the molecule's properties. Shapes are particularly important in how large molecules interact with others.**
- **The rate of reactions among atoms and molecules depends on how often they encounter one another, which is affected by the concentration, pressure, and temperature of the reacting materials. Some atoms and molecules are highly effective in encouraging the interaction of others.**

E. Energy Transformations

Chapter Contents View Research Also See...

Energy is a mysterious concept, even though its various forms can be precisely defined and measured. At the simplest level, children can think of energy as something needed to make things go, run, or happen. But they have difficulty distinguishing energy needs from other needs-plants need water to live and grow; cars need water, oil, and tires; people need sleep, etc. People in general are likely to think of energy as a substance, with flow and conservation analogous to that of matter. That is not correct, but for most people it can be an acceptable analogy. Although learning about energy does not make it much less mysterious, it is worth trying to understand because a wide variety of scientific explanations are difficult to follow without some knowledge of the concept of energy.

Energy is a major exception to the principle that students should understand ideas before being given labels for them. Children benefit from talking about energy before they are able to define it. Ideas about energy that students encounter outside of school-for example, getting "quick energy" from a candy bar or turning off a light so as not to "waste energy"- may be imprecise but are reasonably consistent with ideas about energy that we want students to learn.

Three energy-related ideas may be more important than the idea of energy itself. One is energy transformation. All physical events involve transferring energy or changing one form of energy into another-radiant to electrical, chemical to mechanical, and so on. A second idea is the conservation of energy. Whenever energy is reduced in one place, it is increased somewhere else by exactly the same amount. A third idea is that whenever there is a transformation of energy, some of it is likely to go into heat, which spreads around and is therefore not available for use.

Heat energy itself is a surprisingly difficult idea for students, who thoroughly confound it with the idea of temperature. A great deal of work is required for students to make the distinction successfully, and the heat/temperature distinction may join mass/weight, speed/acceleration, and power/energy distinctions as topics that, for purposes of literacy, are not worth the extraordinary time required to learn them. Because dissipated heat energy is at a lower temperature, some students' confusion about heat and temperature leads them to infer that the amount of energy has been reduced. On the other hand, some students' idea that dissipated heat energy has been "exhausted" or "expended" may be tolerably close to the truth.

Similarly, units and formulas for kinetic and potential energy are more difficult than they are worth for the semiquantitative understanding that we seek here. But the notion of potential energy is still useful for some situations in which motion might occur (for example, gravitational energy in water behind a dam, mechanical energy in a cocked mousetrap, or chemical energy in a flashlight battery or sugar molecule).

Work, in the specialized sense used in physics, is often considered a useful, even necessary, concept for dealing with ideas of energy. These benchmarks propose to do without a technical definition of work for purposes of basic literacy, because it is so greatly confused with the common English-language meaning of the word. The calculation of work as force times distance is not essential to understanding many important ideas about energy. Running makes you tired; rubbing your hands together makes them warmer; coming out of water makes you feel cool.

Older students can grasp these ideas in a general way, but even they should not be expected to understand them deeply. For young students, it may be enough at first to convince them that energy is needed to get physical things to happen and that they should get in the habit of wondering where the energy came from. Then, as they study physical, chemical, and biological systems, many opportunities arise for them to see the many different forms energy takes and to find out how useful the energy concepts are.

Teachers have to decide what constitutes a sufficient understanding of energy and its transformations and conservation. As the benchmarks below indicate, in harmony with *Science for All Americans*, qualitative approximations are more important and should have priority. Much time can be invested in having students memorize definitions-for heat, temperature, system, transformation, entropy, and the like-with little to show for it in the way of understanding.

Kindergarten through Grade 2

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No effort to introduce energy as a scientific idea ought to be organized in these first years. If children use the term energy to indicate how much pep they have, that is perfectly all right, in that the meaning is clear and no technical mischief has been done. By the end of the 2nd grade, students should be familiar with a variety of ways of making things go and should consider "What makes it go?" to be an interesting question to ask. Once they learn that batteries wear down and cars run out of gasoline, turning off unneeded appliances can be said to "save on batteries" and "save on gas." The idea that is accessible at this age is that keeping anything going uses up some resource. (Little is gained by having children answer, "Energy.")

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

- **The sun warms the land, air, and water.**

Grades 3 through 5

Chapter Contents

Investing much time and effort in developing formal energy concepts can wait. The importance of energy, after all, is that it is a useful idea. It helps make sense out of a very large number of things that go on in the physical and biological and engineering worlds. But until students have reached a certain point in their understanding of bits and pieces of the world, they gain little by having such a tool. It is a matter of timing.

The one aspect of the energy story in which students of this age can make some headway is heat, which is produced almost everywhere. In their science and technology activities during these years, students should be alerted to look for things and processes that give off heat-lights, radios, television sets, the sun, sawing wood, polishing surfaces, bending things, running motors, people, animals, etc.-and then for those that seem not to give off heat. Also, the time is appropriate to explore how heat spreads from one place to another and what can be done to contain it or shield things from it.

Students' ideas of heat have many wrinkles. In some situations, cold is thought to be transferred rather than heat. Some materials may be thought to be intrinsically warm (blankets) or cold (metals). Objects that keep things warm-such as a sweater or mittens-may be thought to be sources of heat. Only a continuing mix of experiment and discussion is likely to dispel these ideas.

Students need not come out of this grade span understanding heat or its difference from temperature. In this spirit, there is little to be gained by having youngsters refer to heat as heat energy. More important, students should become familiar with the warming of objects that start out cooler than their environment, and vice versa. Computer labware probes and graphic displays that detect small changes in temperature and plot them can be used by students to examine many instances of heat exchange. Because many students think of cold as a substance that spreads like heat, there may be some advantage in translating descriptions of transfer of cold into terms of transfer of heat.

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

- **Things that give off light often also give off heat. Heat is produced by mechanical and electrical machines, and any time one thing rubs against something else.**
- **When warmer things are put with cooler ones, the warm ones lose heat and the cool ones gain it until they are all at the same temperature. A warmer object can warm a cooler one by contact or at a distance.**
- **Some materials conduct heat much better than others. Poor conductors can reduce heat loss.**

Grades 6 through 8

Chapter Contents

At this level, students should be introduced to energy primarily through energy transformations. Students should trace where energy comes from (and goes next) in examples that involve several different forms of energy along the way: heat, light, motion of objects, chemical, and elastically distorted materials. To change something's speed, to bend or stretch things, to heat or cool them, to push things together or tear them apart all require transfers (and some transformations) of energy.

At this early stage, there may be some confusion in students' minds between energy and energy sources. Focusing on energy transformations may get around this somewhat. Food, gasoline, and batteries obviously get used up. But the energy they contain does not disappear; it is changed into other forms of energy.

The most primitive idea is that the energy needed for an event must come from somewhere.

That should trigger children's interest in asking, for any situation, where the energy comes from and (later) asking where it goes. Where it comes from is usually much more evident than where it goes, because some usually diffuses away as radiation and random molecular motion.

A slightly more sophisticated proposition is the semiquantitative one that whenever some energy seems to show up in one place, some will be found to disappear from another. Eventually, the energy idea can become quantitative: If we can keep track of how much energy of each kind increases and decreases, we find that whenever the energy in one place decreases, the energy in other places increases by just the same amount. This energy-cannot-be-created-or-destroyed way of stating conservation fully may be more intuitive than the abstraction of a constant energy total within an isolated system. The quantitative (equal amounts) idea should probably wait until high school.

Convection is not so much an independent means of heat transfer as it is an aid to transfer of heat by conduction and radiation. Convection currents appear spontaneously when density differences caused by heating (conduction and radiation) are acted on by a gravitational field. (Though not in space stations, unless they are rotating.) But these subtleties are not appropriate for most 8th graders.

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

- **Energy cannot be created or destroyed, but only changed from one form into another.**
- **Most of what goes on in the universe-from exploding stars and biological growth to the operation of machines and the motion of people-involves some form of energy being transformed into another. Energy in the form of heat is almost always one of the products of an energy transformation.**
- **Heat can be transferred through materials by the collisions of atoms or across space by radiation. If the material is fluid, currents will be set up in it that aid the transfer of heat.**
- **Energy appears in different forms. Heat energy is in the disorderly motion of molecules; chemical energy is in the arrangement of atoms; mechanical energy is in moving bodies or in elastically distorted shapes; gravitational energy is in the separation of mutually attracting masses.**

Grades 9 through 12 Chapter Contents

The concepts acquired in the earlier grades should now be extended to nuclear realms and living organisms. Revisiting energy concepts in new contexts provides opportunities to improve student understanding of the basic concepts and to see just how powerful they are.

Two other major ideas merit introduction during these years, but without resort to mathematics. One of these is that the total amount of energy available for useful transformation is almost always decreasing; the other is that energy changes on the atomic scale occur only in discrete jumps. The first of those is not too difficult or implausible for students because they can experience in many ways a wide variety of actions that give off heat. The emphasis should probably be on the practical consequences of the loss of useful energy through heat dissipation.

On the other hand, the notion that energy changes in atoms can occur in only fixed amounts with no intermediate values is strange to begin with and hard to demonstrate. Some evidence should be presented for this scientific belief but not in great detail. The easiest phenomenon to show, which is also a major reason for including quantum jumps in literacy, is the discrete colors of light emitted by separate atoms, as in sodium-vapor or mercury-vapor lights. Another major reason for having students encounter the quantum idea is to illustrate the point that in science it is sometimes useful to invent ideas that run counter to intuition and prior experience.

An important application of the atom/energy relationship to bring to the attention of students is that the distinctive light energies emitted or absorbed by different atoms enable them to be identified on earth, in our sun, and even on the other side of the universe. This fact is a prime example of the "rules are the same everywhere" principle.

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

- **Whenever the amount of energy in one place or form diminishes, the amount in other places or forms increases by the same amount.**
- **Heat energy in a material consists of the disordered motions of its atoms or molecules. In any interactions of atoms or molecules, the statistical odds are that they will end up with less order than they began-that is, with the heat energy spread out more evenly. With huge numbers of atoms and molecules, the greater disorder is almost certain.**
- **Transformations of energy usually produce some energy in the form of heat, which spreads around by radiation or conduction into cooler places. Although just as much total energy remains, its being spread out more evenly means less can be done with it.**
- **Different energy levels are associated with different configurations of atoms and molecules. Some changes of configuration require an input of energy whereas others release energy.**
- **When energy of an isolated atom or molecule changes, it does so in a definite jump from one value to another, with no possible values in between. The change in energy occurs when radiation is absorbed or emitted, so the radiation also has distinct energy values. As a result, the light emitted or absorbed by separate atoms or molecules (as in a gas) can be used to identify what the substance is.**
- **Energy is released whenever the nuclei of very heavy atoms, such as uranium or plutonium, split into middleweight ones, or when very light nuclei, such as those of hydrogen and helium, combine into heavier ones. The energy released in each nuclear reaction is very much greater than the energy given off in each chemical reaction.**

F. Motion

Chapter Contents View Research Also See...

Nothing in the universe is at rest. Motion is as essential to understanding the physical world as matter and energy are. Following the organization of *Science for All Americans*, the benchmarks for motion constitute a wide range of topics, from the movement of objects to vibrations and the behavior of waves. Rotary motion, as interesting as it is, poses much greater difficulties for students and is not included in the benchmarks.

The benchmarks for understanding the motion of objects and repeating patterns of motion do not demand the use of equations. For purposes of science literacy, a qualitative understanding is sufficient. Equations may clarify relationships for the most mathematically apt students, but for many students they are difficult and may obscure the ideas rather than clarify them. For example, almost all students can grasp that the effect of a force on an object's motion will be greater if the force is greater and will be less if the object has more mass-but learning a=F/m (which to many teachers seems like the same thing) is apparently much harder.

Newton's laws of motion are simple to state, and sometimes teachers mistake the ability of students to recite the three laws correctly as evidence that they understand them. The fact that it took such a long time, historically, to codify the laws of motion suggests that they are not self-evident truths, no matter how obvious they may seem to us *once we understand them well*. Much research in recent years has documented that students typically have trouble relating formal ideas of motion and force to their personal view of how the world works.

These are three of the obstacles:

1. A basic problem is the ancient perception that sustained motion requires sustained force. The contrary notion that it takes force to change an object's motion, that something in motion will move in a straight line forever without slowing down unless a force acts on it, runs counter to what we can see happening with our eyes.
2. Limitations in describing motion may keep students from learning about the effect of forces. Students of all ages tend to think in terms of motion or no motion. So the first task may be to help students divide the category of motion into steady motion, speeding up, and slowing down. For example, falling objects should be described as falling faster and faster rather than just falling down. As indicated earlier, the basic idea expressed in Newton's second law of motion is not difficult to grasp, but vocabulary may get in the way if students have to struggle over the meaning of force and acceleration. Both terms have many meanings in common language that confound their specialized use in science.
3. Like inertia, the action-equals-reaction principle is counterintuitive. To say that a book presses down on the table is sensible enough, but then to say that the table pushes back up with exactly the same force (which disappears the instant you pick up the book) seems false on the face of it.

What is to be done? Students should have lots of experiences to shape their intuition about motion and forces long before encountering laws. Especially helpful are experimentation and discussion of what happens as surfaces become more elastic or more free of friction.

Vibrations treated only descriptively bring no special problems, other than the occasional confusion caused by the word speed being used in English for both frequency and velocity. Does a guitar string move quickly (back and forth a thousand times a second) or slowly (only 15 miles or so per hour)? Similarly, is the earth's rotation slow (once a day) or fast (1,000 miles per hour at the equator)? In the overall story of motion, vibrations serve in good part to introduce the ideas of frequency and amplitude. Because there are so many examples of vibrating systems that students can experience directly, they easily see vibration as a common way for some things to move and see frequency as a measure of that motion.

Waves, on the other hand, present a greater challenge. Wave motion is familiar to children through their experience with water. Surface waves on water provide the standard image of what waves are, and ropes and springs can also be used to show some of the properties of waves. Without formal schooling, young people learn that many other kinds of waves exist: radio waves, x rays, radar, microwaves, sound waves, ultraviolet radiation, and more. But they still might not know what these things are, how they relate to one another, what they have to do with motion, or in what sense such waves are waves.

Kindergarten through Grade 2

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From the outset, students should view, describe, and discuss all kinds of moving things-themselves, insects, birds, trees, doors, rain, fans, swings, volleyballs, wagons, stars, etc.-keeping notes, drawing pictures to suggest their motion, and raising questions: Do they move in a straight line? Is their motion fast or slow? How can you tell? How many ways does a growing plant move? The questions count more than the answers, at this stage. And students should gain varied experiences in getting things to move or not to move and in changing the direction or speed of things that are already in motion.

Presumably students will start "making music" from the first day in school, and this provides an opportunity to introduce vibrations as a phenomenon rather than a theory. With the drums, bells, stringed and other instruments they use, including their own voices, they can feel the vibrations on the instruments as they hear the sounds. These experiences are important for their own sake and at this point do not need elaboration.

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

- **Things move in many different ways, such as straight, zigzag, round and round, back and forth, and fast and slow.**
- **The way to change how something is moving is to give it a push or a pull.**
- **Things that make sound vibrate.**

Grades 3 through 5

Chapter Contents

Students should continue describing motion. And they can be more experimental and more quantitative as their measurement skills sharpen. Determining the speed of fast things and slow things can present a challenge that students will readily respond to. They also can work out for themselves some of the general relationships between force and change of motion and internalize the notion of force as a push or pull of one thing on another-whether rubber bands, magnets, or explosions.

Students should also increase their inventory of examples of periodic motion and perhaps devise ways of measuring different rates of vibration. And students should use prisms to see that white light produces a whole "rainbow" of colors. (The idea that white light is "made up of" different colors is difficult and should be postponed to later grades.) There is nothing to be gained at this stage, however, from linking light to wave motion.

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

- **Changes in speed or direction of motion are caused by forces. The greater the force is, the greater the change in motion will be. The more massive an object is, the less effect a given force will have.**
- **How fast things move differs greatly. Some things are so slow that their journey takes a long time; others move too fast for people to even see them.**

Grades 6 through 8

Chapter Contents

The force/motion relationship can be developed more fully now and the difficult idea of inertia be given attention. Students have no trouble believing that an object at rest stays that way unless acted on by a force; they see it every day. The difficult notion is that an object in motion will continue to move unabated unless acted on by a force. Telling students to disregard their eyes will not do the trick-the things around them do appear to slow down of their own accord unless constantly pushed or pulled. The more experiences the students can have in seeing the effect of reducing friction, the easier it may be to get them to imagine the friction-equals-zero case.

Students can now learn some of the properties of waves by using water tables, ropes, and springs, and quite separately they can learn about the electromagnetic spectrum, including the assertion that it consists of wavelike radiations. Wave length should be the property receiving the most attention but only minimal calculation.

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

- **Light from the sun is made up of a mixture of many different colors of light, even though to the eye the light looks almost white. Other things that give off or reflect light have a different mix of colors.**
- **Something can be "seen" when light waves emitted or reflected by it enter the eye-just as something can be "heard" when sound waves from it enter the ear.**
- **An unbalanced force acting on an object changes its speed or direction of motion, or both. If the force acts toward a single center, the object's path may curve into an orbit around the center.**
- **Vibrations in materials set up wavelike disturbances that spread away from the source. Sound and earthquake waves are examples. These and other waves move at different speeds in different materials.**
- **Human eyes respond to only a narrow range of wavelengths of electromagnetic radiation-visible light. Differences of wavelength within that range are perceived as differences in color.**

Grades 9 through 12

Chapter Contents

At this level, students learn about relative motion, the action/reaction principle, wave behavior, the interaction of waves with matter, the Doppler effect now used in weather observations, and the red shift of distant galaxies. Relative motion is fun-students find it interesting to figure out their speeds in different reference frames, and many activities and films illustrate this principle. Learning this concept is important for its own sake and for the part it plays in the changing reference frames of the Copernican Revolution, and in simple relativity.

This level is also a time to show the power of mathematics. Once students are fully convinced that change in motion is proportional to the force applied, then mathematical logic requires that when F = 0, there be no change in motion. (So Newton's first law is just a special case of his second.) Students can move from a qualitative understanding of the force/motion relationship (more force changes motion more; more mass is harder to change) to one that is more quantitative (the change in motion is directly proportional to the amount of force and inversely proportional to the mass). Experimentally, they can learn that the change in motion of an object is proportional to the applied force and inversely proportional to the mass-a step beyond knowing that change in motion goes up with increasing force and down with increasing mass.

Students should come to understand qualitatively that (1) doubling the force on an object of a given mass doubles the effect the force has, tripling triples the effect, and so on; and (2) that whatever effect a given force has on an object, it will have half the effect on an object having twice the mass, a third on one having triple the mass, and so on. This need not entail having students solving lots of numerical problems.

The qualitative principle also applies to waves. Even as simple a relationship as speed = wavelength x frequency poses difficulties for many students. A sufficient minimum is that students develop semiquantitative notions about waves-for example, higher frequencies have shorter wavelengths and those with longer wavelengths tend to spread out more around obstacles.

The effect of wavelength on how waves interact with matter can be developed through intrinsically interesting phenomena-such as the blueness of the sky and redness of sunsets resulting from light of short wavelengths being scattered most by the atmosphere, or the color of grass resulting from its absorbing light of both shorter and longer wavelengths while reflecting the intermediate green. Electromagnetic waves with different wavelengths have different effects on the human body. Some pass through the body with little effect, some tan or injure the skin, and some are absorbed in different amounts by internal organs (sometimes injuring cells).

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

- **The change in motion of an object is proportional to the applied force and inversely proportional to the mass.**
- **All motion is relative to whatever frame of reference is chosen, for there is no motionless frame from which to judge all motion.**
- **Accelerating electric charges produce electromagnetic waves around them. A great variety of radiations are electromagnetic waves: radio waves, microwaves, radiant heat, visible light, ultraviolet radiation, x rays, and gamma rays. These wavelengths vary from radio waves, the longest, to gamma rays, the shortest. In**

empty space, all electromagnetic waves move at the same speed-the "speed of light."

- **Whenever one thing exerts a force on another, an equal amount of force is exerted back on it.**
- **The observed wavelength of a wave depends upon the relative motion of the source and the observer. If either is moving toward the other, the observed wavelength is shorter; if either is moving away, the wavelength is longer. Because the light seen from almost all distant galaxies has longer wavelengths than comparable light here on earth, astronomers believe that the whole universe is expanding.**
- **Waves can superpose on one another, bend around corners, reflect off surfaces, be absorbed by materials they enter, and change direction when entering a new material. All these effects vary with wavelength. The energy of waves (like any form of energy) can be changed into other forms of energy.**

G. Forces of Nature

Chapter Contents View Research Also See...

For a good many school years, force may be treated as the originator of motion, and an explanation of force itself may be postponed. But the force between a bat and a ball has an entirely different origin than that between the earth and the moon. In helping students broaden their understanding of the fundamental forces of nature, the emphasis should be on gravitational and electromagnetic forces. what about nuclear?

The general idea of universal gravitation and how weak it is compared to other kinds of forces is sufficient. Working out numerical problems adds little and is very likely to leave many students behind. The math is not hard but the units are baffling. A paradoxical idea for students is how weak gravity is compared to electric and magnetic forces. Gravity becomes appreciable only when very large accumulations of matter figure, such as that of a student and the entire earth. To students, gravitational forces seem strong compared to the trivial electric forces on dry hair charged by combing. But they can be led to see quite the opposite: The whole earth is required to pull a hair down by gravity, while only a small amount of charge is needed to force it up electrically against gravity.

Electric and magnetic forces and the relationship between them ought also to be treated qualitatively. Fields can be introduced, but only intuitively. Most important is that students get a sense of electric and magnetic force fields (as well as of gravity) and of some simple relations between magnets and electric currents. Direction rules have little importance for general literacy. The priority should be on what conditions produce a magnetic field and what conditions induce an electric current. Diagrams of electric and magnetic fields promote some misconceptions about "lines of force," notably that the force exists only on those lines. Students should recognize that the lines are used only to show the direction of the field.

Kindergarten through Grade 2

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The focus should be on motion and on encouraging children to be observant about when and how things seem to move or not move. They should notice that things fall to the ground if not held up. They should observe motion everywhere, making lists of different kinds of motion and what things move that way. Even in the primary years, children should use magnets to get things to move without touching them, and thereby learn that forces can act at a distance with no perceivable substance in between.

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

- **Things near the earth fall to the ground unless something holds them up.**
- **Magnets can be used to make some things move without being touched.**

Grades 3 through 5

Chapter Contents

The main notion to convey here is that forces can act at a distance. Students should carry out investigations to become familiar with the pushes and pulls of magnets and static electricity. The term gravity may interfere with students' understanding because it often is used as an empty label for the common (and ancient) notion of "natural motion" toward the earth. The important point is that the earth pulls on objects.

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

- **The earth's gravity pulls any object toward it without touching it.**
- **Without touching them, a magnet pulls on all things made of iron and either pushes or pulls on other magnets.**
- **Without touching them, material that has been electrically charged pulls on all other materials and may either push or pull other charged materials.**

Grades 6 through 8

Chapter Contents

The idea of gravity-up until now seen as something happening near the earth's surface-can be generalized to all matter everywhere in the universe. Some demonstration, in the laboratory or on film or videotape, of the gravitational force between objects may be essential to break through the intuitive notion that things just naturally fall. Students should make devices to observe the magnetic effects of current and the electric effects of moving magnets. At first, the devices can be simple electromagnets; later, more complex devices, such as motor kits, can be introduced.

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

- **Every object exerts gravitational force on every other object. The force depends on how much mass the objects have and on how far apart they are. The force is hard to detect unless at least one of the objects has a lot of mass.**
- **The sun's gravitational pull holds the earth and other planets in their orbits, just as the planets' gravitational pull keeps their moons in orbit around them.**

- **Electric currents and magnets can exert a force on each other.**

Grades 9 through 12

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Students should now learn how well the principle of universal gravitation explains the architecture of the universe and much that happens on the earth. The principle will become familiar from many different examples (star formation, tides, comet orbits, etc.) and from the study of the history leading to this unification of earth and sky. The "inversely proportional to the square" aspect is not a high priority for literacy. Much more important is escaping the common adult misconceptions that the earth's gravity does not extend beyond its atmosphere or that it is caused by the atmosphere.

Study of the nature of electric and magnetic forces should be joined to the study of the atom. What is likely to surprise many students is how much more powerful electromagnetic forces are than the gravitational forces, which are negligible on an atomic scale. Some students may have trouble seeing mechanical forces, such as pushing on an object with a stick, as being produced by electric charges on the atomic scale. It may help for them to recognize that the electric forces they do observe commonly (such as "static cling") result from extremely slight imbalances of electric charges. As students come to believe in the action/reaction principle, they will expect forces to be mutual.

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

- **Gravitational force is an attraction between masses. The strength of the force is proportional to the masses and weakens rapidly with increasing distance between them.**
- **Electromagnetic forces acting within and between atoms are vastly stronger than the gravitational forces acting between the atoms. At the atomic level, electric forces between oppositely charged electrons and protons hold atoms and molecules together and thus are involved in all chemical reactions. On a larger scale, these forces hold solid and liquid materials together and act between objects when they are in contact-as in sticking or sliding friction.**
- **There are two kinds of charges-positive and negative. Like charges repel one another, opposite charges attract. In materials, there are almost exactly equal proportions of positive and negative charges, making the materials as a whole electrically neutral. Negative charges, being associated with electrons, are far more mobile in materials than positive charges are. A very small excess or deficit of negative charges in a material produces noticeable electric forces.**
- **Different kinds of materials respond differently to electric forces. In conducting materials such as metals, electric charges flow easily, whereas in insulating materials such as glass, they can move hardly at all. At very low temperatures, some materials become superconductors and offer no resistance to the flow of current. In between these extremes, semiconducting materials differ greatly in how well they conduct, depending on their exact composition.**
- **Magnetic forces are very closely related to electric forces and can be thought of as different aspects of a single electromagnetic force. Moving electric charges**

produce magnetic forces and moving magnets produce electric forces. The interplay of electric and magnetic forces is the basis for electric motors, generators, and many other modern technologies, including the production of electromagnetic waves.

- **The forces that hold the nucleus of an atom together are much stronger than the electromagnetic force. That is why such great amounts of energy are released from the nuclear reactions in the sun and other stars.**

11. COMMON THEMES

View Research

Some important themes pervade science, mathematics, and technology and appear over and over again, whether we are looking at an ancient civilization, the human body, or a comet. They are ideas that transcend disciplinary boundaries and prove fruitful in explanation, in theory, in observation, and in design.

Science for All Americans

Some powerful ideas often used by mathematicians, scientists, and engineers are not the intellectual property of any one field or discipline. Indeed, notions of system, scale, change and constancy, and models have important applications in business and finance, education, law, government and politics, and other domains, as well as in mathematics, science, and technology. These common themes are really ways of thinking rather than theories or discoveries. (Energy also represents a prominent tool for thinking in science and technology, but because it is part of the content of science, it is not included here as a theme.) Science for All Americans recommends what all students should know about those themes, and the benchmarks in the four sections below suggest how student understanding of them should grow over the school years. Although the context of both Science for All Americans and Benchmarks is mainly science, mathematics, and technology, other contexts are identified here to emphasize the general usefulness of these themes.

A. Systems

Chapter Contents View Research Also See...

One of the essential components of higher-order thinking is the ability to think about a whole in terms of its parts and, alternatively, about parts in terms of how they relate to one another and to the whole. People are accustomed to speak of political systems, sewage systems, transportation systems, the respiratory system, the solar system, and so on. If pressed, most people would probably say that a system is a collection of things and processes (and often people) that interact to perform some function. The scientific idea of a system implies detailed attention to inputs and outputs and interactions among the system components. If these can be specified quantitatively, a computer simulation of the system might be run to study its theoretical behavior, and so provide a way to define problems and investigate complex phenomena. But a system need not have a "purpose" (e.g., an ecosystem or the solar system) and what a system includes can be imagined in any way that is interesting or useful. Students in the elementary grades study many different kinds of systems in the normal course of things, but they should not be rushed into explicit talk about systems. That can and should come in middle and high school.

Children tend to think of the properties of a system as belonging to individual parts of it rather than as arising from the interaction of the parts. A system property that arises from interaction of parts is therefore a difficult idea. Also, children often think of a system only as something that is made and therefore as obviously defined. This notion contrasts with the scientific view of systems as being defined with particular purposes in mind. The solar system, for example, can be defined in terms of the sun and planets only, or defined to include also the planetary moons and solar comets. Similarly, not only is an automobile a system, but one can think of an automotive system that includes service stations, oil wells, rubber plantations, insurance, traffic laws, junk yards, and so on.

The main goal of having students learn about systems is not to have them talk about systems in abstract terms, but to enhance their ability (and inclination) to attend to various aspects of particular systems in attempting to understand or deal with the whole system. Does the student troubleshoot a malfunctioning device by considering connections and switches-whether using the terms input, output, or controls or not? Does the student try to account for what becomes of all of the input to the water cycle-whether using the term conservation or not? The vocabulary will be helpful for students once they have had a wide variety of experiences with systems thinking, but otherwise it may mistakenly give the impression of understanding. Learning about systems in some situations may not transfer well to other situations, so systems should be encountered through a variety of approaches, including designing and troubleshooting. Simple systems (a pencil or mousetrap), of course, should be encountered before more complex ones (a stereo system, a plant, the continuous manufacture of goods, ecosystems, or school government).

A persistent student misconception is that the properties of an assembly are the same as the properties of its parts (for example, that soft materials are made of soft molecules). Sometimes it is true. For example, a politically conservative organization may be made up entirely of conservative individuals. But some features of systems are unlike any of their parts. Sugar is sweet, but its component atoms (carbon, oxygen, and hydrogen) are not. The system property may result from what its parts are like, but the parts themselves may not have that property. A grand example is life as an emergent property of the complex interaction of complex molecules.

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Students in the elementary grades acquire the experiences that they will use in the middle grades and beyond to develop an understanding of systems concepts and their applications. They also can begin to attend to what affects what. Frequent discussion of how one thing affects another lays the ground for recognizing interactions. Another tack for focusing on interaction is to raise the question of when things work and when they do not-owing, say, to missing or broken parts or the absence of a source of power (batteries, gasoline).

Students should practice identifying the parts of things and how one part connects to and affects another. Classrooms can have available a variety of dissectable and rearrangeable objects, such as gear trains and toy vehicles and animals, as well as conventional blocks, dolls, and doll houses. Students should predict the effects of removing or changing parts.

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

- **Most things are made of parts.**
- **Something may not work if some of its parts are missing.**
- **When parts are put together, they can do things that they couldn't do by themselves.**

Grades 3 through 5 Chapter Contents

Hands-on experience with a variety of mechanical systems should increase. Classrooms can have "take-apart" stations where a variety of familiar hardware devices can be taken apart (and perhaps put back together) with hand tools. Devices that are commonly purchased disassembled can be provided, along with assembly instructions, to emphasize the importance of the proper arrangement of parts (and incidentally, the importance of language-arts skills, which are needed to read and follow instructions).

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

- **In something that consists of many parts, the parts usually influence one another.**
- **Something may not work as well (or at all) if a part of it is missing, broken, worn out, mismatched, or misconnected.**

Grades 6 through 8 Chapter Contents

Systems thinking can now be made explicit-suggesting analysis of parts, subsystems, interactions, and matching. But descriptions of parts and their interaction are more important than just calling everything a system.

Student projects should now entail analyzing, designing, assembling, and troubleshooting systems-mechanical, electrical, and biological-with easily discernible components. Students can take apart and reassemble such things as bicycles, clocks, and mechanical toys and build battery-driven electrical circuits that actually operate something. They can assemble a sound system and then judge how changing different components affects the system's output, or observe aquariums and gardens while changing some parts of the system or adding new parts. The idea of system should be expanded to include connections among systems. For example, a can opener and a can may each be thought of as a system, but they both-together with the person using them-form a larger system without which neither can be put to its intended use.

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

- **A system can include processes as well as things.**
- **Thinking about things as systems means looking for how every part relates to others. The output from one part of a system (which can include material, energy, or information) can become the input to other parts. Such feedback can serve to control what goes on in the system as a whole.**
- **Any system is usually connected to other systems, both internally and externally. Thus a system may be thought of as containing subsystems and as being a subsystem of a larger system.**

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Students should have opportunities-in seminars, projects, readings, and experiments-to reflect on the value of thinking in terms of systems and to apply the concept in diverse situations. They should often discuss what properties of a system are the same as the properties of its parts and what properties arise from interactions of its parts or from the sheer number of parts. They should learn to see feedback as a standard aspect of systems. The definitions of negative and positive feedback may be too subtle, but students can understand that feedback may oppose changes that do occur (and lead to stability), or may encourage more change (and so drive the system toward one extreme or another). Eventually, they can see how some delay in feedback can produce cycles in a system's behavior.

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

- **A system usually has some properties that are different from those of its parts, but appear because of the interaction of those parts.**
- **Understanding how things work and designing solutions to problems of almost any kind can be facilitated by systems analysis. In defining a system, it is important to specify its boundaries and subsystems, indicate its relation to other systems, and identify what its input and its output are expected to be.**
- **The successful operation of a designed system usually involves feedback. The feedback of output from some parts of a system to input of other parts can be used to encourage what is going on in a system, discourage it, or reduce its discrepancy from some desired value. The stability of a system can be greater when it includes appropriate feedback mechanisms.**

- **Even in some very simple systems, it may not always be possible to predict accurately the result of changing some part or connection.**

B. Models

Chapter Contents Also See...

Physical, mathematical, and conceptual models are tools for learning about the things they are meant to resemble. Physical models are by far the most obvious to young children, so they should be used to introduce the idea of models. Dolls, stuffed animals, toy cars and airplanes, and other everyday objects can stimulate discussions about how those things are like and unlike the real things. The term model should probably be used to refer only to physical models in the early grades, but the notion of likeness will be the central issue in using any kind of model.

The usefulness of conceptual models depends on the ability of people to imagine that something they do not understand is in some way like something that they do understand. Imagery, metaphor, and analogy are every bit as much a part of science as deductive logic, and as much at home in science as in the arts and humanities. Students cannot be expected to become adept in the use of conceptual models, however, until they get to know quite a bit about materials, things, and processes in the accessible world around them through direct, hands-on experience. The curriculum emphasis, therefore, should be on a rich variety of experiences, not on generalizations about conceptual models. Moreover, students need to acquire images and understandings that come from drawing, painting, sculpting, playing music, acting in plays, listening to and telling stories, reading, participating in games and sports, doing work, and living life.

By their nature, mathematical models are usually more abstract than physical and conceptual models. The connection of mathematics to concrete matters, and hence its value for modeling, could be substantially stronger if mathematics were often taught as part of science, social studies, technology, health, gym, music, and other subjects, rather than only during "mathematics time." One of the drawbacks of teaching mathematics entirely as a separate subject is that mathematics is taught before real-world problems are identified, so the related exercises may have mostly to do with learning the procedures rather than with solving interesting problems.

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Every opportunity should be taken to get students to talk about how the things they play with relate to real things in the world. The more imaginative the conversation the better, for insisting upon accuracy at this level may hinder other important developments.

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

- **Many of the toys children play with are like real things only in some ways. They are not the same size, are missing many details, or are not able to do all of the same things.**

- **A model of something is different from the real thing but can be used to learn something about the real thing.**
- **One way to describe something is to say how it is like something else.**

Grades 3 through 5 Chapter Contents

As students develop beyond their natural play with models, they should begin to modify them and discuss their limitations. What happens if wheels are taken off, or weight is added, if different materials are used, or if the model gets wet? Is that what would happen to the real things? Students also can begin to compare their objects, drawings, and constructions to the things they portray or resemble (real bears, houses, airplanes, etc.). Since students are being introduced to geometry, graphs, and other mathematical concepts, they should at the same time reflect on how these representations relate to nature. Similarly, what they are learning in the arts and humanities can supply analogies. Students can begin to formulate their own models to explain things they cannot observe directly. By testing their models and changing them as more information is acquired, they begin to understand how science works.

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

- **Seeing how a model works after changes are made to it may suggest how the real thing would work if the same were done to it.**
- **Geometric figures, number sequences, graphs, diagrams, sketches, number lines, maps, and stories can be used to represent objects, events, and processes in the real world, although such representations can never be exact in every detail.**

Grades 6 through 8 Chapter Contents

Now models and their use can be dealt with much more explicitly than before because students have a greater general knowledge of mathematics, literature, art, and the objects and processes around them. Also, student use of computers should have progressed beyond word processing to graphing and simulations that compute and display the results of changing factors in the model. All of these things can give students a grasp of what models are and how they can be compared by considering their consequences. Students should have many opportunities to learn how conceptual models can be used to suggest interesting questions, such as "What would the atmosphere be like if its molecules were to act like tiny, high-speed marshmallows instead of tiny, high-speed steel balls?"

The use of physical models also can increase in sophistication. Students should discover that physical models on a reduced scale may be inadequate because of scaling effects: With change in scale, some factors change more than others so things no longer work the same way. The drag effects of water flow past a model boat, for example, are very different from the effects on a full-sized boat.

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

- **Models are often used to think about processes that happen too slowly, too quickly, or on too small a scale to observe directly, or that are too vast to be changed deliberately, or that are potentially dangerous.**
- **Mathematical models can be displayed on a computer and then modified to see what happens.**
- **Different models can be used to represent the same thing. What kind of a model to use and how complex it should be depends on its purpose. The usefulness of a model may be limited if it is too simple or if it is needlessly complicated. Choosing a useful model is one of the instances in which intuition and creativity come into play in science, mathematics, and engineering.**

Grades 9 through 12

Chapter Contents

In the upper grades, considerable emphasis should be placed on mathematical modeling because it epitomizes the nature and power of models and provides a context for integrating knowledge from many different domains. The main goal should be getting students to learn how to create and use models in many different contexts, not simply to recite generalizations about models. They can acquire such generalizations too, but that will occur through discussions of models already studied. Research in developmental psychology implies that high-school students may understand that the best model isn't found yet, or that different people prefer different models while waiting for more evidence, but not that there may be no "true" model at all.

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

- **The basic idea of mathematical modeling is to find a mathematical relationship that behaves in the same ways as the objects or processes under investigation. A mathematical model may give insight about how something really works or may fit observations very well without any intuitive meaning.**
- **Computers have greatly improved the power and use of mathematical models by performing computations that are very long, very complicated, or repetitive. Therefore computers can show the consequences of applying complex rules or of changing the rules. The graphic capabilities of computers make them useful in the design and testing of devices and structures and in the simulation of complicated processes.**
- **The usefulness of a model can be tested by comparing its predictions to actual observations in the real world. But a close match does not necessarily mean that the model is the only "true" model or the only one that would work.**

C. Constancy and Change

Chapter Contents View Research Also See...

Much of science and mathematics has to do with understanding how change occurs in nature and in social and technological systems, and much of technology has to do with creating and controlling change. Constancy, often in the midst of change, is also the subject of intense study in science. The simplest account to be given of anything is that it does not change. Because scientists are always looking for the simplest possible accounts (that are true), they are always delighted by any aspect of anything that doesn't change even when many other aspects do. Indeed, many historians and philosophers regard conservation laws in physics (such as for mass, energy, or electric charge) to be among the greatest discoveries in science. Somewhat different aspects of constancy are described by the terms stability, conservation, equilibrium, steady state, and symmetry. These various ideas are interrelated in some subtle ways. But memorizing the distinct meanings for these terms is not a high priority. More important is being able to think about what is happening.

Symmetry is another kind of constancy-or more generally, invariance-in the midst of change. Equilibrium, steady states, and conservation might all be thought of as showing symmetry. But more typically, symmetry implies a pattern whose appearance stays the same when it undergoes a change such as rotation, reflection, stretching, or displacement. The symmetry can be geometrical or more general, as in a social order, set of computer operations, or classification of atomic particles.

When change occurs in a variable, a major issue is the rate at which change occurs. Clearly students have to make sense of a constant rate of change before they can consider increasing or decreasing rates. Yet understanding a constant rate of change is not as simple as it might seem, because of the difficulty of the idea of rate. Graphs would seem to be an immense help for semiquantitative descriptions of change-such as whether the rate is constant, increasing, saturating, etc. But the research results are that, unless the graph is of literal altitude, graph heights and slopes are puzzling to most children. The goal for all Americans should be modest: to understand a graph of any familiar variable against time in terms of reading it and interpreting its ups and downs in a story about what is going on. Eventually, steepness as well as direction of change can become part of the story.

Considering the pattern of change usually involves a scale of observations and a scale of analysis. The rock may appear to sit there on the ground unchanging, but at a distance scale 108 times smaller its atoms are chaotically restless, and at a scale of 108 times larger its planet is turning and orbiting. An ecological system may seem stable over a few centuries, but over days individuals come and go, and over millions of years it is greatly transformed.

Very, very small differences in what a system is like now may produce very large differences in what it is like later. That's not a difficult idea even in the middle school. What is harder to understand is that no matter how small the initial uncertainty may be, the behavior is eventually unpredictable. At the finest level, that of individual atoms, uncertainty is unavoidable. So the future is not determined by the present. For example, long-range weather forecasting now seems to be impossible-in principle, not just because of the limits of observation and analysis.

For the most part, change should not be taught as a separate subject. At every opportunity throughout the school years, the theme of change should be brought up in the context of the science, mathematics, or technology being studied. The first step is to encourage children to attend to change and describe it. Only after they have a storehouse of experience with change of different kinds are they ready to start thinking about patterns of change in the abstract. When students have such a background, a short capstone course on the subject of change could help them integrate their knowledge of patterns of change in physical, biological, social, and technological systems.

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When collecting and observing the things around them, students can look for what changes and what does not and question where things come from and where things go. They may note, for instance, that most animals move from place to place but most plants stay in place, that water left in an open container gradually disappears but sand does not, and so forth. Such activities can sharpen students' observation and communication skills and instill in them a growing sense that many different kinds of change go on all the time. Students should be encouraged to take, record, and display counts and simple measurements of things over time. This activity can provide them with many opportunities to learn and use elementary mathematics. To begin to work toward ideas of conservation, mathematics exercises in which the sum stays the same may be helpful-e.g., "How many ways can you add whole numbers to get 13?"

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

- **Things change in some ways and stay the same in some ways.**
- **People can keep track of some things, seeing where they come from and where they go.**
- **Things can change in different ways, such as in size, weight, color, and movement. Some small changes can be detected by taking measurements.**
- **Some changes are so slow or so fast that they are hard to see.**

Grades 3 through 5

Chapter Contents

With greater emphasis than before on measurement, graphing, and data analysis, students can make progress toward understanding some very important notions about change. At this stage, becoming familiar with a large and varied set of actual examples of change is more important than being able to recite the generalizations set out in the benchmarks.

Notions of symmetry can begin with identifying patterns whose appearance stays the same when they undergo some change (such as rotation, reflection, stretching, or displacement). Children generally are interested in exploring the shapes of things (plants and animals, themselves, buildings, vehicles, toys, etc.) and looking for regularities of shape. Students should have many experiences in discussing and depicting all sorts of change: continuing in the same direction, reaching a high or low value, repeatedly reversing direction, and so on.

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

- **Some features of things may stay the same even when other features change. Some patterns look the same when they are shifted over, or turned, or reflected, or seen from different directions.**
- **Things change in steady, repetitive, or irregular ways-or sometimes in more than one way at the same time. Often the best way to tell which kinds of change are happening is to make a table or graph of measurements.**

Grades 6 through 8

Chapter Contents

Constancy in a system can be represented in two ways: as a constant sum or as compensating changes. When the quantity being considered is a count (as of students or airplanes), then constancy of the total is obvious. When the quantity being considered is a measure on a continuous scale, rather than a packaged unit, then "it has to come from somewhere and go somewhere" may be a more directly appreciable principle. For example, it seems easier to see that heat lost from one part of a system has to show up somewhere else than to say that the total measure for the whole system has to stay the same. This may be particularly true when the quantity can take various, interconvertible forms-say, forms of energy or monetary value.

In these grades, students can look for more sophisticated patterns, including rates of change and cyclic patterns. Invariance may be found in change itself: The water in a river changes, but the rate of flow may be constant; or the rate of flow may change seasonally, but the cycle may have a constant cycle length.

The idea of a series of repeating events is not difficult for students-that is what their day-by-day and week-by-week lives are like. Cyclic variation in a magnitude is more difficult. The cycle length is its simplest feature, whereas the range of variation has little interest unless students are familiar with and care about the variable. (A variation of one degree in body temperature-because of its relevance to whether they have to stay home from school-may be more interesting to students than a tenfold variation in the number of cases of measles.)

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

- **Physical and biological systems tend to change until they become stable and then remain that way unless their surroundings change.**
- **A system may stay the same because nothing is happening or because things are happening but exactly counterbalance one another.**
- **Many systems contain feedback mechanisms that serve to keep changes within specified limits.**
- **Symbolic equations can be used to summarize how the quantity of something changes over time or in response to other changes.**
- **Symmetry (or the lack of it) may determine properties of many objects, from molecules and crystals to organisms and designed structures.**
- **Cycles, such as the seasons or body temperature, can be described by their cycle length or frequency, what their highest and lowest values are, and when these values occur. Different cycles range from many thousands of years down to less than a billionth of a second.**

Grades 9 through 12

Chapter Contents

Most of what is appropriate to study about constancy and change in the high-school years has at least been touched upon in the earlier years, though mostly in a qualitative or semiquantitative way. Although it is still not necessary to become intensely quantitative, many of the applications of the ideas take on more concrete meaning when calculations are made.

Stability, like many concepts in science, has to be considered in some context of scale. On a familiar scale of space and time, a mountain may appear stable for centuries. Yet on the atomic scale, the mountain is a continuous hubbub of restless motion and absorption and radiation of energy. On the scale of millions of years, mountains rise up from plains and erode away. In a practical sense, stability of some object or system means only that for present purposes one does not notice or have to worry about changes in it.

Perhaps the most important ideas to be dealt with are the conservation laws, rates of change, and the general notion of evolutionary change. The emphasis on conservation laws should probably be practical-that is, should show how those concepts led, and continue to lead, to advances in science. The historical cases studied can contribute to this understanding. Rates of change that are approximately constant (or averageable) make possible a variety of practical calculations. Changing rates need not be calculated but can be identified in graphs and sketched. Especially important is the case in which change rate is proportional to how much there already is (as in population growth or radioactive decay).

Evolutionary change is a general concept, of which biological evolution is only one instance. Another point is more philosophical: Although evolution is the kind of change that emerges from and is influenced by the past, the past appears not to completely determine the future.

Two major arguments for indeterminism are included in Benchmarks-the principle of uncertainty at the submicroscopic level and the additional uncertainty owing to the complexity of systems and their sensitivity to vanishingly small differences in conditions. These arguments are not easy to grasp but at least students should be given a chance to debate them. Many students may be reassured to learn that scientists do not claim to be able to predict the future in every detail, nor do they claim that nature is a mechanical system in which every occurrence is already determined.

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

- **A system in equilibrium may return to the same state of equilibrium if the disturbances it experiences are small. But large disturbances may cause it to escape that equilibrium and eventually settle into some other state of equilibrium.**
- **Along with the theory of atoms, the concept of the conservation of matter led to revolutionary advances in chemical science. The concept of conservation of energy is at the heart of advances in fields as diverse as the study of nuclear particles and the study of the origin of the universe.**
- **Things can change in detail but remain the same in general (the players change, but the team remains; cells are replaced, but the organism remains). Sometimes counterbalancing changes are necessary for a thing to retain its essential constancy in the presence of changing conditions.**
- **Graphs and equations are useful (and often equivalent) ways for depicting and analyzing patterns of change.**

- **In many physical, biological, and social systems, changes in one direction tend to produce opposing (but somewhat delayed) influences, leading to repetitive cycles of behavior.**
- **In evolutionary change, the present arises from the materials and forms of the past, more or less gradually, and in ways that can be explained.**
- **Most systems above the molecular level involve so many parts and forces and are so sensitive to tiny differences in conditions that their precise behavior is unpredictable, even if all the rules for change are known. Predictable or not, the precise future of a system is not completely determined by its present state and circumstances but also depends on the fundamentally uncertain outcomes of events on the atomic scale.**

D. Scale

Chapter Contents Also See...

Most variables in nature-size, distance, weight, temperature, and so on-show immense differences in magnitude. As their sophistication increases, students should encounter increasingly larger ratios of upper and lower limits of these variables. But that is only the starting point for the idea of changes of scale. The larger idea is that the way in which things work may change with scale. Different aspects of nature change at different rates with changes in scale, and so the relationships among them change, too. Probably the most easily demonstrated example is that as something changes size, its volume changes out of proportion to its area. So properties that depend on volume (such as mass and heat capacity) increase faster than properties that depend on area (such as bone strength and cooling surface). Therefore a large container of hot water cools off more slowly than a small container, and a large animal must have proportionally thicker legs than a small animal of otherwise similar shape.

As another consequence of disproportional change of properties, some "laws" of science (such as how friction depends on speed) are valid only within a certain range of circumstances. New and sometimes surprising kinds of phenomena can appear at extremely large or small values of a variable. For example, a star many times more massive than the sun can eventually collapse under its own gravity to become a black hole from which not even light can escape.

Looking at how things change with scale requires familiarity with the range of values and with how to express the range in numbers that make some sense. So children should start by noticing extremes of familiar variables and how things may be different at those extremes. There is no problem here, in that most children are entranced by "biggest," "littlest," "fastest," and "slowest"-giants and superlatives in general. In any case, scale should be introduced explicitly only when students already have a rich ground of experiences having to do with magnitudes and the effects of changing them.

The range of numbers that people can grasp increases with age. No benefit comes from trying to foist exponential notation on children who can't grasp its meaning at all. It has been argued that people really can't comprehend a range of more than about 1,000 to 1 at any one moment. One can think of a meter being a thousand millimeters (they are there to be seen in a quick look at a meter stick) and that a kilometer is a thousand meters (it can be run off in a few minutes)-but one may not be able to think of a kilometer as a million millimeters. A million becomes meaningful, however, as a thousand thousands, once a thousand becomes comprehensible. Particularly important senses of scale to develop for science literacy are the immense size of the cosmos, the minute size of molecules, and the enormous age of the earth (and the life on it).

Kindergarten through Grade 2

Chapter Contents

Children at this level are not yet comfortable enough with numbers to succeed much in comparing magnitudes. Their attention should be drawn repeatedly to simple comparisons in observations: What is smaller or larger, what might be still smaller or larger, what is the smallest or largest they could imagine, and do such things exist? A sense of changes in scale can be encouraged by perspective-taking games that challenge imagination (for example, "What would other people look like to you if you were as tall as a house or as small as an ant?").

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

- **Things in nature and things people make have very different sizes, weights, ages, and speeds.**

Grades 3 through 5

Chapter Contents

Children at this level tend to be fascinated by extremes. That interest should be exploited to develop student math skills as well as a sense of scale. Students may not have the mathematical sophistication to deal confidently with ratios and with differences among ratios but the observational groundwork and familiarity with talking about them can begin. At the very least, students can compare speeds, sizes, distances, etc., as fractions and multiples of one another.

Students should now be building structures and other things in their technology projects. Through such experience, they can begin to understand both the mathematical and engineering relationships of length, area, and volume. They can be challenged to measure things that are hard to measure on account of being very small or very large, very light or very heavy.

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

- **Almost anything has limits on how big or small it can be.**
- **Finding out what the biggest and the smallest possible values of something are is often as revealing as knowing what the usual value is.**

Grades 6 through 8

Chapter Contents

As students' familiarity with very large and very small numbers, ratios, and powers of ten improves, extremes of scale become more meaningful. The use of ratios can now be explicit and comparisons of extremes that exceed 10^{10} may make some sense to students. Alternative representations of great scale differences should be used-such as Charles Eames' Powers of Ten film and Haldane's classic essay, "On Being the Right Size." Indeed, this essay might very well serve as the centerpiece for a seminar or short course dealing with the importance of size in nature and in construction.

The topic of scale also lends itself to the use of computer simulation, in which the user can change scales at will, and to the use of elementary statistics-large collections of things may have to be represented by summaries such as averages or typical examples. Approximate powers of ten (orders of magnitude) can be learned if students have become comfortable with estimates and approximations. This use of exponents for comparisons does not justify teaching the full apparatus of exponential notation to all students.

Understanding the notion that things necessarily work differently on different scales is more difficult than recognizing extremes, hence students should study a variety of different examples (for instance, cooling rates of different-sized containers of water, strength of different-sized constructions from the same material, flight characteristics of different-sized model airplanes).

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

- **Properties of systems that depend on volume, such as capacity and weight, change out of proportion to properties that depend on area, such as strength or surface processes.**
- **As the complexity of any system increases, gaining an understanding of it depends increasingly on summaries, such as averages and ranges, and on descriptions of typical examples of that system.**

Grades 9 through 12 Chapter Contents

Facility with powers of ten can make it easier to describe great differences of scale, but not necessarily to make them comprehensible. Students can bootstrap their comprehension of magnitude only by a few factors of ten at a time, perhaps grasping each new level only in terms of the previous one. For instance, once students have come to terms with a million, then they may have a better sense of what it means to say there are over a billion galaxies, each with over a billion stars.

Mathematical sophistication can now also include abstract, algebraic representation of the effects of powers; properties that increase by the square of linear size or the cube; and the relation between those increases. Still, the most important point is not the precise ratio of x3 to x2, but the more approximate idea that one changes out of proportion to the other-therefore relationships change. Things, systems, and models that work well on one scale may work less well, or not at all, if greatly expanded or shrunk. A meter-wide amoeba, for example, would never be able to get enough nutrients and oxygen through its surface to survive; a meter-long bird built like a sparrow could not fly.

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

- **Representing large numbers in terms of powers of ten makes it easier to think** about them and to compare things that are greatly different.

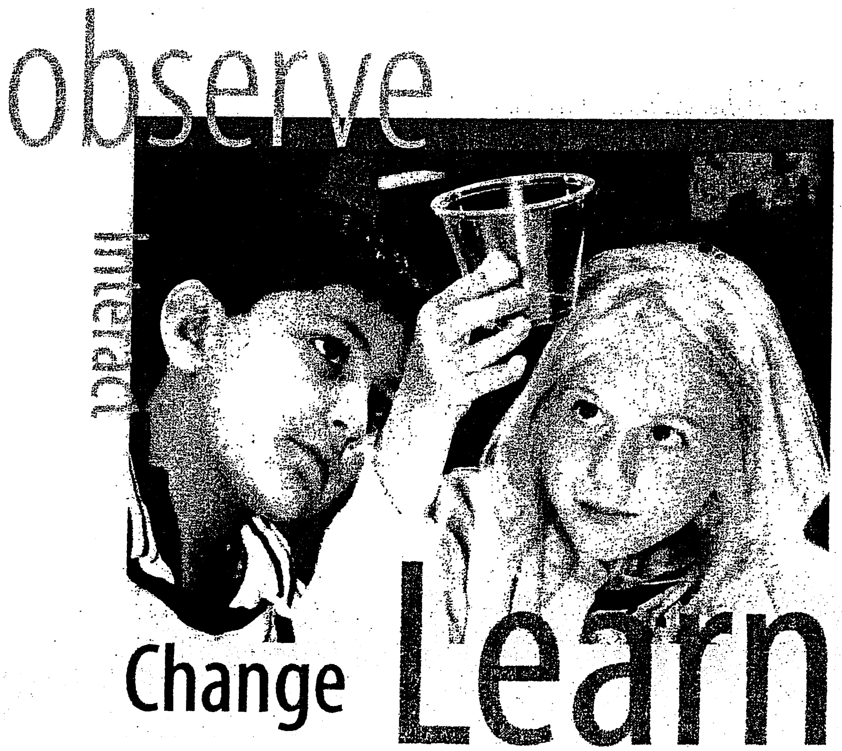
- Because different properties are not affected to the same degree by changes in scale, large changes in scale typically change the way that things work in physical, biological, or social systems.
- As the number of parts of a system increases, the number of possible interactions between pairs of parts increases much more rapidly.

Jane Batterson

NATIONAL

SCIENCE EDUCATION

STANDARDS



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WASHINGTON, DC

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		

See Teaching Standard B in Chapter 3

COMMUNICATE AND DEFEND A SCIENTIFIC ARGUMENT. Students in school science programs should develop the abilities associated with accurate and effective communication. These include writing and following procedures, expressing concepts, reviewing information, summarizing data, using language appropriately, developing diagrams and charts, explaining statistical analysis, speaking clearly and logically, constructing a reasoned argument, and responding appropriately to critical comments.

UNDERSTANDINGS ABOUT SCIENTIFIC INQUIRY

See Unifying Concepts and Processes

- Scientists usually inquire about how physical, living, or designed systems function. Conceptual principles and knowledge guide scientific inquiries. Historical and current scientific knowledge influence the design and interpretation of investigations and the evaluation of proposed explanations made by other scientists.
- Scientists conduct investigations for a wide variety of reasons. For example, they may wish to discover new aspects of the natural world, explain recently observed phenomena, or test the conclusions of prior investigations or the predictions of current theories.

See Content Standard E (grades 9-12)

- Scientists rely on technology to enhance the gathering and manipulation of data. New techniques and tools provide new evidence to guide inquiry and new methods to gather data, thereby contributing to the advance of science. The accuracy and precision of the data, and therefore the quality of the exploration, depends on the technology used.
- Mathematics is essential in scientific inquiry. Mathematical tools and models guide and improve the posing of questions, gathering data, constructing explanations and communicating results.

See Program Standard C

- Scientific explanations must adhere to criteria such as: a proposed explanation must be logically consistent; it must abide by the rules of evidence; it must be open to questions and possible modification; and it must be based on historical and current scientific knowledge.
- Results of scientific inquiry—new knowledge and methods—emerge from different types of investigations and public communication among scientists. In communicating and defending the results of scientific inquiry, arguments must be logical and demonstrate connections between natural phenomena, investigations, and the historical body of scientific knowledge. In addition, the methods and procedures that scientists used to obtain evidence must be clearly reported to enhance opportunities for further investigation.

Physical Science

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

- Structure of atoms
- Structure and properties of matter
- Chemical reactions
- Motions and forces
- Conservation of energy and increase in disorder
- Interactions of energy and matter

DEVELOPING STUDENT UNDERSTANDING

High-school students develop the ability to relate the macroscopic properties of substances that they study in grades K-8 to the microscopic structure of substances. This development in understanding requires students to move among three domains of thought—the macroscopic world of observable phenomena, the microscopic world of molecules, atoms, and subatomic particles, and the symbolic and mathematical world of chemical formulas, equations, and symbols.

The relationship between properties of matter and its structure continues as a major component of study in 9-12 physical science. In the elementary grades, students studied the properties of matter and the classification of substances using easily observable properties. In the middle grades, they examined change of state, solutions, and simple chemical reactions, and developed enough knowledge and experience to define the properties of elements and compounds. When students observe and integrate a wide variety of evidence, such as seeing copper "dissolved" by an acid into a solution and then retrieved as pure copper when it is displaced by zinc, the idea that copper atoms are the same for any copper object begins to make sense. In each of these reactions, the knowledge that the mass of the substance does not change can be interpreted by assuming that the number of particles does not change during their rearrangement in the reaction. Studies of student understanding of molecules indicate that it will be difficult for them to comprehend the very small size and large number of particles involved. The connection between the particles and the chemical formulas that represent them is also often not clear.

It is logical for students to begin asking about the internal structure of atoms, and it will be difficult, but important, for them to know "how we know." Quality learning and the spirit and practice of scientific inquiry are lost when the evidence and argument for atomic structure are replaced by direct assertions by the teacher and text. Although many experiments are difficult to replicate in school, students can read some of the actual reports and examine the chain of evidence that led to the development of the current concept of the atom. The nature of the atom is far from totally understood; scientists continue to investigate atoms and have discovered even smaller constituents of which neutrons and protons are made.

Laboratory investigation of the properties of substances and their changes through a range of chemical interactions provide a basis for the high school graduate to understand a variety of reaction types and their applications, such as the capability to liberate elements from ore, create new drugs, manipulate the structure of genes, and synthesize polymers.

Understanding of the microstructure of matter can be supported by laboratory experiences with the macroscopic and microscopic world of forces, motion (including vibrations and waves), light, and electricity. These experiences expand upon the ones that the students had in the middle school and provide new ways of understanding the movement of muscles, the transport of materials across cell membranes, the behavior of atoms and molecules, communication technologies, and the movement of planets and galaxies. By this age, the concept of a force is better understood, but static forces in equilibrium and students' intuitive ideas about forces on projectiles and satellites still resist change through instruction for a large percentage of the students.

On the basis of their experiences with energy transfers in the middle grades, high-school students can investigate energy transfers quantitatively by measuring variables such as temperature change and kinetic energy. Laboratory investigations and descriptions of other experiments can help students understand the evidence that leads to the conclusion that energy is conserved. Although the operational distinction between temperature and heat can be fairly well understood after careful instruction, research with high-school students indicates that the idea that heat is the energy of random motion and vibrating molecules is difficult for students to understand.

GUIDE TO THE CONTENT STANDARD

Fundamental concepts and principles that underlie this standard include

STRUCTURE OF ATOMS

- Matter is made of minute particles called atoms, and atoms are composed of even smaller components. These components have measurable properties, such as mass and electrical charge. Each atom has a positively charged nucleus surrounded by negatively charged electrons. The electric force between the nucleus and electrons holds the atom together.
- The atom's nucleus is composed of protons and neutrons, which are much more massive than electrons. When an element has atoms that differ in the number of neutrons, these atoms are called different isotopes of the element.
- The nuclear forces that hold the nucleus of an atom together, at nuclear distances, are usually stronger than the electric forces that would make it fly apart. Nuclear reactions convert a fraction of the mass of interacting particles into energy, and they can release much greater amounts of energy than atomic interactions. Fission is the splitting of a large nucleus into smaller pieces. Fusion is the joining of two nuclei at extremely high temperature and pressure, and is the process responsible for the energy of the sun and other stars.
- Radioactive isotopes are unstable and undergo spontaneous nuclear reactions, emitting particles and/or wavelike radiation. The decay of any one nucleus cannot be predicted, but a large group of identical nuclei decay at a predictable rate. This predictability can be used to estimate the age of materials that contain radioactive isotopes.

STRUCTURE AND PROPERTIES OF MATTER

- Atoms interact with one another by transferring or sharing electrons that are furthest from the nucleus. These outer electrons govern the chemical properties of the element.
- An element is composed of a single type of atom. When elements are listed in order according to the number of protons (called the atomic number), repeating patterns of physical and chemical properties identify families of elements

with similar properties. This "Periodic Table" is a consequence of the repeating pattern of outermost electrons and their permitted energies.

- Bonds between atoms are created when electrons are paired up by being transferred or shared. A substance composed of a single kind of atom is called an element. The atoms may be bonded together into molecules or crystalline solids. A compound is formed when two or more kinds of atoms bind together chemically.
- The physical properties of compounds reflect the nature of the interactions among its molecules. These interactions are determined by the structure of the molecule, including the constituent atoms and the distances and angles between them.
- Solids, liquids, and gases differ in the distances and angles between molecules or atoms and therefore the energy that binds them together. In solids the structure is nearly rigid; in liquids molecules or atoms move around each other but do not move apart; and in gases molecules or atoms move almost independently of each other and are mostly far apart.
- Carbon atoms can bond to one another in chains, rings, and branching networks to form a variety of structures, including synthetic polymers, oils, and the large molecules essential to life.

CHEMICAL REACTIONS

See Content Standard C (Grades 9-12)

- Chemical reactions occur all around us, for example in health care, cooking, cosmetics, and automobiles. Complex chemical reactions involving carbon-based molecules take place constantly in every cell in our bodies.
- Chemical reactions may release or consume energy. Some reactions such as the burning of fossil fuels release large amounts of energy by losing heat and by emitting light. Light can initiate many chemical reactions such as photosynthesis and the evolution of urban smog.
- A large number of important reactions involve the transfer of either electrons (oxidation/reduction reactions) or hydrogen ions (acid/base reactions) between reacting ions, molecules, or atoms. In other reactions, chemical bonds are broken by heat or light to form very reactive radicals with electrons ready to form new bonds. Radical reactions control many processes such as the presence of ozone and greenhouse gases in the atmosphere, burning and processing of fossil fuels, the formation of polymers, and explosions.
- Chemical reactions can take place in time periods ranging from the few femtoseconds (10^{-15} seconds) required for an atom to move a fraction of a chemical bond distance to geologic time scales of billions of years. Reaction rates depend on how often the reacting atoms and molecules encounter one another, on the temperature, and on the properties—including shape—of the reacting species.
- Catalysts, such as metal surfaces, accelerate chemical reactions. Chemical reactions in living systems are catalyzed by protein molecules called enzymes.

MOTIONS AND FORCES

- Objects change their motion only when a net force is applied. Laws of motion are used to calculate precisely the effects of forces on the motion of objects. The magnitude of the change in motion can be calculated using the relationship F = ma, which is independent of the nature of the force. Whenever one object exerts force on another, a force equal in magnitude and opposite in direction is exerted on the first object.

- Gravitation is a universal force that each mass exerts on any other mass. The strength of the gravitational attractive force between two masses is proportional to the masses and inversely proportional to the square of the distance between them.
- The electric force is a universal force that exists between any two charged objects. Opposite charges attract while like charges repel. The strength of the force is proportional to the charges, and, as with gravitation, inversely proportional to the square of the distance between them.
- Between any two charged particles, electric force is vastly greater than the gravitational force. Most observable forces such as those exerted by a coiled spring or friction may be traced to electric forces acting between atoms and molecules.
- Electricity and magnetism are two aspects of a single electromagnetic force. Moving electric charges produce magnetic forces, and moving magnets produce electric forces. These effects help students to understand electric motors and generators.

CONSERVATION OF ENERGY AND THE INCREASE IN DISORDER

See Content Standard C (grades 9-12)

- The total energy of the universe is constant. Energy can be transferred by collisions in chemical and nuclear reactions, by light waves and other radiations, and in many other ways. However, it can never be destroyed. As these transfers occur, the matter involved becomes steadily less ordered.
- All energy can be considered to be either kinetic energy, which is the energy of motion; potential energy, which depends on relative position; or energy contained by a field, such as electromagnetic waves.
- Heat consists of random motion and the vibrations of atoms, molecules, and ions. The higher the temperature, the greater the atomic or molecular motion.
- Everything tends to become less organized and less orderly over time. Thus, in all energy transfers, the overall effect is that the energy is spread out uniformly. Examples are the transfer of energy from hotter to cooler objects by conduction, radiation, or convection and the warming of our surroundings when we burn fuels.

INTERACTIONS OF ENERGY AND MATTER

See Content Standard D (grades 9-12)

- Waves, including sound and seismic waves, waves on water, and light waves, have energy and can transfer energy when they interact with matter.
- Electromagnetic waves result when a charged object is accelerated or decelerated. Electromagnetic waves include radio waves (the longest wavelength), microwaves, infrared radiation (radiant heat), visible light, ultraviolet radiation, x-rays, and gamma rays. The energy of electromagnetic waves is carried in packets whose magnitude is inversely proportional to the wavelength.
- Each kind of atom or molecule can gain or lose energy only in particular discrete amounts and thus can absorb and emit

light only at wavelengths corresponding to these amounts. These wavelengths can be used to identify the substance.

In some materials, such as metals, electrons flow easily, whereas in insulating materials such as glass they can hardly flow at all. Semiconducting materials have intermediate behavior. At low temperatures some materials become superconductors and offer no resistance to the flow of electrons.

Life Science

CONTENT STANDARD C:

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

- The cell
- Molecular basis of heredity
- Biological evolution
- Interdependence of organisms
- Matter, energy, and organization in living systems
- Behavior of organisms

DEVELOPING STUDENT UNDERSTANDING

Students in grades K-8 should have developed a foundational understanding of life sciences. In grades 9-12, students' understanding of biology will expand by incorporating more abstract knowledge, such as the structure and function of DNA, and more comprehensive theories, such as evolution. Students' understandings should encompass scales that are both smaller, for example, molecules, and larger, for example, the biosphere.

Teachers of science will have to make choices about what to teach that will most productively develop student understanding of the life sciences. All too often, the criteria for selection are not clear, resulting in an overemphasis on information and an underemphasis on conceptual understanding. In describing the content for life sciences, the national standards focus on a small number of general principles that can serve as the basis for teachers and students to develop further understanding of biology.

Because molecular biology will continue into the twenty-first century as a major frontier of science, students should understand the chemical basis of life not only for its own sake, but because of the need to take informed positions on some of the practical and ethical implications of humankind's capacity to manipulate living organisms.

In general, students recognize the idea of species as a basis for classifying organisms, but few students will refer to the genetic basis of species. Students may exhibit a general understanding of classification. However, when presented with unique organisms, students sometimes appeal to "everyday" classifications, such as viewing jellyfish as fish because of the term "fish," and penguins as amphibians because they live on land and in water.

Although students may indicate that they know about cells, they may say that living systems are made of cells but not molecules, because students often associate molecules only with physical science.

Students have difficulty with the fundamental concepts of evolution. For example, students often do not understand natural

A Critique of the "Research Basis" for the National Science Education Standards and the AAAS Benchmarks for Science Literacy

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ABSTRACT

Although the authors and publishers of the National Education Standards (1996) and the Benchmarks for Science Literacy (1993) claim that their recommendations are based on sound, extensive research about the way children learn, in fact the evidence is generally weak and unconvincing. In some cases the studies cited misstate the cohort of students whose learning was examined. In others, the studies were based on relatively small groups of students, and in still others, the students whose learning was examined were from foreign countries whose cultural and educational backgrounds are quite different from those of American students. In many cases the papers cited were not published in peer-reviewed journals or were merely papers presented at meetings of specialists in science education.

Keywords: Education – general; education – science; education – geoscience; education – testing and evaluation.

Introduction

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-PhD-granting institutions are similarly able to bring undergraduate students into the laboratory to conduct basic research.

The "California Standards," the "NSES," and "Benchmarks"

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!

Research Basis of NSES and Benchmarks

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 no 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 seven 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.

Children's Understanding of Inherited Traits

In discussing children's 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 and others, 1980) reports on the results of half-hour interviews with 32 Canadian students, with ages ranging from seven to thirteen. 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 fifth grade.

Students were asked the following question (Kargbo and others, 1980, 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" (Kargbo and others, 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 fifth 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.

Children's Understanding of Cooling Objects.

My second example, on children's 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 (1993) conducted interviews with 34 German students in Grade ten, 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. (Kesidou and Douit, 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 seventh grade. As I'm sure you all know, hot objects can become cooler by emitting infrared radiation, and do not need to interact with other objects to do so. This error is repeated in the AAAS Benchmarks (p. 337) 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.

The paper by Kesidou and Duit has been favorably cited in a recent letter from Bruce Alberts, President of the National Academy of Sciences (Alberts, 1998). 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.

Children's 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 (1992) report the mental models children hold of the shape of the earth. These authors conducted interviews on 60 students between the ages of six and eleven, and evaluated artwork they drew of the earth situated in space. Their rubric for scoring these children's 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. (Vosniadou and Brewer, 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 round. 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 for the Establishment of Academic Content and Performance Standards (1998) has recently taken a different course in developing content-rich academic standards in science for the K-12 schools. A copy of these standards has 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 (Council for the Indian School Certificate Examinations, 1994). 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 ninth 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. They learn about the expansion of solids, liquids, and gases, and paths of heat conduction, convection, and radiation. 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 (Shanker, 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 (Issues, Evidence and You, 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.

Conclusion

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 (Sampson, 1997). 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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Food for Thought

The core spirit of science is to seek truths through unrelenting effort and utmost honesty and to uphold truths with courage and integrity. These are vital elements for all societies.... Science also teaches people to think independently, and to question and reason objectively.

Chenjian Li, 1996, Science in China (letter): Science, v. 273, p. 1477-1478.

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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.

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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

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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 <u>and</u> 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 exact 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

ARISE Project Director
Leon M. Lederman

Compiled and edited by
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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

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2 Measurement
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4 Atomic Structure
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6 Chemical Names and Formulas/Compounds and Elements
7 Moles
8 Chemical Reactions
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10 Phases, Solids, Liquids and Gases (States of Matter)
11 Thermochemistry
12 Gases/Gas Laws/Kinetic Theory
13 Electrons in Atoms
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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 Covers" 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.).

2005

The State of State SCIENCE Standards

by Paul R. Gross

WITH

Ursula Goodenough
Susan Haack
Lawrence S. Lerner
Martha Schwartz
Richard Schwartz

FOREWORD BY

Chester E. Finn, Jr.

THOMAS B. FORDHAM
INSTITUTE

The State of State SCIENCE Standards

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DECEMBER 2005

THOMAS B. FORDHAM
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The Thomas B. Fordham Institute is a nonprofit organization that conducts research, issues publications, and directs action projects in elementary/secondary education reform at the national level and in Ohio, with special emphasis on our hometown of Dayton. It is affiliated with the Thomas B. Fordham Foundation.

Further information can be found at www.edexcellence.net/institute or by writing to the Institute at:
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Washington, D.C. 20006.

This report is available in full on the Institute's web site; additional copies can be ordered at www.edexcellence.net/institute/publication/order.cfm or by calling 410-634-2400. The Institute is neither connected with nor sponsored by Fordham University.

TABLE OF CONTENTS

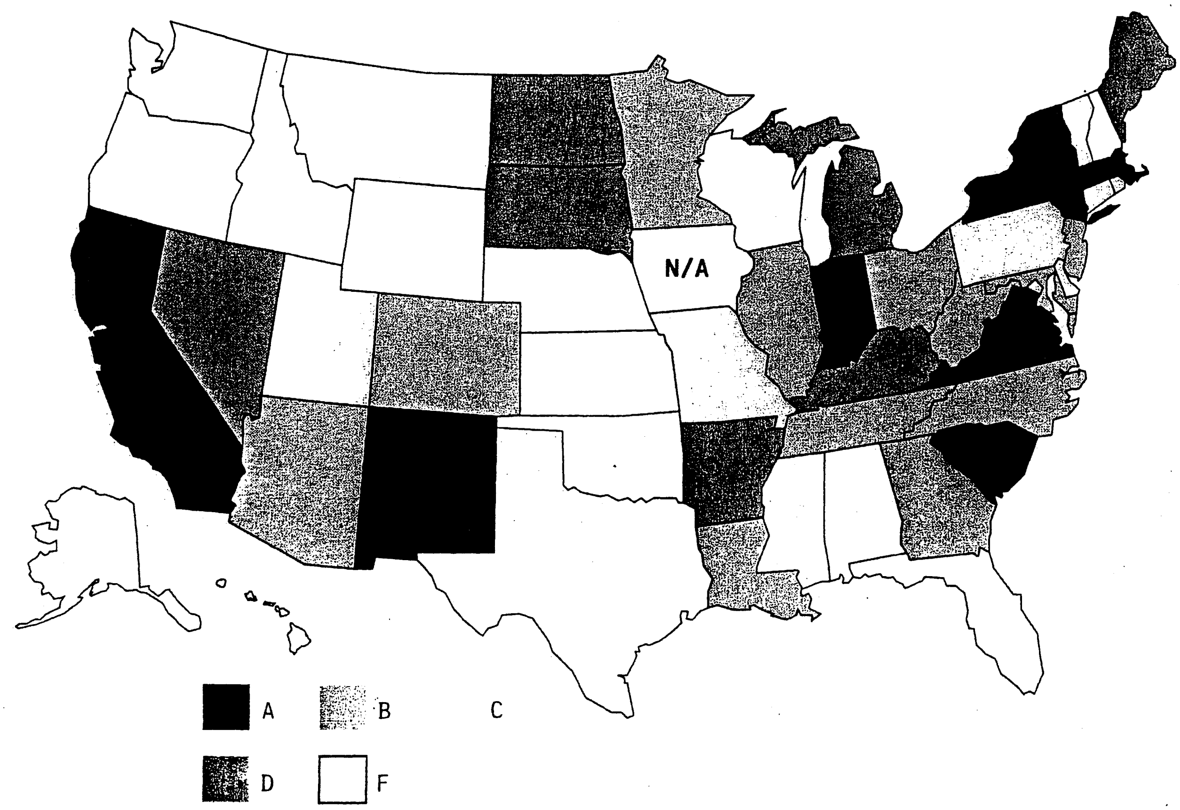
EXECUTIVE SUMMARY

The nation's policy and business leaders are increasingly and understandably anxious about maintaining America's scientific and technological leadership in a competitive world. Naturally they look to the education system, where they issue urgent calls for higher standards and greater rigor. But are states heeding the calls? In setting standards for their K-12 science programs, are they expecting enough of their students? As they prepare to implement the No Child Left Behind Act's science testing mandate, are states seizing the opportunity to raise the bar to a level that will ensure the nation's scientific prowess in years to come?

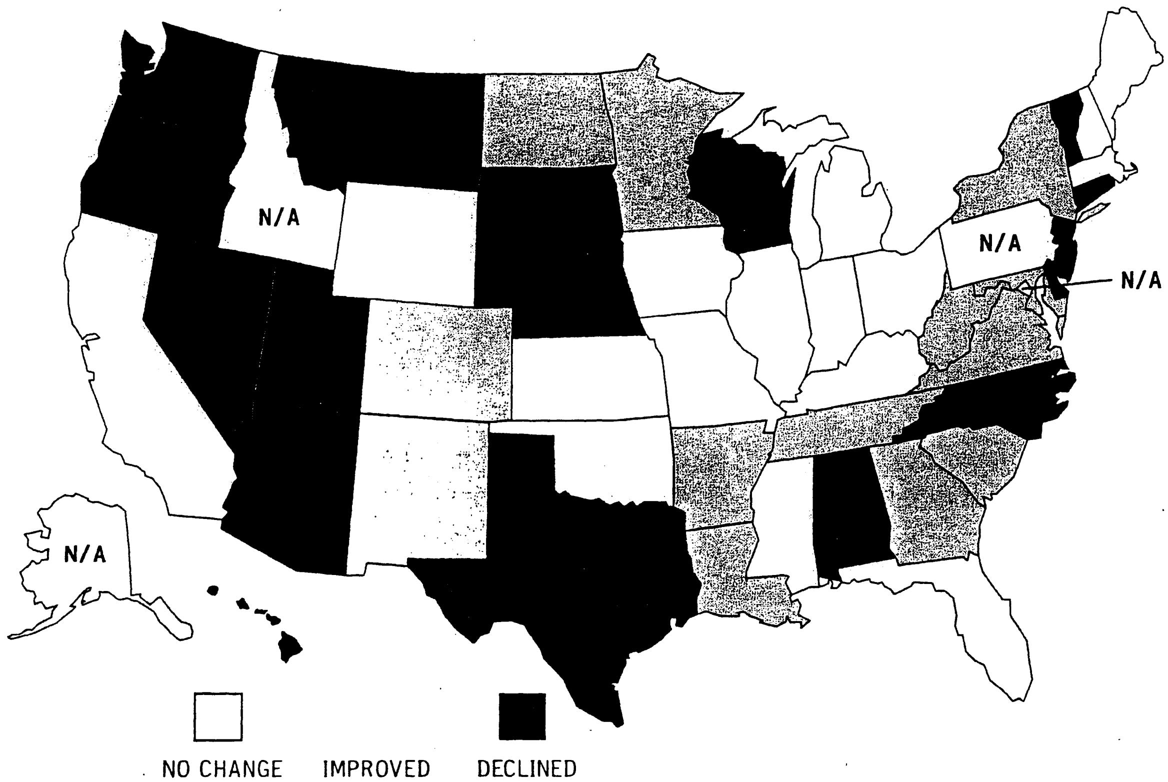
The answer—provided in this, the first comprehensive review of state science standards since 2000—is mixed. The good news is that 19 states have put in place standards clear and rigorous enough to earn them an "honors" grade of "A" or "B." Over half of U.S. children attend school in these states. Unfortunately, 15 states deserve failing grades, signifying either that they have no real standards for their science program, or that their standards are so vague and weak as to be meaningless. The remaining 16 jurisdictions get "C" or "D" marks. (Iowa is not included because it does not publish science standards.)

Have the states raised their expectations over the last half-decade? As is apparent on page 6, most states received a different grade in 2005 for their science standards than in 2000. However, while state standards are very much in flux, the nation, in its entirety, is neither making progress nor losing ground when it comes to expectations for what students should learn in science during the K-12 years. The same number of states received "honors" grades this year as in 2000, while the percentage of failing grades inched up just slightly from 26 percent to 30 percent. This flat trend line at the national level is worrisome, especially as America's world competitors make their own countries' science education a major focus.

Assigned letter grades for 49 states and the District of Columbia



Trends in grades from 2000 to 2005 for 49 states and the District of Columbia.

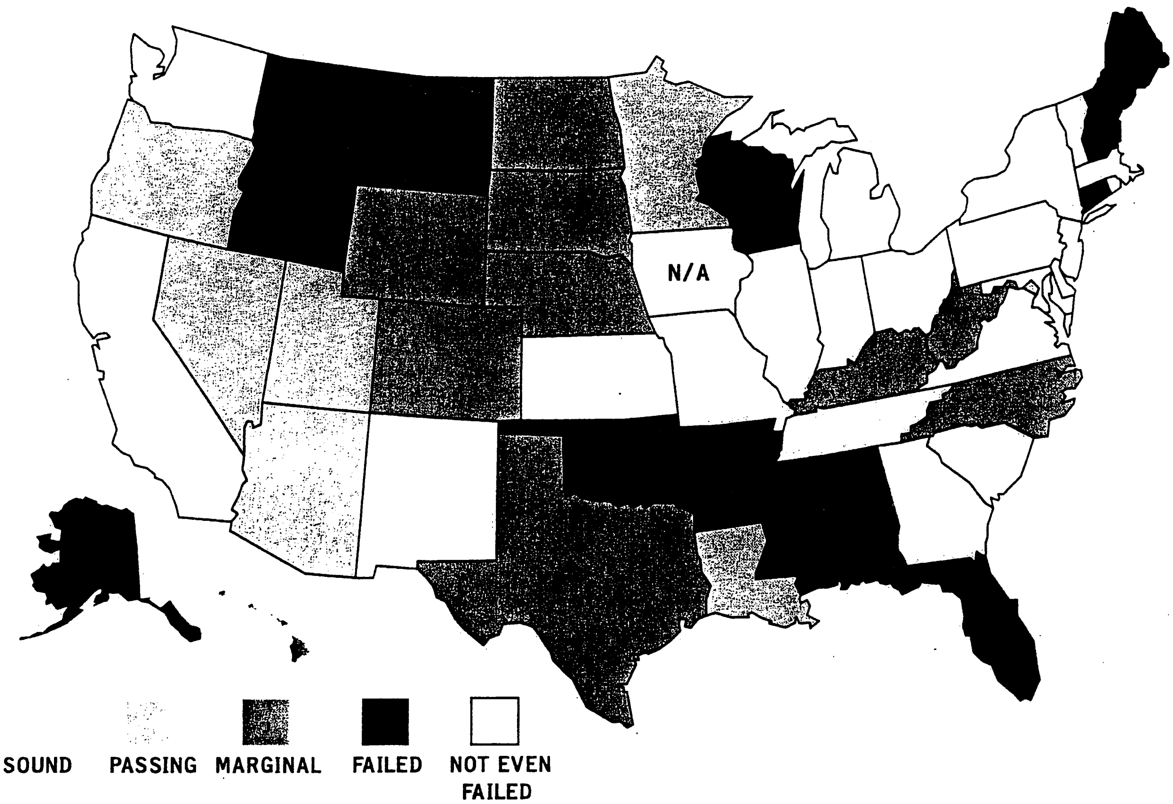


Common Problems

Some states—notably A-rated California, Indiana, Massachusetts, New York, New Mexico, South Carolina, and Virginia—produced exceptional academic standards documents that, if followed in the classroom, would result in excellent science programs. But most state standards have serious problems. These include:

1. **Excessive Length and Poor Navigability.** Sprawling, almost impenetrable documents, uncontrolled in size and poorly organized, are too common a result of a push to cover everything.
2. **Thin Disciplinary Content.** States' zealous embrace of "inquiry-based learning" has squeezed real science content (astronomy, biology, chemistry, ecology, physics, etc.) out of the curriculum to make room for "process." Of course, without content, there is little for science students to process.
3. **Do-It-Yourself Learning.** Many state standards documents take a very good idea—*Whenever practical, science learners should find things out for themselves*—and take it to an absurd level, declaring that all knowledge should be "discovered" by the student rather than passed along by the teacher. In many areas of science—e.g., atomic structure, plate tectonics, population genetics, thermodynamics—this is simply not possible.
4. **Good Ideas Gone Bad.** Too many state standards documents create a false dichotomy between "rote" and "hands-on" learning. Of course students should engage science in the laboratory or field, but they also must learn and memorize some things—facts, words and definitions, and problem-solving techniques, for example. Yet many states minimize the importance of the latter. At the same time, several states promote the fallacious idea that "all cultures" have made similar contributions to science. Alas, that's simply not true.
5. **Shunning Evolution.** A disturbing and dangerous trend over the past five years, in response to religious and political pressures, is the effort to water down the treatment of evolution, as shown by the map on page 7.

Treatment of Evolution in 49 States and the District of Columbia



Evolution

The attack on evolution is unabated, and Darwin's critics have evolved a more-subtle, more dangerous approach. A decade ago, the anti-evolution movement, which acquired a command post and funding source in the Discovery Institute of Seattle, Washington, argued vigorously for explicit teaching of the evidence for intelligent design—for the role of external, conscious agency in the history of life on Earth. When examined by qualified scientists and mathematicians, however, that evidence turned out not to be evidence, and so it remains—no evidence—at the time of writing. The promoters of intelligent design creationism have perforce retreated to arguments that invoke the popular and conveniently vague educationist formula, "critical thinking." The claim now is that evidence against "Darwinism" exists, that curriculum-makers should include it as an exercise in critical thinking, and that "freedom of speech" or "fairness" requires that they do so. The hidden agenda is to introduce doubt—any possible doubt—about evolution at the critical early stage of introduction to the relevant science.

Still, even under relentless attack, defenders of the teaching of evolution are holding their ground. In fact, comparing this year's scores of how states are handling evolution with the scores assigned in 2000, when Dr. Lawrence Lerner did a similar survey for Fordham (See table 6 on page 25), we find that the teaching of evolution hasn't changed much. Twenty states earned a "sound" grade this year for their treatment of evolution, down slightly from 24 in 2000. The number of states earning "passing" grades held steady at 7, while those earning "marginal" grades rose from 6 to 10. Failing grades (or worse, as in Kansas) held steady at 13

FOREWORD

Science education in America is under assault, with "discovery learning" attacking on one flank and the Discovery Institute on the other. That's the core finding of the first comprehensive review of state science standards since 2000.

Academic standards are the keystone in the arch of American K-12 education in the 21st century. They make it possible for a sturdy structure to be erected, though they don't guarantee its strength (much less its beauty). But if a state's standards are flabby, vague, or otherwise useless, the odds of delivering a good education to that state's children are worse than the odds of getting rich at the roulette tables of Reno.

Standards are where a state spells out the skills and knowledge that its next generation should acquire as youngsters pass through primary and secondary schooling. They are aspirational, to be sure, but they are also an indispensable blueprint for curriculum, textbooks, testing, teacher preparation, and much else. When joined to a workable assessment-and-accountability system, they become far more than a blueprint. They become benchmarks by which to determine whether a child is promoted to the next grade or receives a diploma at the end of high school. They become the criteria for judging whether a school is effective, whether it warrants accolades or interventions, and whether, in a regimen of options and choice, it's worth selecting for one's daughter or son.

Until now, the No Child Left Behind Act of 2001 (NCLB) has focused everyone's attention on reading and math—and on whether schools are making "adequate yearly progress" in those two core subjects. Although some states incorporate additional subjects into their own accountability systems, reading and math have dominated most discussions of state standards, student achievement, and school performance.

That's about to change, with the addition of science to the NCLB regimen. Federal law requires that, beginning in 2007-2008, states must test students in science at least once in grades 3-5, once in grades 6-9, and once in grades 10-12. While the science results don't (yet) influence whether a school makes "adequate yearly progress," they must be reported at state and district levels. Formal consequences are avoided, but not sunlight, praise, and shame.

Thus the NCLB accountability spotlight will soon start illuminating states' and schools' and students' performance in science as well as reading and math. (Some of us wish it would do the same for history, but I'll defer that discussion for a later time.)

But the importance of sound science education doesn't hinge on NCLB. Its real significance has to do with the scientific literacy of the American people and the future economic competitiveness—and national security—of the United States. A recent National Academy of Sciences report concludes that "Without high-quality, knowledge-intensive jobs and the innovative enterprises that lead to discovery and new technology, our economy will suffer and our people will face a lower standard of living." In his best-selling book *The World is Flat*, Thomas Friedman hammers the point: "The truth is, we are in a crisis now.... And this quiet crisis involves the steady erosion of America's scientific and engineering base, which has always been the source of American innovation and our rising standard of living."

Solving those problems and safeguarding our children's future means paying serious attention to science education in today's public schools.

There's plenty of evidence that it needs work. Long-term trend results on the National Assessment of Educational Progress (NAEP) show essentially no change in students' science prowess over the past 30 years. According to TIMSS—the Trends in International Math and Science Study that measures the math and science acumen of students across the globe—American youngsters' grasp of science is actually slipping. In 1995, U.S. 4th graders were outperformed by their peers in four countries; eight years later, seven other lands had 4th graders that bested ours in science.

Which brings us back to state academic standards. Sure, one *can* get a solid education in science (as in other subjects) even where the state's standards are iffy—so long as all the other stars align and one is fortunate enough to attend the right schools and benefit from terrific, knowledgeable teachers. It's also possible, alas, to get a shoddy education even in a state with superb standards, if there's no real delivery-and-accountability system tied to those standards.

But standards remain the keystone of standards-based reform as well as an indispensable feature of choice-based reform. And so, with states revising their standards and tests in time for the new NCLB mandate, we resolved to appraise the science standards of the 49 states that have them and the District of Columbia.

We had done this in 1998 and 2000, and one important question was whether the situation had improved. Five years ago, it was unacceptable. In 2000, reviewer Lawrence Lerner conferred "honors" (A and B) grades on the standards of just 19 states, Cs on 6, Ds on 9, and failing marks on a full dozen. (Iowa and four other jurisdictions had no reviewable science standards at the time.)

Science education in America is under assault, with "discovery learning" on one flank and the Discovery Institute on the other.

Since then, most states have revised or replaced (or launched) their K-12 science standards. So it was time to evaluate them again, not just because of the added weight that NCLB will place upon them but also because of the additional pressure that science education has come under from the forces of anti-science, particularly (though not solely) the neo-creationists flying the banner of intelligent design creationism.

To lead this appraisal, we turned to the most distinguished scientist we know who has a keen interest in K-12 education as well, biologist Paul Gross, former head of the Marine Biological Laboratory at Woods Hole and former provost of the University of Virginia.

Paul graciously assented to take on this immense task and recruited a terrific panel of experts (including Dr. Lerner) to join him. All but one member of the panel are experienced science teachers; one teaches, among other things, philosophy of science. Their combined expertise covers elementary-secondary science, university science education through the postdoctoral level, scientific research, and the management of large research enterprises. Their disciplinary coverage spans biology, chemistry, geology, and physics, as well as environmental science, epistemology, and logic. (Biographical sketches of Dr. Gross and his team are in Appendix B.)

The results of this review are now in, and we're pleased to present them—but none too pleased with what they show.

Bottom line: same as five years ago. Though a number of states did better (the criteria were similar but not identical this time), an equivalent number did worse. The revisions made in the science standards didn't always yield improvement. As you will see in the text and charts that follow, 19 states again deserve honors grades—but now there are 9 Cs, 7 Ds, and 15 Fs.

If there's good news, it's that 55 percent of U.S. children attend school in the "honors" states.

But 45 percent do not.

The seven states with "A" grades demonstrate, once again, that it's possible to craft outstanding standards despite all the pushing and pulling and hollering. That being the case, we find ourselves, once again, wondering why other states don't use *those* standards as models for their own. And yes, we also find ourselves speculating that America might be better off with high-quality national standards for science, instead of leaving every state to craft its own. How much difference is there, after all, between what kids in Jacksonville should learn about science and what those in Worcester or Terre Haute should learn? (For that matter, how much difference is there between Jacksonville and Seoul, Prague, or Cape Town?)

Five other conclusions also leap out from the pages that follow.

First, evolution is still a flashpoint and the intelligent design folks (led by the Discovery Institute) are relentless. (They've even recruited President Bush and Senate Majority Leader Bill Frist to urge "equal time" for intelligent design creationism and Darwin, which is not unlike recommending that mustard plasters and bleeding be taken as seriously as antibiotics and heart-bypass surgery.) A number of states have resisted this madness in their science standards, but too many are fudging or obfuscating the entire basis on which biology rests. Kansas is the most notorious instance of this, but far from the only one. (Other observers have reached the same conclusion. A new analysis by *Education Week* says "many ... standards ... fail to address the fundamental evidence supporting the theory, which explains how life on Earth developed.")

Second, "discovery learning" is getting more weight than it can support in science. This is largely due to states' over-eager, oversimplified, and misguided application of some pedagogical advice enshrined in the so-called "national standards" propounded by the American Association for the Advancement of Science (AAAS) and the National Research Council. If schools taught nothing but science, the school day *might* be long enough to contain a full measure of lab work and student-directed learning as *well* as teacher-led instruction in fundamental scientific knowledge, skills, and procedures. Given the tight limits within which science education typically occurs, however, and given many educators' proclivity to choose constructivist pedagogy over old-fashioned instruction, American students run a grave risk of being expected to replicate for themselves the work of Newton, Einstein, Watson, and Crick. That's both absurd and dysfunctional.

Third, the follies in today's "national" science standards need to be kept in mind not just by states reworking their own standards but also in any future effort to substitute national for state standards. The swarming panels of science educators that drafted a new science "framework" for the National Assessment of Educational Progress (NAEP) delivered a weak product. (See Fordham's recent report, *Less Than Proficient: A Review of the Draft Science Framework for the 2009 National Assessment of Educational Progress.*) The National Assessment Governing Board wisely adjusted their draft—but this bears close scrutiny as NAEP moves from framework to actual science test (slated to start being used in 2009).

Fourth, many of the shortcomings in states' science standards are easily fixed. What they mainly need (apart from the simple remedy of substituting the outstanding versions already crafted by other states) is deeper involvement by bench scientists and better editing!

Fifth, and finally, it bears repeating that terrific standards are no guarantor of a terrific education being delivered or absorbed. Science may be the subject that U.S. teachers are least able to teach well—and the subject where traditional personnel practices for teachers (e.g., ed-school preparation, state certification, uniform salary schedules) are least apt to yield the teachers we need in 2005.

Based on the avalanche of recent commission reports, high-profile speeches, and calls for action, it appears that the nation's policy and business elite is ready to raise the bar on U.S. science education. State science standards are the right point of leverage. It's past time to get these right.

We are indebted to many individuals and organizations for making this study possible. Allow me, in particular, to thank the Carnegie Corporation of New York and the Ewing Marion Kauffman Foundation for their financial assistance and wise counsel. At the Fordham Institute, Michael Connolly and Justin Torres gave birth to the project and saw it through its toughest days. Martin Davis, Jr., Liam Julian, and Michael O'Keefe helped it across the finish line. Anne Elliott corrected our many errors and omissions. And the layout and design talents of Holli Rathman are evident throughout this report; we appreciate her hard work and endless patience. Most importantly, we thank Paul Gross and his colleagues (Ursula Goodenough, Susan Haack, Lawrence S. Lerner, Martha Schwartz, and Richard Schwartz) for their tireless commitment and sound judgment. This was no easy undertaking and they gave it their all.

States' science standards are easily fixed
What they need is
deeper involvement by bench scientists
and better editing!

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The Thomas B. Fordham Institute is a nonprofit organization that conducts research, issues publications, and directs action projects in elementary/secondary education reform at the national level and in Ohio, with special emphasis on our hometown of Dayton. It is affiliated with the Thomas B. Fordham Foundation. Further information can be found at www.edexcellence.net/institute or by writing to the Institute at 1701 K Street, NW, Suite 1000, Washington, D.C., 20006. This report is available in full on the Institute's web site; additional copies can be ordered at www.edexcellence.net/institute/publication/order.cfm or by calling 410-634-2400. The Institute is neither connected with nor sponsored by Fordham University.

— *Chester E. Finn, Jr., December 2005*

Members of the evaluation team were at times, in the course of this review of K-12 science standards, greatly encouraged. A few of the best documents we examined could serve as models for other states. They are worthy of the positive things we say about them. But we have some general and serious concerns about the universe of these documents. In the order of the discussion that follows, these are about problems of: excessive length, poor organization, and careless writing; inadequate disciplinary content; vaguely, often empty, constructivist sentiments; mere catchwords signifying a strong empirical base for the design of standards, which base is in fact weak; and, (in some cases) a politically motivated avoidance or minimizing of evolutionary biology.

More about these problems later in the report.

We start by describing in detail the criteria upon which we based our judgments of the standards. These criteria are somewhat altered from the set used in the Fordham Foundation reports of 1998 and 2000. Explanatory comment is therefore interspersed. Such comment covers changes in the criteria, especially the addition of two new ones necessitated by recent trends. They are concerned with scientific inquiry and the handling of evolutionary biology. Methods employed in applying the criteria to the objects of study are described next. Then we present quantitative results of the evaluation, including tabular and graphical displays of scores, ranks, and grades, and we consider the progress (or lack thereof) made since 2000. Next, we discuss common problems found in many of the standards. A final section offers brief, but considered, summary observations on each state's standards documents, as they stood when we were able to study them. This was in most cases the late spring and early summer of 2005.

Criteria & Methods

Our criteria for evaluation of the standards fall into five categories. There are 21 main criteria, derived from and closely related to those used to evaluate K-12 science standards in earlier Fordham reviews (1998 and 2000). This relationship allows the new findings to be considered in light of, and compared with, previous studies.

Sustained public demand, as one response to the need to report progress in science education, has spurred rapid evolution of form and detail in the documentation of standards. A recent headline in *Education Week* is representative: "As Test Date Looms, Educators Renewing Emphasis on Science." This article refers to "the approaching mandates of the No Child left Behind Act…." Most states have revised or expanded their science standards documents since the last Fordham review in 2000.

Thus, what we appraise here as the offering of a particular state is most often not what was evaluated half a decade ago. Moreover, in a number of cases, what we review here will be changed again in coming months. Comparison of our reported grades with their predecessors is therefore possible, and is of interest for a number of states. But consistency is not necessarily or realistically to be expected. Our emphasis here must be on the time-slice of K-12 science standards as they were in mid-2005, and on the auguries for revisions to come, rather than on the situation in 1998 or 2000.

For some of the criteria used in the present study, we have inserted additional comments—not included in the working texts of the criteria—as an aid to the reader. Such comments are enclosed in editorial brackets—[]—immediately below the relevant text, to separate them from the criteria actually used by the reviewers.

There are a few instances of overlap between criteria in different groups. This is not accidental; the different groups represent broadly different kinds of quality judgment; so the overlap is not redundant.

Group A: Expectations, Purpose, and Audience

1. The expectation is unambiguous that throughout the primary and secondary grades all students will become scientifically literate, at levels appropriate to grade.

   [This and all the following criteria, taken together, provide an effective definition of science literacy. So defined, the condition "literate" is understood to be a minimum achievement. This is a point we must emphasize. There is no implication in criterion A1 that all students can and must become equally accomplished in science, or, conversely, that a good standard describes all that the best students know or can do.]

2. The standards can be used in designing effective assessments of student learning, theoretical and practical, appropriate to grade.

3. The presentation is as free as possible of jargon; it is lucid and comprehensible to all its audiences: educators, subject matter experts, policy makers and legislators, parents, and the general public.

   [This is very important, and for more than curriculum making and assessment design. Many of those audiences are not K-12 education professionals but are deeply, and justifiably, concerned about the quality of standards, and about the consequences of their application. Standards documents that are not *readable and lucid, not of reasonable length,* not *purged of redundancies, or not organized so that a committed and intelligent lay reader can understand them, have failed in one of their central purposes.]*

4. The standards call for student work written in good English and, where appropriate, in suitable mathematical language. They require student oral presentations that are clear, logical, and appropriate to grade.

Group B: Organization

1. Standards are organized by grade or by clusters of no more than four grades.

2. They are grouped in categories or themes that reflect the fundamental theoretical structures in modern science. Examples: Newtonian dynamics; conservation of mass and energy; cosmological evolution; plate tectonics; cells and organisms, inheritance, populations and ecosystems, and organic evolution.

   [Evolution—organic, planetary, cosmological, and formal (as in computer science)—is one of those fundamental theoretical structures of modern science. For the life sciences it is the central one. Thus it must not be ignored, nor hidden in obscure language, nor subjected to disclaimers, which arise, not from science but from political pressures. Because such pressures have increased greatly since the last review of state science standards, it has become necessary to provide a supplementary evaluation of the treatment of evolution in each state's documents, in addition to the attention it receives automatically in the general review of life science. More on this elsewhere in the report.]

3. Classroom instruction within each topic is devoted at each grade level to developing skills of observation and data gathering; to the planning, recording, and interpretation of observations; and ultimately to the design of experiments.

Group C: Science Content and Approach

1. The standards provide explicitly for substantial laboratory and (as appropriate) field experience. Replication of classical experiments is encouraged. The importance of empirical evidence and of sound criteria for the acceptance of data is emphasized.

A few of the state standards could serve as models. But we have serious concerns about the universe of these documents.

2. Unambiguous terminology and rigorous definition are stressed. Such terms as cell, continental drift, cosmic background radiation, energy, genotype, magnetic reversal, mass, metabolism, natural selection, pH, and valence are defined as carefully as possible for the grade level in which they are introduced.

3. At appropriate grade levels, data analysis, experimental error, reliability, and the practices needed to optimize the quality of raw information are taken up—as subject matter.

4. The standards call for mastery of tabular and graphical techniques for analysis and reporting, with increasing sophistication as grade succeeds grade.

5. The continuing interplay of data and theory, and well-justified modifications of theory, are stressed at all grade levels, in a manner commensurate with student maturity. Important conceptual shifts and innovations in the history of science are elements of the curriculum.

   [This body of content has come to be dealt with, almost universally, under the head of "Inquiry," a category now treated in most standards as separate from science content categories such as "Earth and Space Science" or "Life Science." The

formats, styles, and cogency of Inquiry treatments vary enormously. We have therefore found it necessary to appraise the handling of "Inquiry" in these documents independently. More below.]

6. The primary curriculum content is an adequately representative set of basic principles, explicit or contained within science themes. Examples (only) of basics: In physics, Newton's laws of motion, conservation laws, and the macroscopic - microscopic nexus; in astronomy, evolution of the universe and the structure of its parts (including the solar system); in geology, planetary structure, and plate tectonics; in chemistry, mass and energy conservation, atomic structure, and the nature of the chemical bond; in biology, cells, organisms, ecosystems, biochemical unities, history of life, and evolution.

Sustained public demand has spurred rapid evolution of form and detail in standards documents.

7. These principles are first introduced via facts and simple examples; they emerge as themes and theory in higher grades. Students' increasing ability to grasp generalizations and abstractions is taken into account. An adequate factual knowledge base, laid down in the early grades, is deepened systematically by means of increasingly refined theory.

8. The standards emphasize recognition of good inquiry as well as some of the distinctive methodologies of natural science; but they do not oversimplify these as "*the* scientific method." Common features of every kind of competent inquiry, including good science, as well as distinctions among different disciplines, are made clear.

   [As is argued later in the report and also indicated under criterion C5, emphasis upon Inquiry has become insistent since state academic standards began to be published. This has been a matter of pedagogic more than of philosophical (epistemological) or historical emphasis. The new emphasis is due in large part to a preoccupation with inquiry-as-learning in those influential national scientific and science-education organizations attempting to guide K-12 curriculum development. Thus we have found it appropriate in 2005 to provide additional evaluation of philosophy and history of science, treated in most of these state standards under Inquiry or an equivalent name.]

9. The standards provide for careful definition of technology and do not confuse it, or its social consequences, with the content of science. They do address relationships between science and technology and the way that science has shaped the modern world.

Group D: Quality

1. The standards are demanding as to science-disciplinary content; their expectations are neither so broad as to be vague nor so narrow as to be trivial. They are neither mere prosy encouragements nor simple lists of things to be memorized.

2. They cover many of the basic understandings of physical reality as the scientific community recognizes them; but the document makes no effort to be encyclopedic.

3. The standards, taken as a whole, define a core scientific literacy for all students in all public schools of the state. At the same time, they are sufficiently challenging to ensure that students who achieve proficiency by the final year will be ready for college work.

   [Please see the comment under Criterion A1.]

Group E: Seriousness

1. Nowhere do the standards offer or encourage—as though they were science—pseudo-scientific or discredited proposals such as medical doctrines not based on objective evidence, vaguely defined "energy fields," "auras," folk-cosmologies and mythologies, creationist or neo-creationist anti-evolution disguised as "critical thinking," UFO visits, astrology, or divination.

2. Nowhere do the standards suggest or imply that basic scientific principles are race-, ethnic-, or gender-specific; nor do they distort the history of science in an effort to inculcate particular social or political doctrines.

Assigning Scores
The degree to which a standard meets the requirement of a criterion was measured on a four-point scale:

0—The requirement is not met, or its treatment is useless
1—The requirement is addressed, but incompletely, erratically, or inconsistently
2—The requirement is addressed adequately but with no distinction
3—The requirement of the criterion is met and in a thoughtful manner

Additional Review and Scoring
Two additional scores, one for Inquiry and one for Evolution, joined the twenty-one above, employing the same 0—3 scale.

a. On Inquiry.
A separate grade for Inquiry—or for *process* ("*doing* science"), or history of science, or philosophy of science, or science-and-society, or some combination of these—has, as indicated, become necessary. As standards, or threads, or benchmarks, these subjects are now treated in most standards documents as independent content or even as skills the students are expected to acquire. Yet these meta-scientific issues, accompanied as they are by fulsome praise of hands-on learning, are sometimes little more than pedagogical advocacy. They are thus of no great help in accomplishing the proper purposes of standards. In most of the documents here reviewed, Inquiry is some combination of real and useful subject matter (usually distinct from basic science) with pedagogic theory. We felt it necessary to examine this element independently of the other content areas. The score (scale of 0 to 3) was added to the final score for science disciplinary content. To earn a "3," a state that gives the now-customary prominence to Inquiry had also to offer substantive, correct, and grade-appropriate material—subject matter—on the processes of scientific inquiry or on history or philosophy of science rather than empty encouragements toward good behavior.

b. On Evolution.
"It ill befits our great people, four generations after Darwin and Wallace published their epochal discovery of evolution by natural selection, to turn our backs on it, to pretend that it is unimportant or uncertain, to adopt euphemistic expressions to hide and soften its impact, to teach it only as one alternative theory, to leave it for advanced courses where the multitude cannot encounter it, or, if it is dealt with at all in a school or high school biology course, to present it as unobtrusively and near the end of the course as possible, so that the student will fail to appreciate how every other feature and principle found in living things is in reality an outgrowth of its universal operation."

—Hermann J. Muller, 1959,
(Nobel Prize for Physiology or Medicine, 1946)[3]

Criterion E1, the first of the two concerned with seriousness about science education, denies credit points to any standards that include, *inter alia*, "creationist anti-evolutionism disguised as critical thinking." The inclusion of such anti-evolution content is a goal of contemporary "intelligent design" creationism, now overtaking other, older forms of creationism in the

The claim is that evidence against "Darwinism" exists.... The hidden agenda is to introduce doubt at the critical early stage of science learning.

perennial struggle to discredit "Darwinism."[4] A decade ago, this movement, which acquired a command post and funding source in the Discovery Institute of Seattle, Washington, argued vigorously for explicit teaching of the evidence *for* intelligent design—*for* the role of external, conscious agency in the history of life on Earth. When examined by qualified scientists and mathematicians, however, that evidence turned out not to be evidence,[5] and so it remains—no evidence—at the time of writing. The promoters of intelligent design creationism have perforce retreated to arguments that invoke the popular and conveniently vague educationist formula, "critical thinking." The claim now is that evidence *against* "Darwinism" exists, that curriculum-makers should include it as an exercise in critical thinking, and that "freedom of speech" or "fairness" requires that they do so. The hidden agenda is to introduce doubt—any possible doubt—about evolution at the critical early stage of introduction to the relevant science.

However, political assertions and public relations escapades to the contrary, *no* sound evidence has so far been adduced against descent with modification. In the (at least) two-billion-year history of life on this planet, evolution has been a *fact.* For creationists of all varieties, this is a painful predicament. It leaves standards-writers or school committee members who may themselves be sympathetic to creationism, or who are pressured by creationist constituencies, only two means of response. One is to require disclaimers somewhere in the standards or in the curricular materials that flow from them, to the effect that evolution is "just a theory." The clear implication of this misuse of "theory" is that evolution may be, or is likely to be, false,

Most of the state documents indulging in some downplaying of evolution were also weak in other ways.

and in any case has not been "proven." The other main technique is to insist in the standards that nothing in the documentation or in the classroom is intended to, or can, or will, have any effect upon anyone's conflicting beliefs. This is a conciliatory move, but it leads to the smart student's dangerous question: "Then why bother to learn it?"

Actually, there are more practical ways of getting the desired effect, visible in the standards documents of several states. One is simple: just ignore or ruthlessly scant the history of life on earth and avoid any discussion of descent and mechanisms. Set forth a few of the basics, even to the extent of mentioning the fossil record and some interpretation of it. But then simply avoid using the E-word or hide it somewhere in a mass of secondary verbiage. Some weasel words that don't mean the same thing, such as "change over time," may be substituted. Alternatively, however fully or scantily other biological and geological content is covered, the core science of evolution—physical as well as biological—can be passed over as though it were peripheral, or a curiosity. We have found it necessary to add, beyond Criterion E1, a grade (on the usual 0—3 scale) specifically for the handling of evolution in the life sciences and the other historical sciences.

A standards document that gives evolutionary science appropriate weight, at least within biology, that introduces the main lines of evidence, including findings in the fossil record, genetics, molecular biology, and development, and that connects all this with Earth history, merits a "3." The above, but with some big gaps, gets a "2." "1" is a marginally acceptable treatment. If the treatment is useless, disguised, or absent, the grade is "0."

It has turned out that most of the state documents indulging in some downplaying of evolution were also weak in other ways, so we have been largely—but not completely—spared the burden of lowering their letter grades because of their irresponsible treatment of evolution. Kansas is a special case, however, not so much of irresponsibility as of hardball politics, in aid of sectarian religion, substituting for science education. We explain this later.

Grading

In the very large body of files and text comprising the available standards documents for K-12 science, those for most states were read by all members of the reviewing group, each reader giving special but not exclusive attention to the subject matter of his or her professional expertise. All members of the reviewing group and the author of this report are veteran teachers of science and/or philosophy of science. Their combined expertise covers school science plus university programs through postdoctoral. Some of us have been deeply involved in standards-based reform. Professor Lerner is the author of earlier Fordham Foundation reports in this series. Five members of the reviewing group are scientists as well as science teachers. One has been the director of an international research institute and a senior science administrator. The reviewers' professional science disciplines include physics, chemistry, biology, geology, and environmental science. One is a philosopher of science and the author of important texts on epistemology and logic. Throughout the period of review, there was regular and detailed exchange of views among all the readers.

The maximum number of points available for award under the scoring system is 69 (23 criteria x 3 points). Each reviewer's actual score was rendered as a percentage of that maximum. The final score for each state is the mean of the final percentage scores provided by all readers of the documents for that state. These scores were then used as primary data in the assignment of letter grades. In general, there was unanimity among reviewers about the documents from a state. That testifies to the comprehensiveness of the criteria for evaluation and to the seriousness with which each reviewer employed them in reading and comparison.

Of course, there were some state documents in which one or another of the science disciplines was especially well, or poorly, handled. Where such differences were noteworthy, they are discussed in the comments that follow. However, the final scores reported here and employed in grading are the average scores for all criteria for all reviewers.

Finally: because a single number cannot reflect important but unquantifiable properties of documents (or, more accurately, multi-documents, as are these standards), we allowed for final adjustment. Each standards document was assigned an initial letter grade based on the numerical score; but we then considered additional factors that might justifiably change it. If group opinion based on all the evidence supported such a change, the grade could be adjusted one letter up or down. In the very few cases where they arose, such considerations are mentioned in the comments on the state's standards.

We did not assign pluses or minuses. For quality judgments as complex as those required for massive and complex documents, neither the criteria nor our judgments in applying them are fine enough to justify fifteen, rather than five, grade categories.

Disclaimers: Two members of the group were involved in production of the California K-12 science standards; they did not participate here in the assignment of a grade for California. One of us was consulted for editorial assistance in the preparation of the South Carolina standards, but was not a writer of the document. One of us offered comment at an early stage of preparation of the Massachusetts standards, but again, was not involved in their writing or presentation.

Results

Score spans for the award of letter grades are shown in Table 1. Letter grades A through C were awarded for numerical spans of 15 points: the point span for grade D is shorter—10 points. The reason for this is that, when the evaluations were complete, a clear break in mean numerical scores and in overall quality was evident on both sides of that 10-point span. Forty-five through 54 points was therefore a range appropriate to what we saw as "better than failing but by no means adequate." There are, however, fewer D grades than would have been dictated by the numerical score distribution in that range. Some otherwise D-worthy standards were downgraded for failure to treat evolution seriously.

Table 1. *Initial score spans for the assignment of letter grades.*

Final Score (Percentage)	Grade
≥85	A
70 – 84	B
55 – 69	C
45 – 54	D
< 45	F

Table 2. *Final, adjusted letter grades.*

Grade	Number of States
A	7
B	12
C	9
D	7
F	15

Table 3. *Average raw scores, derived final percentage scores, and assigned letter grades for 49 states and the District of Columbia.*

STATE	AVERAGE RAW SCORE	FINAL SCORE (PERCENTAGE)	LETTER GRADE
Alabama	28.8	42	F
Alaska	13.3	19	F
Arizona	49.6	72	B
Arkansas	30.8	45	D
California	66.7	97	A
Colorado	52.1	76	B
Connecticut	40.6	59	C
Delaware	46.8	68	C
District of Columbia	43.3	63	C
Florida	32.9	48	F
Georgia	51.6	75	B
Hawaii	26.9	39	F
Idaho	23.7	34	F
Illinois	48.6	70	B
Indiana	62.8	91	A
Kansas	44.7	65	F*
Kentucky	35.3	51	D
Louisiana	51.3	74	B
Maine	35.0	51	D
Maryland	49.6	72	B
Massachusetts	64.7	94	A
Michigan	32.9	48	D
Minnesota	48.8	71	B
Mississippi	32.4	47	F
Missouri	45.8	66	C
Montana	26.8	39	F
Nebraska	26.1	38	F
Nevada	35.1	51	D
New Hampshire	24.9	36	F
New Jersey	53.1	77	B
New Mexico	59.4	86	A
New York	60.5	88	A
North Carolina	54.6	79	B
North Dakota	33.2	48	D
Ohio	51.1	74	B
Oklahoma	34.8	50	F
Oregon	27.6	40	F
Pennsylvania	44.6	65	C
Rhode Island	39.9	58	C
South Carolina	64.1	93	A
South Dakota	35.7	52	D
Tennessee	57.1	83	B
Texas	23.6	34	F
Utah	42.6	62	C
Vermont	41.6	60	C
Virginia	66.0	96	A
Washington	44.8	65	C
West Virginia	48.4	70	B
Wisconsin	20.1	29	F
Wyoming	25.3	37	F

**Just before going to press, the grade for Kansas was reduced from "C" to "F," as explained in the comments on Kansas standards to follow.*

Percentage scores for the subject areas are indicated in Table 4, where the numbers are the average final scores by specific content emphasis. The average quality of handling of Inquiry, broadly understood, was about the same as the treatment of evolutionary biology (reconsidered independently): just passing—57 percent of the maximum score of 3 in each case. Chemistry seems to cause more trouble for standards writers than do the other sciences. Yet its basic content is just as important for science literacy as that of any of the other disciplines. Indeed, the natural sciences have today become so interdependent that many of the traditional demarcations within the body of "basic" science have become arbitrary and are being abandoned at the research level. We might speculate that the quality differences among disciplines in the state documents speak to the science backgrounds of the K-12 standards writers, rather than to the relative difficulty of the subjects or to our biases as a reviewing body.

State standards are in flux, but the nation, as an entirety, is neither making progress nor losing ground when it comes to its expectations for student learning.

The tabulated results are averages, not applicable to individual standards documents. In a few cases, sound handling of content in one of these broad categories helped to pull up the mean score for a standards document in which others were weak. And vice versa. The relatively high "68" for biology does *not* represent the average quality of treatment of evolution alone.

As is apparent in Table 5, most states received a different grade in 2005 than in 2000. Of the 46 states with standards reviewed in both years, 13 earned higher grades in 2005, 14 received the same grade, and 19 earned lower grades. Does that mean that state science standards are, on the whole, getting worse? No. The same number of states received "honors" grades (A or B) this year (19) as in 2000, and the percentage of failing grades inched up just slightly from 26 percent to 30 percent. What's the lesson? While state standards are very much in flux, the nation, in its entirety, is neither making progress nor losing ground when it comes to its expectations for what students should learn in science. Unfortunately, that's hardly news worth celebrating.

Comparisons, 2000 and 2005

Table 5 compares the states' final percentage scores and letter grades from this evaluation with those reported in *The State of State Standards 2000.*[7] The sort is by 2005 final score. There is some consistency and matching, especially at the high and low ends of the grade distribution. However, there are some surprising mismatches, too. Some of these are happy. Georgia, New York, New Mexico, Tennessee, Virginia, and West Virginia, for example, have moved sharply and unequivocally upward into the honors range. A few others have moved, just as unequivocally, in the opposite direction (Nebraska, Oregon, Rhode Island, Texas, and Wisconsin). For all such cases, up or down, the dominant cause is changes in the state documents during the half-decade elapsed since they were last reviewed. Much less significant are changes in form and application of the criteria from 2000 to 2005, and in our broad but very close scrutiny of science content. The standards reviewed in 2005 are for the most part major or total revisions of their predecessors in 2000, responding to guidance, mandates, and pressures already different from those obtaining during the late 1990s.

Table 4. *Mean percentage score for all states by discipline.*

Discipline or Issue	Mean Percentage Score
Earth/Space Science	61
Chemistry, Environmental Science	50
Physical Science	64
Biological Sciences	68
Inquiry	57
Evolution	57

Common Problems

1. Excessive Length, Poor Navigability

For the entire complement of a state's science standard papers to add up to a bulky document is not unexpected. There is a lot to be covered. But sprawling, almost impenetrable documents, uncontrolled in size and poorly organized, are unfortunately too common a result of the push toward comprehensiveness. One gets the impression, after reading a dozen standards documents chosen at random from the 50, that they have grown by accretion rather than by plan. They seem to have been written by large committees whose members could not communicate with one another. In some cases (Ohio's and Vermont's massive undertakings come

Table 5. *Final scores and letter grades by state, sorted on the 2005 scores.*

STATE	SCORE 2005 %	GRADE 2005	GRADE 2000	TREND
California	97	A	A	↔
Virginia	96	A	D	↑
Massachusetts	94	A	A	↔
South Carolina	93	A	B	↑
Indiana	91	A	A	↔
New York	88	A	C	↑
New Mexico	86	A	F	↑
Tennessee	83	B	F	↑
North Carolina	79	B	A	↓
New Jersey	77	B	A	↓
Colorado	76	B	D	↑
Georgia	75	B	F	↑
Louisiana	74	B	C	↑
Ohio	74	B	B	↔
Arizona	72	B	A	↓
Maryland	72	B	D	↑
Minnesota	71	B	A	↓
Illinois	70	B	B	↔
West Virginia	70	B	F	↑
Delaware	68	C	A	↓
Missouri	66	C	C	↔
Kansas	65	F	F	↔
Pennsylvania	65	C	NA	NA
Washington	65	C	B	↓
District of Columbia	63	C	NA	NA
Utah	62	C	B	↓
Vermont	60	C	B	↓
Connecticut	59	C	B	↓
Rhode Island	58	C	A	↓
South Dakota	52	D	B	↓
Kentucky	51	D	D	↔
Maine	51	D	D	↔
Nevada	51	D	C	↓
Oklahoma	50	F	F	↔
Michigan	48	D	D	↔
North Dakota	48	D	F	↑
Florida	48	F	F	↔
Mississippi	47	F	F	↔
Arkansas	45	D	F	↑
Alabama	42	F	D	↓
Oregon	40	F	B	↓
Hawaii	39	F	D	↓
Montana	39	F	D	↓
Nebraska	38	F	B	↓
Wyoming	37	F	F	↔
New Hampshire	36	F	F	↔
Texas	34	F	C	↓
Idaho	34	F	NA	NA
Wisconsin	29	F	C	↓
Alaska	19	F	NA	NA

to mind), editing and proofreading must have been done hastily, as an afterthought, or not at all.

Of course, there are honorable exceptions. Certain documents, including some in the group graded "A," are indeed long (some are too long), but in those cases the organization is transparent and the exposition is clear. Most of the very long documents, however, are far from clear. Their length, and often their poor organization, works against one of the fundamental requirements of a state standards presentation: that it be accessible to all interested readers.

The standards' excessive length is a result of accretion, prolixity, a tendency to dress up rather than clarify.

A few of the state documents are short. Some but not all of those are of acceptable quality. Thoughtful brevity is therefore not, *ipso facto*, a defect in standards documents. (Maine's standards certainly go too far. Its treatment of "The Universe" fits on half a page.) The excessive length of most current standards documentation is simply a result of accretion, prolixity, a regrettable tendency to dress up[8] rather than to clarify the documents, and—especially troublesome here—repetition. Repetition of words, sentences, or paragraphs in standards, whether in tabular or systematic format, can have genuine purposes— to convey meaning or to make the documents easy for certain readers, such as teachers, to use. But tedious repetition has the opposite effect. Navigation becomes burdensome; the chance that readers who ought to be acquainted with everything in the standards will really absorb the whole becomes negligible.

The easy solution to this problem is probably cheaper by an order of magnitude than the cost in time and money of putting these huge productions together. Hire a good, independent, professional editor, one who knows science and loves the English language. Grant him or her the right to get answers to queries from any and all contributors to the original—and to edit!

2. Thin Disciplinary Content

By "disciplinary" science content we mean the facts, the concepts, and the special methods of the scientific subjects that these standards *should* represent. Adequate disciplinary content must be there, even if the facts and ideas come from non-disciplinary, abstract, or thematic presentations that cross the traditional boundaries of the standard disciplines. By "discipline" we mean physics, astronomy, cosmology, chemistry, geology, biology (including ecology, genetics, and evolution), and what has now grown up as the derivative but nevertheless quite independent discipline, environmental science.

The problem of absent or meager disciplinary content is due in part to the success of the Inquiry movement, to its banners rather than to its good core substance. In science, as wherever else honest inquiry is done, acquisition of the investigative discipline's content requires skills in the acquisition process itself. And some aspects of investigative process are especially characteristic of natural science: development and use of technology to extend the reach of the senses, for example, or stringent peer review (which is *not* the same thing as cooperating nicely with fellow students). But process is useless if there is nothing to process, and substance never materializes if the processes of seeking it are missing or flawed.

So students need both: they need process and real content. Therefore we are distressed when we read a sprawling standards document in which all is more or less well except that there is not nearly enough *systematically developed* physics or chemistry or biology to make sense of the lofty thematic generalizations that are supposed to contain them. We are concerned when the K-8 science content is unable to support the content of grade 9-12 science courses, which are in turn inadequate to prepare those students who want to get ready for college science. And this happens even in some cases where the high school science courses are well planned.

More commonly, what we find is that the science know-how of the writers is adequate for K-8, perhaps, but falters thereafter. Thence the content proposed for the secondary grades becomes thin and superficial, or emerges error-ridden, or disorganized, or all of these. For such ills, too, the cure is straightforward: ensure that scientists competent in the subject at least check the proposed science content, or, even better, help to strengthen it.

3. Do-It-Yourself Learning

Many standards documents justify their learning expectations for science by reference to one or another educational or pedagogical theory. Nowadays the vogue is to mention constructivism, or discovery learning, or some combination of the two. They are indeed related ideas in

Educational Constructivism

Constructivism is not new. It was evident in the first draft (1992) of the National Science Education Standards, where it took the form of a claimed *postmodern* philosophy of science. That, in turn, incorporates one kind of constructivism ("social" constructivism) about knowledge, including scientific knowledge. The adopted philosophy was an application to learning standards of the increasingly popular *educational* constructivism, whose main tenet is that learning happens only by an individual's action, his or her making and doing things in the world, not as a result of any conveyance of knowledge (as in teaching).[10] A revision of that early draft eliminated the praise of postmodernism but left in place the notion that a learner can do no more than to construct knowledge, which is therefore personal, from things and events in his or her sensed environment. It is *supposed* to follow from this that scientific knowledge cannot be transferred from one person—a teacher (or from a book)—to another. The learning expectations of standards should therefore focus much more on *process*, the "doing" of science by the student, and much less on its reputed facts.[11]

By the late 1990s, emphasis on process as opposed to content was synergistic with various social pressures for such pedagogy, eventually under the explicit banner of constructivism. The slogans "depth instead of breadth" and "less is more" became catchwords. Typical of that stirring time, and not very different from materials now appearing every day, were such exhortations as the following, quoted from a series of papers entitled "Research Matters—to the Science Teacher," at the web site of the National Association for Research on Science Teaching:

> ... The constructivist epistemology asserts that the only tools available to the knower are the senses. It is only through seeing, hearing, touching, smelling, and tasting that an individual interacts with the environment. With these messages from the senses the individual builds a picture of the world.... Therefore constructivism asserts that knowledge resides in individuals; that knowledge cannot be transferred intact from the head of a teacher to the heads of students. The student tries to make sense of what is taught by trying to fit it with his/her experience.... 'Others' are so important for constructivists that cooperative learning is a primary teaching strategy.... Thus, from a constructivist perspective, science is not a search for truth....[12]

But as the physicist and science educator Alan Cromer argued,

> ... Constructivism is a postmodern antiscience philosophy that is based upon Piaget's work on how children construct concepts and conceptual relations and on the philosophy of two early nineteenth-century opponents of the Scientific Revolution, Giambattista Vico and George Berkeley.... It's a form of subjective empiricism that puts its emphasis on the thoughts of the knower and views the search for truth as an illusion.... Such an ideology would be of no interest to scientists and science educators were it not, in effect, the official ideology of the reform movements in the United States and elsewhere.... *But when push comes to shove, no one knows how students are to construct their own theories of atoms and electrons, of stars and galaxies, of DNA and genetics...* "[13]

The constructivist turn in K-12 science education is another case of good ideas gone bad. The good ideas are certainly there in the national models and are sometimes reflected in the standards documents we studied for this report. Inquiry now shares pride of place in science curriculum with disciplinary science content. Recently and in some places, the former has even begun to dominate the latter.

In 2000, the National Academy Press and the National Research Council issued *Inquiry and the National Science Education Standards*, a follow-up to the earlier standards models. This volume was intended to illuminate and justify the shift of emphasis. Central to its argument is a brief survey of current research on "How Students Learn Science." [15] Explicit constructivist argument is (again) absent. The stress, instead, is on research data bearing on the attributes of scientific expertise and on the stages through which children go in learning science.

As far as it goes, the account is even-handed. But it doesn't go far enough and is clearly a promotion of Inquiry (or, to use an older and more limited catchphrase, "discovery learning") as the preferred pedagogy for K-12 science. About the empirical support for Inquiry in science learning, this account is not entirely satisfactory. First, from research on the nature of expertise, which is indeed relevant to learning as inquiry, the evidence reported is that people who have it—the experts— "... *have a deep foundation of factual knowledge* [emphasis added]."[16] That is nothing like a finding in favor of "less is more"!

Second, an up-or-down verdict on Inquiry-based science learning is not yet available: meta-analyses of the large and uneven literature yield no compelling conclusion.[17] What the meta-analyses do indicate is that Inquiry—here, the processes of practical science—ought not to be ignored in the design of standards and curricula (with which principle every competent science teacher must surely agree). To us the meta-analyses indicate that more, and much better, research still needs to be done. They do *not* confirm "less is more."

the sense in which most educators understand their meanings, although in fact both terms have multiple meanings that are sometimes contradictory. Held up as the newest educational philosophy, as they have been for the last decade, these words imply that the standards writers (or writers of the national standards models) really know—at last! —how children learn science, and have systematically applied the new knowledge.

That knowledge, it is claimed, has a strong role in determining the new design of standards. Improvement in student learning would therefore appear to be inevitable. For all this, however, there is no conclusive

[illegible] of the standards' writers is adequate for K-8, perhaps, but falters thereafter.

evidence.[9] If, on the other hand, the terms "discovery" or "constructivism" are paraded in a standards document simply to indicate solidarity, or depth of empirical evidence, or robust theoretical support for the design decisions taken, then they are JUST catchwords—in this case, a form of self-congratulation.

There is insufficient justification for epistemological radicalism in curriculum design. Constructivism has been, and remains, a largely ideological battleground. There is no agreement on its merits among philosophers who define and argue about different constructivisms (idealist, rationalist, Piagetian, social, and educational—as in the much-cited work of E. von Glasersfeld[18]). Much less is there informed consensus on the superior effectiveness of constructivist pedagogy.[19] There is no preponderance of evidence, from good research on a population scale, for the claim that science education based upon constructivism—or discovery learning—really does better, *ceteris paribus*, than "traditional" methods, so-called. The rare, recent investigation that incorporates controls (that is, isolates the variable of interest) tends rather toward the opposite conclusion.[20]

To recapitulate, underlying the stylish words is a perfectly sound idea: *Whenever practicable, science learners should find things out for themselves.* They should have ample opportunity to observe, to perform experiments. These should be self-planned when possible, and prearranged when appropriate. Students should be encouraged to devise their own methods of answering questions. And our criteria reflect all this. But it is ridiculous to expect schoolchildren to "construct" any substantial part of the core knowledge of modern science. That core is a vast, multidimensional matrix whose cells are facts, experiments, and theories, interconnected, mutually reinforcing, in continuous change and expansion, and inaccessible to purely inductive activity. Yet, to give but one example, Wyoming's standards declare, "Scientific inquiry is the foundation for the development of content and processes of science that enable students to construct their own knowledge." Are Wyoming's teachers, parents, and students to take that statement seriously?

4. Good Ideas Gone Bad

Catchword, n: *A word or phrase whose original, explicit meaning dissolves in excessive repetition, becoming a mere label, usually for a school of thought or a theory.*

Readers of the current science standards encounter a few prevalent catchwords, of which we have now had a glimpse. By itself, that is neither surprising nor troubling. Every profession has catchwords; and science standards documentation—despite its ostensibly public character—is written by and for the education profession. But the state science standards certainly *should* be written for a wider audience. Documents written by and for educationists often include jargon that can be annoying, but is mostly innocuous. They also include catchwords, however, and those may not be innocuous. Our concern is with catchwords that arise from initially good ideas about how science can be taught and learned, but that have gone through a process of degradation. Certain of these good ideas have become so familiar that the natural process of simplification and abbreviation has followed. When and if the resulting words or phrases are used to suggest *more* truth, *better* evidence, more confidence than is justified by the reality, then they are troublesome. They spell trouble when, by taking precedence over genuine knowledge, they are allowed to drive the design of the standards. They are good ideas driven bad by overemphasis and repetition. Here are two examples.

a. Hands-On (Minds-On) Learning

A splendid idea: *Don't limit the study of natural science to memorization.* Arrange curriculum so that students acquire and employ some of the processes of knowledge acquisition known to work in real science. Two examples are (1) physical engagement with the subject in the field, laboratory, and library and (2) cooperation among inquirers with the same interest. Such approaches surely allow students to learn more and better science (and anything else!) than mere mechanical memorizing. To this idea, every working scientist and science teacher gives unqualified assent. But observe how it becomes corrupted and counterproductive by being run into the ground.

No science course among the hundreds the writer has ever taken, taught, or observed during 40 years as a faculty member, K-12 or college, has offered its subject matter *solely* as lists of things to be memorized, with no work or manipulation in the field, laboratory, or library. Yes, science courses require students to memorize some things: facts, words and definitions, and problem-solving techniques. But no survey is needed to establish this minimal but critical point: the widespread polarity between "rote" learning and hands-on, minds-on learning is a caricature. Yet many state standards include statements like this one, found in Washington's documents: "Learning in science depends on actively doing science. Active engagement in hands-on, minds-on science learning experiences enables students to make personal sense of the physical world...."

The real problem is, rather, in determining reasonable demands on student memory. It is not at all a matter of "just memorizing" versus "doing" science. You can't just "do" science, or any other intellectual work, without a minimum acquaintance with the facts. Caricatures are essential to politics, but they are inimical to making serious distinctions that play a role in deciding how to teach. The charge against "traditional" science education (so mocked), that it is just memorization of facts ("factoids"), is false. The implication that science can be learned "hands-on" *without* memorization is also false.

Science is learned, as the experience of at least two centuries shows, by a combination of memorizing facts, words, and methods of thought, and reinforcement of what does get into memory by repetition and by investigation in the field, laboratory, or library. So there is nothing new about "hands-on" science learning. "Hands-on" is a catchword, used to suggest that something new and different is going on when, often, it is not. Physical, investigative activity, if that's what "hands-on" is meant to suggest, should not be an excuse for eliminating content. Of "minds-on" nothing more need be said than that it is not even a catchword. *By definition*, the minds for whose education the standards document is a guide are on while learning, including learning in the field or laboratory.

False Dichotomy

For decades, it has been understood that facts and process, theory and practice, are needed together for the learning of science. As the editor of the *Journal of Geoscience Education* put it,

> It often seems as if the *au courant* proponents of post-modern educational theory and practice believe that it is possible to understand a subject, to think critically about it, and to solve problems in it without bothering to learn and know the details of the subject. This is nonsense and should be emphatically branded as such. .... [T]here are no shortcuts to comprehension that avoid the difficult task of learning, knowing, and appreciating the "facts" of the subject at issue.[21]

Finally, there is plenty of good science in which the hands are *not* on. The heart of theory making is thinking, not doing, and theory is central to all science. To be sure, good theory in science is eventually a matter of testing: of observation and experiment, verification or refutation. But in the first instance, thought alone, based upon what is already in memory or in books, is indispensable. There are theorists who do nothing but think (and read, and talk, and write about their thoughts).

It is ridiculous to expect schoolchildren to "construct" any substantial part of the core knowledge of modern science.

They are among the most honored scientists. Consider, for example, the stature accorded to "theoretical physics." The chant, therefore, of "hands-on," as the core principle of science learning and as new pedagogy, is another form of self-congratulation.

b. Everybody does it

A genuinely great idea and also a fact: *Ethnicity, national origin, age, sex, race, and religion have nothing to do with a person's native ability to learn or do science.* Therefore opportunities to learn and to practice it, should a student's interests grow in that direction, must never be limited by his or her background. It is a productive thing in science, as history has demonstrated, to emphasize the universals of human cognition. The inescapable result of modern experience is that such universals exist. It is proper to emphasize the worldwide production of important basic science and engineering.

[illegible] arise from initially good ideas about teaching science, [illegible] they have gone [illegible]

Examples of real and important scientific achievement in cultures different from our own, past and present—real science from the ancient Chinese and Arab cultures, for example—are welcome in science teaching. But: none of this means that every individual is, or can be, a scientist.

Much less does it mean, as is sometimes suggested in standards documents, that each and every *culture* has done or now does good science. Even less justified is the implication that, because everybody can do and does his own kind of "science," scientists of one culture have no right to judge the scientific claims of another culture. It would be absurd for an aeronautical engineer in America or Europe or Asia to believe—or teach—that the twigs-and-foliage mock-ups made by cargo cultists of the Pacific islands during World War II were airplanes—just because in that culture they were believed to be airplanes, or an adequate substitute.

Thus, to assert repeatedly, explicitly or by implication, that all cultures everywhere contribute equally to science, that everybody has done it, or does it, or *can* do it, is silly. (Yet states such as Alaska, Arizona, New Jersey, and South Dakota cannot resist doing so.) It implies, also, that as compared with other kinds of performance, there are no differences in science ability or inclination among children (or cultures). That contradicts another catchword found in these documents: multiple intelligences, which argues exactly to the contrary.

"Everybody does it and can do it," repeated as a mantra, takes a good and important idea and drives it into the ground. The search for happy examples by writers not deeply knowledgeable about science leads to such absurdities as the citation of Ayurvedic medicine, instead of any of half a dozen brilliant mathematicians and physicists, as representative of Indian scientific intellect, or—even in Western science—the naming of Rachel Carson or Sally Ride rather than, say, Lise Meitner, or Irène Joliot-Curie, or Barbara McClintock as representing great women in science. Even the children, in support of whose self-confidence such things are usually said, don't necessarily believe them.

5. Avoiding Evolution

Appendix A displays a table of average scores earned by each state for each of our criteria. One criterion—new since the last Fordham review of state standards in 2005—calls specifically for serious treatment, especially but not exclusively within the life sciences, of the facts and theories of evolution. That is, this criterion is used to judge the expectation for students' understanding of the history of life on Earth. Our scoring system is less elaborate than that employed by Lerner in his September 2000 review of the state treatments of evolution.[23] The schemes are, however, similar enough to allow comparison and comment.

Lerner employed a six-level grade scale: A, B, C, D, F, and F-minus, best to worst. Our scale was (as indicated earlier) 3, 2, 1, 0, best to worst. It does no real violence to the earlier system if we translate its results to the terms of this, our current evaluation. We can combine the 2000 "A" and "B" categories (scores 80 – 100 in that review) to correspond with our category "3." We may then rename the categories of the two reviews, 2000 and 2005, as follows: "Sound," "Passing," "Marginal," "Failed," and "Not even failed" (Lerner's F-minus), best to worst—provided that we make room for that last grade of Lerner's (below 0) in our 2005 set. As it happens, it is still needed. Here, in Table 6, is the comparison of the results. (Note that these 2005 results include a last-minute change of the grade for Kansas.)

Table 6: *Earned grades for evolution, 2000 and 2005*

Grade Earned	Number of States 2000	Number of States 2005
Sound (A+B; 3)	24	20
Passing (C; 2)	7	7
Marginal (D; 1)	6	10
Failed (F; 0)	12	12
Not Even Failed (F-)	1	1
Total States	50	50

The outcome of this comparison is that, for the population of states, nothing much has changed in the intervening five years except a shift of four states from the category "sound" to "marginal." This distribution difference isn't significant. Of interest is the need for us to add a grade, for one state's effort in 2005, *below* "failed," just as did Lerner in 2000. As it happens, it is for the same state, Kansas, although this is for a new and different attack by the state's creationists.

First, as to the general lack of progress in dealing with evolution: It seems to us, examining our state documents in the grade categories "1" and "0," (see Appendix A) that the undistinguished performance of the whole group of states is not due to any notable success of current adventures in anti-science or plain bad science, such as intelligent design "theory" or the older, more literalist forms of creationism. *Rather, it looks as though things haven't changed much because the weak handling of evolution science content is just sister to the general weakness of disciplinary content for all science—despite the active revision of standards in most states since 2000.*

In a painful sense then, that is good news. It means that ongoing, strenuous, and well-supported efforts, political and in public relations, to change the purposes and tenor of K-12 science—by catering to the anti-evolutionism of fundamentalist religious groups—has yielded little or nothing over the last half decade. The bad news is that those efforts have not ceased, but are instead growing in funding, intensity, public relations skill, and reach, particularly political reach, even to the highest levels of government.

The decent (if not excellent) standards written for Kansas by a competent standards-writing committee have now (and for the time being, until the next election) been disabled by an incumbent and irremediably divided board of education. Its creationist majority is determined to resist evolution in any way it can. The just-adopted Kansas standards explain, inter alia, that there is no evidence for "macroevolution." In other words, that evolution as defined and described in biology didn't and can't occur. They also redefine the term "*science.*" According to the Kansas board, "science" does and must recognize not only natural phenomena but also supernatural phenomena. Never mind that this is a contradiction in terms. "Supernatural" phenomena are those that by definition cannot be studied or explained by the methods of natural science. For these reasons we have had to revert to Lerner's F-minus, assigned to Kansas in 2000 for its treatment of evolution.

> *For us to have made no progress in establishing sound standards for K-12 education in evolution is discouraging.*

We have yet to learn the decision of the judge in the federal court case of Kitzmiller et al. (parents, plaintiffs) v. Dover (PA) School District, defendant, now just ended. Most of the board members who forced anti-evolution and intelligent design on the biology curriculum of Dover were, however, defeated in the elections of November 9, 2005. The science standards of the state—Pennsylvania —have to date no hint of creationist influence.

Evolution is the organizing principle of modern biology, and its simple but powerful principles and algorithms have colonized scholarly disciplines formerly as remote from biology as economics, engineering, and literature. For us to have made no progress in establishing sound standards for K-12 education in evolution is very discouraging; but then, things could clearly have been worse. We aren't doing brilliantly—in general—in other, less controversial but equally important areas of natural science.

For the life sciences, treatments of fundamentals—mitosis, meiosis, and cell division; basic embryology; the genetics of evolutionary change—are rather weak, and grade-wise progression is often in the form of mere repetition. Grade: "D."

CALIFORNIA

	Points	Out of a Possible
A. Expectations, Purpose, Audience	11.7	12
B. Organization	9.0	9
C. Science Content and Approach	25.0	27
D. Quality	9.0	9
E. Seriousness	6.0	6
Inquiry	3	3
Evolution	3	3
Raw Score	66.7	69
Final Percentage Score	97	100
GRADE	**A**	

Reviewed: Science Content Standards for California Public Schools and Science (1998)
Framework for California Public Schools (2004)

On science processes, and on history and philosophy of science, California's standards vary delightfully from the norm: they are *brief*, there is no bombast, and they are realistic about the capacities of children for making sense of abstract ideas. Process is stressed where it should be, and in plain and appropriate language. For example: Grade 3: "Repeat observations to improve accuracy, and know that the results of similar scientific observations seldom turn out exactly the same ... differentiate evidence from opinion and know that scientists do not rely on conclusions unless they are backed by observations that can be confirmed."

A reviewer of the physics materials finds that "The standards are remarkably free of error and ambiguity." A very few errors are found nevertheless; but they are minor. From grade 5, for example,

> "*Students know* metals have properties in common, such as high electrical and thermal conductivity. Some metals, such as aluminum (Al), iron (Fe), nickel (Ni), copper (Cu), silver (Ag), and gold (Au), are pure elements; others, such as steel and brass, are composed of a combination of elemental metals."

Steel is indeed composed of two or more elements, but the basic component other than iron is carbon—which is not a metal.

Quoting and paraphrasing a reviewer of the life science treatment: "This is a honey of a document. You get the standards in one pdf, nicely organized, and flowing. Then you get a series of framework documents where these are set out a second time, only now there are also lots of concise descriptions of the phenomena, with terms carefully defined, information about what will actually go on in the classroom." It is encouraging to see more specific attention than usual to digestion, circulation, and other physiological processes even in the lower grades. In the 7th grade standards, earth sciences content is sensibly integrated with evolution. Physical principles are discussed, when the opportunity arises, in the context of living systems. For example these principles explore properties of light and of the eye, leverage in connection with musculoskeletal action, and pressure with the cardiac cycle and its function.

California has produced an exemplary set of standards for school science; there was no question among readers about the "A" grade. Now one must hope that teaching and learning follow apace.

COLORADO

	Points	Out of a Possible
A. Expectations, Purpose, Audience	8.8	12
B. Organization	7.3	9
C. Science Content and Approach	20.0	27
D. Quality	6.0	9
E. Seriousness	6.0	6
Inquiry	3	3
Evolution	1	3
Raw Score	52.1	69
Final Percentage Score	76	100
GRADE	**B**	

Reviewed: Colorado Model Content Standards for Science (1995)
NB: Colorado is currently revising its standards, which are due out in September 2006.

Evidently influenced by the National Science Education Standards, Colorado introduces six "standards." Three of these present science content, and three deal with science as process. The latter material is in part intertwined for cellular, molecular, and organismal biology, but also a sophisticated treatment of ecology. The first mention of evolution is in grade 8, but it is a good start. High school biology includes a major section, well done, on evolutionary biology. The only lack is some introduction of human evolution.

Chemistry standards are rather thin, but what exists is clear and reasonable. In grade 4 students learn that weight can be measured on a spring scale and mass on a balance. In grade 6 they really do learn that volume of solids can be determined by water displacement, that chromatography can be used to separate mixtures, and what density is. Grade 7 students classify acid, base, and neutral solutions using the pH scale. Overall, though, too much chemistry content is missing, and there is no serious attention to the role of mathematics in science.

The process standards suffer from the usual illiteracies ("Identify that inventions ... have made work easier ..." in first grade) and some curiosities, such as "beehive" provided as an example of design in nature. Perhaps the writers meant "honeycomb." These are little things, but words matter. "Issue" and "problem" are used as synonyms, in the currently stylish fashion. But they are not synonyms, and interchanging them causes confusion in non-casual writing. Then there are the repetitious comforters to the effect that everyone can and does contribute to the advance of science and invention. Good intentions, and no great harm done here; but the work that standards are meant to do is not done by belaboring these sentiments. Maryland's documents are a good start, not yet the potential accomplishment. Grade, with recognition of serious effort and future hope: "B."

MASSACHUSETTS

	Points	Out of a Possible
A. Expectations, Purpose, Audience	10.8	12
B. Organization	9.0	9
C. Science Content and Approach	24.3	27
D. Quality	8.6	9
E. Seriousness	6.0	6
Inquiry	3	3
Evolution	3	3
Raw Score	64.7	69
Final Percentage Score	94	100
GRADE	A	

Reviewed: Massachusetts Science and Technology/Engineering Curriculum Framework (May 2001)
NB: Massachusetts is currently updating its high school assessment framework.

The standards are contained in a Science and Technology/Engineering Curriculum Framework. After a full but relatively platitude-free introduction, it organizes the expectations for science learning under categories Earth and Space Sciences; Life Sciences; Physical Sciences; and Technology/Engineering. Content is presented in grade clusters of PreK-2, 3-5, 6-8, and 9-10. Standards are also provided for course development beyond Grade 10. The scope is ambitious: this Framework calls for science to be taught every year, with full courses in high school and a separate technology offering in middle and high school.

The standards are well and clearly organized; writing and editing have been done with care. Hence the entire presentation—from generalized statements of standards to generous detail on what is actually to be done in the classroom or laboratory—is comprehensible. The audience for standards documents ranges from academic content experts to high school students and their parents. From the Massachusetts document, all members of this variegated audience can understand, with reasonable effort, exactly what is required and expected at each level.

The document is also comprehensive. Material on Science as Inquiry is integrated, throughout, with the disciplinary content, which is adequately specific; and so makes it an organic element of instruction and learning rather than an add-on. Mathematical problem solving is stressed in concert with investigation and experimentation. Finally, the need for students to communicate effectively about their work in science, orally and in writing, is made clear.

Like the few other state offerings that receive high praise from all our reviewers, this one is not entirely free of oblique or trivial "activities" and of small but annoying errors—errors that would be detected and corrected if a final editing were done by properly qualified scientists. Examples: "4.1 Differentiate between wave motion (simple harmonic nonlinear motion) and the motion of objects (nonharmonic)." This doesn't make sense. Wave motion is often produced by sources in simple harmonic motion; but it is not the same thing at all. And the last part of the sentence is mere words. "4.6 Recognize the effects of polarization, wave interaction, and the Doppler effect." These cannot be lumped together in any straightforward way. And, "4.8 Explain the relationship between the speed of a wave (e.g., sound) and the medium it travels through." There is no way a high-school student can do this properly, since it requires differential equations. For sound, there is a relation between speed and air temperature. But if only that is the issue, the statement should say so.

There are six Environmental Science standards. These relate to energy sources and are found, logically, under Earth Science in grades 9-10. The life science material, including evolutionary biology, starts early (K-2) and is sound. Especially impressive for instruction in biological diversity and evolution is the recently posted high school material, free as it is of common errors and glosses. For the Massachusetts standards, "A."

MICHIGAN

	Points	Out of a Possible
A. Expectations, Purpose, Audience	4.0	12
B. Organization	4.0	9
C. Science Content and Approach	12.4	27
D. Quality	4.0	9
E. Seriousness	4.5	6
Inquiry	1	3
Evolution	3	3
Raw Score	32.9	69
Final Percentage Score	48	100
GRADE	**D**	

Reviewed: Michigan Curriculum Framework Science Benchmarks (Summer 2000)
NB: Michigan is starting to revise its standards.

The Michigan science standards are organized under three strands: "Using scientific knowledge," "Constructing new scientific knowledge," and "Reflecting on scientific knowledge." "Using" here includes what, in principle, these standards documents are supposed to present: substantive content that science students are expected to learn in the course of schooling. The subdivision of knowledge by level is coarse: elementary, middle, and high school. Science content tables are presented as "using scientific knowledge in life science," "using scientific knowledge in physical science," and "using scientific knowledge in earth science."

In earth science, the standards themselves (statements of expectations) are general and thin, as in "Describe features of the earth's surface." There are sections called Geosphere, Hydrosphere, Atmosphere and Weather, and Solar System, Galaxy and Universe. But lists of "key concepts," which are primarily lists of single words, follow these. Were it the case that the constituent science implied by those words, e.g. "rivers," were taught thoroughly and at the appropriate levels, there would be more than adequate earth science content in the Michigan standards. But one can't tell from the documents.

The breadth of the thematic standards is supposed to be enriched by detail in the Key Concepts (KC) and Real-world Contexts (RWC) that follow each Standard. But the KC are long lists of words, synecdoches, presumably, for what students are supposed to learn. For example, an identical Standard (C) I.1 in both middle and high school asks the students to "Design and conduct scientific investigations." What follows is a laundry list: test, fair test, hypothesis, theory, evidence, observations, measurements, data, conclusion, forms for recording and reporting data, tables, graphs, journals. The KC do not really specify what the student is actually to know or do and the RWC add little.

In elementary chemistry, there is no stated opportunity to learn about atoms and molecules. IV 2.2 for middle school says, "Describe common chemical changes in terms of properties of reactants and products." The RWC lists "alkaline drain cleaners." So far in this document there has been no mention of acids, bases, neutralization, alkaline—let alone the reaction that turns fat into soap. IV 2.1 for high school says, "Explain chemical changes in terms of the breaking of bonds...." This is doubly careless. Chemical bonding has not been covered in any previous standard; and chemical reactions involve the making, as well as the breaking, of bonds.

Physics is given shortest shrift. The implication that there is no need for specific discussion of forms of energy is unacceptable. There is essentially nothing under "Motion of Objects" at the high-school level—the very level at which kinematics and Newtonian dynamics should be the central subject matter. Provided are mere lists of things or phenomena, with little or no discussion of their significance. On p. 33, the high-school student is encouraged to join the writers in confusion about the distinction between kinetic and potential energy and the distinction among different forms of energy such as electrical and heat energy.

Biology does better. The treatment of evolution, *inter alia*, is reasonably comprehensive. There is enough

In the form of supplementary material, this document has much more. All Standards are for grade clusters PreK-4, 5-8, and 9-12. Science Standards proper start with Inquiry, Experimentation, and Theory. There is some extravagant language, such as the requirement that learners in PreK-4 "Complete a pure mathematics investigation, or complete research." For grades 5-8, there is the immodest "Examine important contributions made to the advancement of science, technology, and mathematics, and respond to their impact on past, present, and future understanding." Translated into substantive knowledge or activities, such imperatives would be well beyond the competence even of the best students. Here, as in many other state science standards, process seems to be the most important product.

Vermont's best documentation is in the life sciences. Despite an organization plan that sometimes defies navigation, much of the expected content turns up somewhere. There is a sincere effort, moreover, to sequence it decently, juxtaposed with suitable material from the other science disciplines. Structure and function of cells is developed from an early start; physiology and heredity are introduced thoughtfully; there is enough embryology, something far from typical of science standards. Ecology is introduced but not confused, as elsewhere, with political and other externalities.

There are some mistakes. Example: "Cell differentiation is regulated through the expression of different genes within the embryo cells. During embryonic development of complex multicellular organisms, chemicals within the cells deactivate portions of the genetic code as influenced by the cell's environment and past history." No. Vastly more important in embryogenesis is that "chemicals" (morphogens) within embryonic cells activate different suites of genes.

Evolution starts in the beginning grades with the introduction of extinct species (woolly mammoths). It becomes serious in middle school and is given proper exposition in high school.

Physics starts well enough, and its content is well organized. Details in the lower grades are good; but a disappointed reviewer reports, "... it gets worse and worse with increasing grade level, revealing the fatal limitations of the physical knowledge of the writers." There are also infelicities, errors, and misstatements. S7-8:21: "b. If there is a change in the speed or direction of an object, an outside force needs to be applied and the forces acting on the object are unbalanced (Newton's First Law)." Very confusing; this interchanges cause and effect. S7-8:23: "Creating a diagram, model, or analogy for a material in a warmer and cooler state showing or describing the motion of the molecules." Could it possibly be that the writers were unfamiliar with the concept of "higher or lower temperature"?

Such errors, but omissions as well, multiply for chemistry despite a conscientious beginning in the earliest grades. A reviewer: "Grade 5-6 students are ... offered [no more than] the same tired examples of a chemical reaction: rusting and vinegar/baking soda. Page S32 gives 'electrophoresis' of water as an example of the formation of a new substance ... the word meant is electrolysis; and that produces two products, not one.... [T] hat minor topic, Chemical Equilibrium ... [has been] forgotten .... A discussion of bond energies is missing...."

In earth and space science, overarching, abstract themes often detract from interesting content and continuity. Earthquakes and volcanoes appear as fast and slow processes and as consequences of moving plates, but not as the fascinating phenomena they are in their own right. The word "mineral" shows up once in the section, but in a general way so that students learn nothing about individual minerals. Rocks are acknowledged to "change" but the processes involved are merely hinted at. "Change is something that happens to many things." There is no mention of metamorphism. The statement of the water cycle never quite says that evaporation and precipitation cause water (and heat energy) to move from one place to another.

The Vermont Standards are another sincere, large-scale effort with good features. But the effort is flawed by careless writing and editing, and, for some scientific disciplines, by inadequate knowledge of the science on the part of the writers. Grade: "C."

VIRGINIA

	Points	Out of a Possible
A. Expectations, Purpose, Audience	11.5	12
B. Organization	9.0	9
C. Science Content and Approach	24.5	27
D. Quality	9.0	9
E. Seriousness	6.0	6
Inquiry	3	3
Evolution	3	3
Raw Score	66.0	69
Final Percentage Score	96	100
GRADE	**A**	

Reviewed: Revised Science Standards of Learning Curriculum Framework and Science Standards for Learning (2003)

Virginia's is another enormous package. Unlike most, however, this one can be read with profit—even, in places, with pleasure—by a literate layperson. It was written to be read, and not just by state or school employees who *must* read it. There are two documents: "Science Standards of Learning," and a significant expansion, the "Standards of Learning Curriculum Framework." Standards are arranged in grade levels for K-6, then as life science and physical science for middle school (7-8), and finally by courses in high school.

A reviewer reported as follows: "Despite the great number of pages, I didn't see much verbiage and no silliness.... Elementary content grows through the strands Scientific Investigation, Reasoning and Logic; Force, Motion and Energy; Matter; Living Systems; Interrelationships in Earth/Space Systems; Earth Patterns, Cycles, and Change; and Resources. The introduction states that the standards are 'not intended to encompass the entire science curriculum' nor 'prescribe how the content should be taught.' I found this refreshing; and if the standards are the whole curriculum (at least in Earth/Space Science) it is enough. ..."

The "Framework" repeats the Standards and amplifies them under three heads: Understanding the Standard; Overview; and Essential Knowledge, Skills, and Processes. These explain each standard and provide examples of what is to be learned and done. Such an organization, executed conscientiously, does demand a great deal of paper. In this case, then, the bulk may be justified. The combination of broad standards and detailed explication in the Framework reveals a well-sequenced curriculum, starting before grade 1 and culminating with a certain sophistication in high school—even in chemistry, where so many states fall down.

In physics, errors and misstatements do turn up, albeit fewer than in other state standards whose writers have tried to offer something comprehensive on the subject. The errors are mostly minor. Thus, "... refraction of light through water and prisms...." Refraction does not occur "through" uniform transparent media but at their interfaces. This seems a common misconception in state standards. Or, "*Work* is the product of the force exerted on an object and the distance the object moves in the direction of the force." Wrong. Work is the product of the distance an object moves and *the component of the force along the direction of motion.* The object may not move at all in the "direction of the force." Curiously, several important quantitative relations are expressed algebraically in the physical science section but not in the physics section.

The life science treatment is sophisticated. It begins in kindergarten, but grade 1 already introduces material that is both serious and interesting to children: "Conduct simple experiments/investigations related to plant needs by changing one variable (food, air, water, light or place to grow) at a time. Students do not need to know the term variable." Interweaving of science content with science process continues through grade 6. In middle school, cell biology is balanced by ecology. Genetics begins, and so does the real study of evolution. The high school program opens with the history of discovery in biology! This, to keep things balanced, is matched in the program by biotechnology. Evolution has its appropriate place and is presented without the usual glosses and misunderstandings. The standards draw evidence from a variety of sources, including the fossil record, radiometric dating, genetics, biogeography, comparative morphology, and embryology.

Virginia, finally, manages to get matters of Inquiry and process right that most other states muddle. Virginia defines "theory" with the right words: "A theory is an explanation of a large body of information, experimental and inferential, and serves as an overarching framework ... subject to change as new evidence becomes available." Grade: "A."

WASHINGTON

	Points	Out of a Possible
A. Expectations, Purpose, Audience	6.8	12
B. Organization	7.0	9
C. Science Content and Approach	17.0	27
D. Quality	4.0	9
E. Seriousness	6.0	6
Inquiry	1	3
Evolution	3	3
Raw Score	44.8	69
Final Percentage Score	65	100
GRADE	C	

Reviewed: Washington Science Grade Level Expectations (2005)

Content Panel Report:

Chemistry

1

Introduction

The National Research Council's Committee on Programs for Advanced Study of Mathematics and Science in American High Schools (parent committee) formed a chemistry panel to compare and evaluate the Advanced Placement (AP), the International Baccalaureate (IB), and alternative programs for advanced study in chemistry with respect to their pedagogy, content, assessments, and outcomes (the charge to the panel is presented in Appendix A). The chemistry panel met twice (in June and July 2000) to address its charge from the parent committee. The panel was chaired by a member of the parent committee, who served as liaison to the committee and consolidated the panel's findings and recommendations into this report. Panel members also included high school chemistry teachers with AP, IB, and New York State Regents examination experience, along with experienced college and university chemistry professors noted for their work in chemical education (for biographical sketches, see Appendix B).

Neither independent researchers nor the AP or IB program has published systematic data about the programs. Thus few data on the ways in which AP and IB courses are actually implemented in U.S. high schools, the long-term consequences to students who take AP or IB courses, or the effects of an increasing number of students who arrive at college with multiple AP and IB credits to use toward advanced placement or to meet graduation requirements were available to the panel. Because important data about the programs have not yet been published by either the programs or independent researchers, the panel focused its analysis on what the programs say they do, using available program materials such as course guides, released examinations, teacher manuals, program goals, and mission statements.

The chemistry panel carefully reviewed a substantial volume of background materials related to the AP and IB programs; those materials are listed in Appendix C. The findings and recommendations reached by the panel and presented in this report were consensus opinions, arrived at by reading the background materials and holding extensive discussions. Panel members also contributed written materials that were incorporated into this final report.

The remainder of this report is divided into four chapters. Chapter 2 presents an overview of advanced study in chemistry for high school students. Chapters 3 through 5 respond to the questions under the panel's charge. Chapter 3 focuses on the students who enroll in the AP chemistry course and the IB program, what is taught and how well it is being taught, the grade levels at which these advanced courses are offered, and the background and prerequisites needed to take and succeed in the courses. Chapter 4 addresses those who teach AP and IB chemistry courses, including their academic preparation, credentials, and appropriateness for the task. Chapter 5 provides an analysis of the assessments and outcomes associated with the AP chemistry course, the IB chemistry program, and their affiliated examinations. Throughout these chapters, key findings appear in italic type. The report concludes in Chapter 6 with a summary and recommendations regarding the AP chemistry course and the IB program, including the panel's consideration of whether advanced study options in high school should be associated with opportunities for students to earn college or university credit.

2

Overview of Advanced Study Programs in Chemistry in U.S. High Schools

CHARACTERISTICS OF AP CHEMISTRY

In addition to recommending that at least 290 minutes per week be allotted to Advanced Placement (AP) chemistry courses, the College Board characterizes the AP chemistry course as follows:

> The AP chemistry course is designed to be the equivalent of the general chemistry course usually taken during the first college year. For some students, this course enables them to undertake, as freshmen, second-year work in the chemistry sequence at their institution or to register in courses in other fields where general chemistry is a prerequisite. For other students, the AP chemistry course fulfills the laboratory science requirement and frees time for other courses.
>
> AP chemistry should meet the objectives of a good general chemistry course. Students in such a course should attain a depth of understanding of fundamentals and a reasonable competence in dealing with chemical problems. The course should contribute to the development of the students' abilities to think clearly and to express their ideas, orally and in writing, with clarity and logic. The college course in general chemistry differs qualitatively from the usual first secondary school course in chemistry with respect to the kind of textbook used, the topics covered, the emphasis on chemical calculations and the mathematical formulation of principles, and the kind of laboratory work done by the students. Quantitative differences appear in the number of topics treated, the time spent on the course by students, and the nature and variety of experiments done in the laboratory. *Secondary schools that wish to offer an AP chemistry course must be prepared to provide a laboratory experience equivalent to that of a typical college course* (College Entrance Examination Board [CEEB], 1999a, p. 1).[1] (Note: Italics added for emphasis by the College Board.)

[1]These publications are commonly referred to as *Acorn Books* because of the distinctive logo on their covers.

Thus by design, AP chemistry courses (and all other AP courses) are modeled after typical college-level introductory courses in the discipline. As a result, these high school courses are supposed to follow trends in college-level introductory general chemistry (not introductory chemistry, which typically denotes remedial or nonscience major chemistry courses).

The College Board goes on to say that:

> *The AP chemistry course is designed to be taken only after the successful completion of a first course in high school chemistry.* A survey of students who took the 1986 AP Chemistry Examination indicates that the probability of achieving a grade of 3 or higher on the AP Chemistry Examination is significantly greater for students who successfully complete a first course in high school chemistry prior to undertaking the AP course. Thus it is strongly recommended that credit in a first-year high school chemistry course be a prerequisite for enrollment in an AP chemistry class. (CEEB, 1999a, p. 1)[2] (Note: Italics added for emphasis by the College Board.)

Whether schools offering AP courses follow this recommendation probably depends on local practice. In any case, the *chemistry panel unanimously agrees that, unless truly exceptional circumstances dictate, students should not take advanced chemistry as their first chemistry course in high school.*[3] Although the College Board also recommends against this practice, it does happen, and the panel believes it is detrimental to the student, who is academically short changed by such circumstances. It is in the first course that the requisite concepts are learned and the laboratory skills developed that are needed to legitimize advanced study in the second high school chemistry course.[4]

An appropriate background in mathematics is needed to succeed in AP chemistry, and the College Board addresses this matter as well: "*In addition, the recommended mathematics prerequisite for an AP chemistry class is the*

[2]The College Board (2001b) reports that in 2001 of the 55,000 students taking AP Chemistry, 3,000 were in the ninth or tenth grades, and 28,000 were in the eleventh grade. However, it is unclear from these data what percentage of students take AP Chemistry as their first course in the subject. Of the 28,000 students in the eleventh grade taking AP Chemistry, it is possible that many or most of them took introductory chemistry in the tenth grade. Additional research is needed to determine the actual proportion of students who take AP Chemistry as their first course in the subject.

[3]Exceptional circumstances that would enable some students to succeed in an advanced course in chemistry as their first exposure to the discipline could include students who have had unusual preparation in science and mathematics or who have proven that they can acquire the concepts taught in introductory chemistry on their own. The panel emphasizes that such exceptions would be made only in very rare cases.

[4]There are few data on the extent to which this practice occurs. The panel believes that gathering such data is important and calls on the College Board to gather and publish data describing the ways in which their courses are implemented in schools and the effects of those courses on student learning and achievement.

successful completion of a second-year algebra course" (CEEB, 1999a, p. 1). (Note: Italics added for emphasis by the College Board.)

The College Board also is explicit regarding the place of AP chemistry in the total science curriculum: "The advanced work in chemistry should not displace any other part of the student's science curriculum. It is highly desirable that a student have a course in secondary school physics and a four-year college preparatory program in mathematics" (CEEB, 1999a, p. 2).

Because of the structure of the AP program, the AP chemistry course can be a stand-alone course offered by a high school in the absence of any other AP course offerings at that high school or other high schools in the district. Moreover, students who enroll in and complete AP chemistry, or any other AP courses, are not required by the College Board to take the AP examination developed by the College Board and administered by the Educational Testing Service.[5]

Administered each May, the AP chemistry examination takes 3 hours and consists of 2 sections. The first section (90 minutes) consists of 75 multiple-choice questions and represents 45 percent of the final grade. The College Board uses some common multiple-choice questions from year to year as a consistency check on the performance of the students taking the exam. The second section of the examination (also 90 minutes) represents 55 percent of the final grade and consists of several short-answer and essay-style questions that purportedly provide for a more in-depth assessment of students' understanding of chemistry principles. The questions may require calculations, a short essay response, or the determination of reaction products. Section II contains both required questions to which all students must respond and opportunities for students to choose two of four additional questions that they think they are best prepared to answer.[6] The examinations are collected and sent to a central location, where they are graded by a national team of graders.[7] All of the examinations are graded during a 1-week period. The College Board has developed procedures to ensure uniformity in the scoring process.[8] The AP score (1–5) is determined by a complex formula that factors in how well others who took the test performed, how scores were distributed over the past 3 years, and how well college

[5]Although the College Board has no such requirement, some state and local school districts are now requiring students to take the examination. In these circumstances, the district or state sometimes pays for part or all of the costs to students of taking the exams.

[6]For example, in 2001 the AP Chemistry examination required that students answer questions 1, 4, 5, and 6 and allowed them to choose between questions 2 and 3 and between questions 7 and 8.

[7]Graders are drawn from a pool of experienced high school AP teachers and college faculty with expertise in the discipline. Individuals are nominated or apply to become graders.

[8]For example, more than one grader reads each paper, and large discrepancies between assigned scores are resolved by third and sometimes fourth readers.

students at the end of their introductory course performed on the AP examination.

CHARACTERISTICS OF THE IB PROGRAMME AND IB CHEMISTRY

Whereas the AP program is a collection of individual, unrelated courses, the International Baccalaureate (IB) Diploma Programme is a comprehensive 2-year curriculum consisting of six academic areas.[9] IB courses may be taken at either the Standard Level (SL) or Higher Level (HL).[10] Chemistry is included with Group 4, the Experimental Sciences. IB Diploma candidates must take one subject from each of the six subject areas, with at least three and not more than four being HL. The other courses taken are SL. Thus, a chemistry student can take either the HL or SL version of the IB chemistry course and related examination. IB students are permitted to take two science subjects simultaneously from Group 4.

Students can and do take individual IB courses without working toward an IB Diploma. These students are known as certificate candidates, as opposed to diploma candidates. Only diploma candidates are required to take one subject from each area, as well as to fulfill additional requirements. Approximately 65 percent of IB students work for and complete the requirements for a diploma.

IB Diploma candidates must also complete three other requirements: (1) the interdisciplinary Theory of Knowledge course; (2) an extended essay of approximately 4000 words; and (3) participation in the school's Creativity, Action, Service (CAS) program involving sports, artistic pursuits, and community service work. Unlike the AP program, the IB program seeks to provide interdisciplinary preparation for university work rather than attempting to meet particular university course requirements, although strong perfor-

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[9]Although AP courses are not traditionally offered as an integrated program, the panel notes that for several years the College Board has offered an International Diploma for Advanced Placement. This program is designed for students who plan to pursue undergraduate studies outside the United States or Canada. The total number of students seeking this diploma is relatively small. To earn the diploma students take four AP courses in three different subject areas and must receive an average grade of 3 or higher. In 2000, the College Board initiated a pilot test of a new AP Diploma that is similar to the IB Diploma in many respects. To qualify for this diploma, students must take one AP course from each of the following areas: languages and literatures, sciences, mathematics, history, and social sciences. They must also take one additional AP course in any area. In addition, students must earn an average grade of 3 on all exams taken. Additional information is available at http://www.collegeboard.org/ap/students/benefits/int_diploma.html [4/24/02].

[10]SL courses entail 150 hours of class time, while HL courses require 240 hours. HL courses are generally taught over 2 years.

mance in IB courses is used to grant advanced placement at colleges and universities (International Baccalaureate Organisation [IBO], 1999).

All Group 4 subjects include required practical (laboratory) work, which makes up a significant portion of the course.[11] Although this laboratory work focuses primarily on the assessment of laboratory skills, it also offers opportunities for students to perform experiments and experience first-hand the benefits and limitations of scientific methodology. Individual teachers plan the Practical Scheme of Work (PSOW) for students in their classes. Thus, the laboratory experiences of students in different IB classrooms will vary. The PSOW should represent the breadth and depth of the subject syllabus, but students are not required to conduct an investigation for each topic in the syllabus. To ensure quality and to foster improvements, teachers are required to submit copies of their PSOW annually to the IBO for moderation and feedback.

As noted above, the College Board recommends that at least 290 minutes per week be allotted for an AP chemistry class (174 total hours per year, assuming a 36-week academic year). Of this total, 54 hours is recommended for laboratory work. By comparison, IB recommends a total of 240 hours for HL and 150 hours for SL courses per academic year. Of this time, it is recommended that 60 hours for HL courses and 40 hours for SL courses be devoted to investigative activities that, along with the Group 4 project, comprise the internal assessment (IA) component of the course.

A common core curriculum applies to both HL and SL chemistry courses. The core material taken by SL students is a subset of the HL program. At the SL level, the core topics make up about 60 percent of the material, while at the HL level the core represents 75 percent of the covered topics. Both SL and HL students also study optional topics that their teacher selects from among a list of topics included in the course syllabus. SL students study three options of 20 hours each, while HL students study two options of 30 hours each chosen by the school. The only option available exclusively to SL students is higher physical organic chemistry (15 hours). Options available to both SL and HL students (15 and 22 hours, respectively) include medicines and drugs, human biochemistry, environmental chemistry, chemical industries, and fuels and energy. The options available to HL students only (22 hours) are modern analytical chemistry and further organic chemistry. Additional hours of internally assessed practical work are required for both SL and HL options.[12] Further, both SL and HL students must spend 10–15

[11]The IBO recommends that 25 percent of the course be devoted to practical (laboratory) work.

[12]SL options require an additional 5 hours of practical work that is internally assessed; options that are suitable for both SL and HL require an additional 5 hours for SL students and 8 hours for HL students; and options exclusively for HL students require 8 hours of internally assessed practical work.

hours on an interdisciplinary Group 4 project, which is a common element of all IB science programs and constitutes 10 hours of the internally assessed practical scheme of work.[13]

The IB chemistry examination is given annually and is taken at either the SL or HL, depending on the student's course of study. The SL exam consists of three papers. The first paper (0.75 hour) consists of 30 multiple-choice questions. The second paper (1 hour) contains short-answer questions and brief calculations in Part A and offers students a choice of answering one of two more extended questions in Part B. The remaining paper (1.25 hours) consists of one or two questions based on the course options completed by an individual student. The HL examination also comprises three papers with the same distribution as that of the SL examination but with topics examined in greater depth. The time allotted for the first HL paper is 1 hour, for the second 2.25 hours, and for the third 1.25 hours.

IB examinations are sent to examiners around the world who mark and return them to the IBO offices in Cardiff, Wales. During the grading process, examiners measure each student's performance against seven grade descriptors, given in the form of levels of performance that candidates can demonstrate on the examination. To ensure uniformity in the grading across examiners who are not centrally located, a representative sample of graded examinations from individual examiners is sent to the chief examiner for moderation. IB examination grades (1–7) are based on established criteria that represent an *absolute standard* of quality; thus, the interpretation of a student's performance is criterion referenced. A grade of 7 represents "excellent performance," while grades of 4 and 1 represent "satisfactory" and "very poor" performance, respectively. All IB group subjects, including chemistry, have a significant IA component involving laboratory work and a project, which constitutes 24 percent of a student's final grade. The IA component is internally assessed at the student's school by the teacher and is also externally moderated by the IBO. Final IB scores for each student are a combination of the results of the IA and the external scoring of the examination papers but are reported to the school as a single total.

QUALIFICATIONS FOR TEACHING ADVANCED HIGH SCHOOL COURSES IN CHEMISTRY

To provide a chemistry course consistent with the criteria noted above for an advanced study course in chemistry at the high school level, those

[13]The Group 4 project is an interdisciplinary activity that involves all of the IB science students at the school in identifying and investigating an issue, usually of local interest. The project requirements emphasize sharing concepts and theories from across the disciplines and the processes involved in scientific investigation, rather than producing products.

who teach such a course must be adequately prepared. *The chemistry panel takes this to mean a B.S. or B.A. degree in chemistry and preferably an M.A. or M.S. degree in chemistry.* The preparation of AP and IB chemistry teachers is discussed in detail in Chapter 4.

DEFINITION OF ADVANCED STUDY IN CHEMISTRY FOR HIGH SCHOOL STUDENTS

The chemistry panel agrees that the prerequisite first-year high school course in chemistry should provide students with an introduction to the atomic-scale view of matter, including its connection to macroscopic physical and chemical properties and to the language used to express these relationships, using the periodic table as an organizing entity. Moreover, as befits the nature of chemistry as an experimental science, the introductory (first-year) course should include experimentation and the use of scientific methodology.

Members of the panel also agree that *any* high school course in chemistry that is labeled as advanced study, whether or not it is structured according to an established curriculum and assessment such as AP or IB, should enable students to develop the ability to explore the chemistry concepts and laboratory practices introduced in the first-year course in greater depth and, where appropriate, to conduct some form of research. Under the guidance of a qualified advanced study instructor, desirable features of such advanced study would include some combination of the following characteristics:

- Application of basic ideas to more complex materials, systems, and phenomena
- Use of modern instrumentation, methods, and information resources
- Integration of concepts within and between subject areas, including extensions to other disciplines
- Use of appropriate mathematical and technological methods
- Extended use of inquiry-based experimentation
- Development of critical thinking skills and conceptual understanding
- Use of appropriate tools for assessing student performance and attitude that reflect current best practices
- Promotion of communication skills and teamwork

These characteristics are consistent with visions for undergraduate education articulated in the National Science Foundation's (NSF) *Shaping the Future* (1996) and the National Research Council's *Transforming Undergraduate Education in Science, Mathematics, Engineering, and Technology* (1999) reports. These two reports summarize what undergraduate science, mathematics, engineering, and technology courses, including introductory courses in chemistry, should encompass if they are to serve the dual objectives of enhancing scientific literacy and providing adequate preparation for a diverse, talented technical workforce.

Catalyzed by programs sponsored by NSF, the American Chemical Society, and other organizations concerned with improving undergraduate science education, some college and university chemistry courses are being revamped to achieve the objectives that those reports recommend (see, e.g., *ChemConnections*;[14] *Chemistry: Structure and Dynamics* [Bodner, Rickard, and Spencer, 1999]; Landis and Peace [1998]; *The Chemical World: Concepts and Applications*, 2nd edition [Moore, Stanitski, Wood, Kotz, and Joest, 1998]; and the *Discovery Chemistry* curriculum developed at the College of the Holy Cross[15]). However, many faculty who oversee undergraduate programs in chemistry have not yet confronted and addressed these issues.

FINDINGS AND CONCLUSIONS

Although exceptions exist among schools and teachers, *the chemistry panel finds that in general the material taught in advanced courses (as specified in the guidebooks provided by the College Board and the IBO) fail to meet many of the criteria outlined in the previous section.* In addition, the panel finds the AP and IB final examinations to be formulaic and predictable from year to year in their approaches and question formats. Thus, with sufficient practice in taking such examinations and enough drill on the major concepts that the examinations are likely to test, students can score well primarily by rote, without actually understanding the major concepts associated with the topics being tested.

The panel also agrees that laboratory work should be a significant component of an advanced chemistry course, and assessment of laboratory skills should be a major part of the final examinations. However, the examinations reviewed for this study led the panel to conclude that the AP and IB final examinations do not adequately test understanding of laboratory techniques or the interpretation of laboratory data. In fact, it was only recently that the College Board added a question to the AP assessment that purportedly tests laboratory-based knowledge and skills. The panel notes that the final IB examination does emphasize laboratory-based knowledge and skills through assessments other than the final examination. For example, the IBO recommends that 25 percent of the time in the course be spent on investigations and projects and that 24 percent of the final grade be awarded for this component. Additionally, all IB science examinations contain a required data analysis question on the second paper.

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[14]http://mc2.cchem.berkeley.edu/ [4/23/02].

[15]http://www.holycross.edu/departments/chemistry/discovery/ [4/23/02].

3

Quality and Content of the Learning Experience for Students

MOTIVATION FOR TAKING ADVANCED COURSES IN HIGH SCHOOL

The motivation to take an Advanced Placement (AP) or International Baccalaureate (IB) chemistry course comes from a wide range of external as well as internal sources. Some students simply enjoy science, and such courses offer the opportunity to learn about chemistry in greater depth than is offered by a first-year course. Other students may want to take the most rigorous program of studies offered by their high school (with less regard for the specific courses taken); others may want to develop an academic profile that is sufficiently competitive to gain admission to highly selective colleges. Still others may enroll more from parental or peer pressure than from a real desire to undertake a second course in chemistry. Students and parents increasingly may see the completion of these courses as a way to enhance a student's transcript when applying for college admission (College Entrance Examination Board [CEEB], 1994). Parents may also believe that students in AP and IB courses have access to better teachers and more resources and that the atmosphere will be more academically focused than in other courses.

Completing an AP chemistry course and passing the examination at the minimum level designated by individual colleges and universities may make a student eligible to earn college course credit, to place out of first-semester or first-year college chemistry, or to receive credit for completion of a general education or distribution requirement in science. Depending on the options available at the receiving institution and which option is selected, a student may be able to reduce the amount of matriculation time required for a degree, thereby saving tuition and other fees. Likewise, although the IB program was not designed to offer students opportunities for college credit, increasing numbers of colleges and universities are now offering such credit to IB students who have earned specified scores.[16]

IMPACT OF ADVANCED CHEMISTRY COURSES ON THE CURRICULUM

The availability of a selection of AP courses, including AP chemistry, provides opportunities for students to extend their knowledge and academic skills beyond those required by first-tier courses. Despite these advantages, however, the existence of AP courses can also create curricular difficulties. The AP program of courses can have two negative effects on the overall high school science curriculum.[17] The first of these is compression of that curriculum. Although there is variation among schools, the first-year chemistry course has generally been offered during the junior year. However, schools offering a range of AP science courses have helped foster a national shift toward offering biology to ninth-grade students and chemistry to tenth-grade students so the final 2 years of high school can be used for advanced work, including AP chemistry. Alternatively, this shift allows for making physics available in the eleventh grade, thereby offering opportunities to focus on advanced work in the twelfth grade. The panel believes that such a shift does not coincide well with the academic preparation and intellectual skills of high school freshmen and sophomores and therefore believes that the science concepts being taught may be too abstract for the age of many students at that level.

Curriculum compression may also prevent students from being able or electing to take the full range of first-year courses in science (biology, chemistry, and physics) during their high school years. Such students may substitute AP biology or AP chemistry for first-year physics, thereby leaving them with significant lacunae in their quantitative understanding of physical science concepts. This practice is contrary to the College Board's recommendation (CEEB, 1999a, p. 2). Moreover, those who take first-year chemistry as sophomores but elect not to take AP chemistry in their junior or senior year have a 2-year hiatus between their study of high school chemistry and the time at which they enter college and major in a discipline requiring them to take general chemistry. This time lag, extended in chemistry by 1 year be-

[16]If a particular college requests help, the International Baccalaueate Organisation (IBO) will work with the institution to develop appropriate policies related to credit and placement decisions that are based on IB examination scores (see, http://www.ibo.org [4/24/02]).

[17]The issues associated with compression of curriculum are discussed in detail in Chapter 10 of the parent committee's report. The present discussion serves only to raise the issue as it may pertain to chemistry.

cause of curriculum compression, can cause difficulty for some students in making the transition from high school to college chemistry.

Advanced mathematics is the gateway to advanced science, particularly advanced chemistry and physics. The College Board recommends that students taking AP chemistry previously have completed 2 years of algebra and 1 year of geometry in addition to having taken the first-year chemistry course. To take AP chemistry as a junior, a student must complete these mathematics prerequisites by the end of the sophomore year. Thus, these mathematics requirements also compress the mathematics curriculum. The result is that Algebra I must be completed in eighth grade. Given the small percentage of minority and rural youth who either have access to or enroll in Algebra I in grade 8, the need to have completed these courses by the end of grade 10 in effect sets up a de facto homogenous grouping of students that continues throughout the 4 years of high school. Such tracking has serious implications with regard to which students are able to take advantage of advanced courses in chemistry and other sciences and thereby raises issues of access and equity with regard to the benefits of college admission, credit, and placement that currently accrue to students who have such opportunities for advanced study (see Chapters 2 and 10 in the parent committee's report for more discussion of these issues).

COURSE CONTENT

The IB curriculum, in some sense, flanks the AP course, with expectations that are either higher or lower than those for AP chemistry. The IB Standard Level (SL) course is at a lower level than AP with respect to the content coverage; the IB Higher Level (HL) course is at a somewhat higher level than AP in terms of the topics discussed, especially in light of the HL options. The AP curriculum deals in greater depth than IB with concepts related to kinetic molecular theory, chemical kinetics, and equilibrium. In contrast, the IB curriculum at least introduces concepts from organic chemistry, an area generally not included in the AP course. The IB courses also provide students with some opportunities to develop conceptualizations of the material presented; most such opportunities are lacking in AP courses. In IB courses, chemical concepts are often taught within a context, and examination questions are designed to assess several aspects of a concept, not merely one or two. To cite one example, enthalpy changes in solution are linked to thermal changes, as well as experimental design and sources of error. Bond dissociation energies are associated with environmental changes such as stratospheric ozone depletion. In these aspects, the IB course is broader in content and outlook than its AP counterpart. A comparison of the differences between the two approaches is summarized in Table 3-1.

TABLE 3-1 Comparison of AP and IB Chemistry Courses

AP	IB
1 level	2 levels: SL or HL
1 year	1 or 2 years for SL; 2 years for HL
Less conceptualization of topics	Deeper conceptualization of topics
Molecular-level interpretation of KMT (kinetic molecular theory)	More descriptive (macroscale) approach to KMT
More quantitative treatment of kinetics and equilibrium	Less quantitative treatment of kinetics and equilibrium, but better conceptualization of the topics
No organic chemistry, biochemistry, or environmental chemistry	Organic chemistry, biochemistry, and environmental chemistry concepts covered in SL and HL
Consideration of phase diagrams, colligative properties, and Nernst equation	No consideration of phase diagrams, colligative properties, and Nernst equation
Minimum of 90 minutes per week recommended (not required), preferably in one session, to be spent engaged in laboratory work	Laboratory work required, making up 25% of teaching time; required Group 4 project (student-designed research investigation) makes up 10 hours of work. (The project's intention is that students analyze a topic or problem that can be investigated in each of the science disciplines offered by a school. The topic can be set in a local, national, or international context.)

SOURCE: Adapted from CEEB (2001a) and IBO (2001).

MATERIALS USED

A list of suggested textbooks is given in the *Advanced Placement Program Course Description: Chemistry* (CEEB, 1999a, 2001a). These suggested textbooks are among those most frequently used in introductory college chemistry courses. In many cases, especially in classes taught by inexperienced teachers, the textbook forms the basis of the AP chemistry course. In an effort to finish the book, many of these teachers may try to cover all of the text before the May examination date. The broad scope of these textbooks contributes to an emphasis on breadth of coverage at the expense of depth of understanding.

Because of the unique structure of the IB chemistry courses, the IBO maintains that there are no suitable textbooks that can serve as the basis for its courses. Instead, the IBO publishes and disseminates a document, *Chemistry Bibliography*, which lists general resources. It is divided into Pre-IB, Core/General, Core and Higher Level, Organic, and General/Organic textbooks. It lists resources for each option and suggests sources for practical work (laboratories), comprehension exercises/review material, post-IB, and demonstrations, as well as periodicals and a list of data/useful sources of information (including Web sites). Teachers are encouraged to select the materials that best align with the common core and optional topics that they teach in their classrooms.

LABORATORY WORK

The average length of a high school class per day (42–58 minutes) poses a challenge with regard to the amount of material that can be presented and actually learned in advanced chemistry courses. Increasingly, schools have adopted block-scheduling options, allowing up to 90 minutes for class and laboratory sessions. Even with this additional time allotted to laboratory work, however, time can be a true barrier to meaningful laboratory activities, especially those that are investigative in nature rather than applying a confirmatory or validation approach to preexisting knowledge. Investigative laboratories can occupy large amounts of time, and the amount of time recommended by the College Board for more traditional laboratories may not be sufficient for these new paradigms and approaches. In addition, college and university chemistry courses typically have affiliated weekly 3- or 4-hour laboratory periods during which students can perform actual investigative experimentation that includes multiple trials, replications, and the examination and evaluation of varying methodologies. This raises questions about the alignment of students' AP laboratory experiences with those available to college students. The panel notes that increasing numbers of high schools are working to find innovative ways of extending opportunities for laboratory work, which the panel commends.[18] The panel applauds the College Board's clearly expressed guidelines that AP chemistry courses need to have a weekly extended laboratory period.[19] The College Board explicitly states that "***it is not possible to complete high-quality AP laboratory work within standard 45-to-50 minute periods***" (CEEB, 1999a, p. 35) (emphasis in original). The College Board recommends that a minimum of 90 minutes weekly be spent in laboratory instruction, preferably in one session. It would

[18]One reviewer of this report pointed out that a serious curricular problem is the increasing tendency for high schools to condense the AP course into one semester through the use of block scheduling. The panel contends that, to benefit most from the AP chemistry experience, students should take the course throughout an entire academic year. The panel views as counterproductive any attempt to complete the AP chemistry course in one semester. The panel contends that the material in a college-level chemistry course contains too many concepts to be mastered in this truncated period of time. A one-semester course also does not allow the practice time needed to fully grasp what are for most high school students sophisticated chemical and affiliated mathematical concepts.

[19]The College Board recommends but does not require that students participate in particular types of laboratory experiences.

be desirable to know what percentage of AP chemistry courses follow this recommendation.

High school chemistry laboratory experiences are of mixed quality as a result of variations in resources, time available for faculty to set up and maintain laboratory experiments, and the academic background of faculty who teach these courses. When done at all, laboratory work can tend more toward verification than problem-solving investigations. The chemistry panel believes it would be desirable to avoid the former exercises and instead emphasize inquiry-based experiments. Moreover, teachers and administrators would likely pay more attention and commit more time and resources to enhancing laboratory experiences if the culminating AP examination stressed and tested for the knowledge, skills, and techniques that are gained primarily, if not exclusively, through laboratory experiences.

The IB examination has more laboratory-based questions than its AP counterpart, but still relatively few. Unlike the AP program, however, IB includes a student's laboratory grade as a component of the final course grade. It should be noted that the IB program also requires students to prepare portfolios in which they demonstrate their ability to plan, design, and analyze scientific experiments. While these components of the portfolio may draw on experiences in addition to those from the laboratory, they contribute to the student's development of skills and understanding of scientific procedures provided by laboratory experiences. Finally, the IB program requires teachers to submit a detailed description of the Practical Scheme of Work (PSOW) completed by all students, as well as examples of work from each individual student. Guidelines for assessing laboratory work are detailed extensively in the IB Diploma Programme Guides.

The chemistry panel notes that in 1999 the AP examination introduced a required laboratory-based question in the free-response section (CEEB, 1999b). Should this question continue to be structured so as to assess students' understanding of laboratory techniques and data acquisition, this will be a positive step. The panel believes, however, that *all* of the subparts of the laboratory-based question should be directed to laboratory techniques, experimental design, and data acquisition and interpretation, rather than to theoretical constructs. Because the AP examination contains only one question about laboratory work, including experimental techniques, an AP student could score well enough on the other parts of the examination to earn college credit without ever having undertaken any of the suggested laboratory work.

The chemistry panel heard anecdotal accounts of AP chemistry teachers who omit or defer laboratory activities to review previous AP examinations. In such circumstances, laboratory work, if done at all, is crammed into the course after students have taken the AP examination. This deplorable practice appears to result from teachers recognizing and taking advantage of the lack of laboratory questions on the examination. Such practices disregard the validity of laboratory work as a means of introducing, reinforcing, consolidating, and amplifying chemistry principles. The fact that a number of colleges and universities require proof of sufficient chemistry laboratory work before granting credit or placement out of the general chemistry course indicates that laboratory work is a weak link in the AP course because of the variability in the way the laboratory component is administered.

In contrast, the IBO requires that teachers assess student work, with samples being sent to the IBO for moderation. The IBO allows only 2–3 hours of work to be carried out after the deadline, which prevents teachers from leaving laboratory work until the end of the course. Further, the IBO provides detailed guidelines and rubrics for assessing practical work (IBO, 2001, pp. 15–32).

CURRICULUM AND METHODS OF INSTRUCTION

Given the broad scope of the AP and IB chemistry curricula, it can logically be inferred that large components of AP and IB chemistry courses may be taught by the traditional method of "filling the open vessel"—lecture, note taking, and assessment by recall. These practices are in stark contrast with the constructivist model of learning recommended by the *National Science Education Standards* (*NSES*) (National Research Council [NRC], 1996) and other recent reports (NRC, 2000b). Those studies clearly demonstrate that students learn more deeply when they develop an understanding of the material while undertaking inquiry-based, problem-centered activities. Based on the materials examined, the chemistry panel agrees that neither AP nor IB appears to emphasize such approaches to learning. Rather, the breadth of topics included in AP and IB course outlines and syllabi indicates that far too much emphasis is being placed on covering a large body of information deemed necessary for success on the examination.[20]

The kinds and levels of questions that appear on both the AP and IB examinations reinforce the emphasis on broad but shallow coverage of topics. Thus, an overarching, largely unintended, but nevertheless real and perverse effect is that the exam-driven nature of both programs may cause the development of intellectual curiosity in students to fall victim to the pace of the courses—all in the name of "rigor."

The chemistry panel also is concerned that the current system of basing the AP chemistry course on typical or average general chemistry courses

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[20]The panel notes that the IB's internal assessment component is not taught in a traditional manner and is consistent with the recommendations and emphases for teaching and learning in the *NSES*.

(using information gathered through surveys of chemistry departments at colleges and universities that receive the greatest number of AP candidates [see, e.g., CEEB, 1999a]) precludes incorporating emerging best practices that are beginning to appear in some college-level chemistry courses. Further, because AP courses are based on average college general chemistry courses, these changes will not be reflected in AP courses until changes in college-level chemistry become widespread.

A far better model would be to base AP chemistry courses on best practices in the teaching of college chemistry, even if the resulting course were less similar to typical college courses than is now the case. The panel notes that neither the AP nor IB chemistry course as yet accurately reflects recent efforts to restructure and change teaching and learning in general chemistry at the college/university level. Among such changes are emphases on "less is more" in terms of course coverage, a wider variety of assessment techniques, small-group and inquiry-based learning, and inquiry-based laboratories (NRC, 1999). *The AP and IB chemistry courses also do not yet recognize the increasingly interdisciplinary nature of modern chemistry; its incorporation of highly important related fields, such as materials science and biochemistry; and the opportunities presented by such fields to teach related chemical concepts in a contextual manner.* It is important to note that the College Board established the Commission on the Future of the Advanced Placement Program (CFAPP) to make recommendations regarding the future of the AP program. The commission recommends in its recent report, *Access to Excellence: A Report of the Commission on the Future of the Advanced Placement Program* (CFAPP, 2001), that leaders in the subject disciplines, pedagogy, and research be engaged to ensure that current reforms and best practices are reflected in AP examinations.

QUALITY CONTROL

To be successful, an AP chemistry course should be initiated only after a school's administrators and faculty have carefully considered the valid reasons for offering such a course. Such consideration should be followed by a thorough analysis of the resources—personnel, facilities, and supplies—available at the school to support the course. While these considerations would appear obvious, high schools are not bound by them (CEEB, 1999a). A school can offer an AP chemistry course by administrative fiat, even when the personnel, facilities, and supplies available for the purpose are not up to the expectations of the College Board, as noted in the Acorn Book for chemistry. It is not unreasonable to expect the College Board to exercise some control over where AP chemistry courses are offered and who teaches them. It is therefore encouraging to note that *Access to Excellence*, completed after the chemistry panel had conducted its deliberations, contains the recommendation to develop and implement standards for AP programs in schools and school systems, for AP teachers, and for professional development workshops and institutes for AP teachers. *Access to Excellence* also recommends that the College Board take a more proactive approach to leading educational reform by changing the emphasis of the AP program from one of replicating typical college courses to one of emulating best practices in the discipline. The report further recommends that leaders in the subject disciplines, pedagogy, and research be engaged to ensure that current reforms are reflected in AP examinations. The chemistry panel endorses these recommendations fully and is pleased to learn that the College Board is willing to serve as a forum and vehicle for stimulating educational reform.

The College Board's expectations for teacher qualifications are explicit: "if the objectives of a college-level general chemistry course are to be achieved, the teaching should be done by a teacher who has completed an undergraduate major program in chemistry including at least a year's work in physical chemistry" (CEEB, 1999a, p. 3). However, the College Board does not have a means of verifying that AP chemistry teachers have these minimum qualifications or certifying them as competent to teach AP-level courses and associated laboratory activities. This lack of oversight and control is in addition to the College Board's lack of a mechanism for determining whether a school has adequate facilities and supplies before allowing it to offer an AP chemistry course. Nor does a mechanism exist for making such a determination once an AP chemistry course is being taught or for preventing a school from continuing to offer the course if the school is found lacking until the shortcomings are addressed. The CFAPP (2001) does not recommend certification of schools or teachers, but recommends instead that the College Board develop and disseminate AP quality standards for teachers, schools, and school systems. The commission also recommends that the College Board undertake a rigorous and systematic program of research to validate that (1) AP examinations actually test what is covered in the corresponding college courses and (2) students who earn specific scores on AP examinations have indeed mastered subject matter at a level equivalent to that of students who take these courses in college.

In contrast, before a school is authorized to offer an IB chemistry course, the school must be authorized to offer the complete IB Diploma Programme. One factor in this authorization process is an evaluation of the qualifications of the people who will teach the individual IB courses. In the sciences, a school that is seeking authorization also must demonstrate a plan for an acceptable set of laboratory activities relative to its resources. Sample laboratory reports must be sent periodically to IBO headquarters for critical review (IBO, 1999). It should be noted, however, that IB program administrators provide minimal oversight to ensure that the program standards are maintained over time. However, assistant examiners who encounter schools experiencing difficulties with the program try to inform the IBO of these situations. Further, in the sciences, ongoing evaluation of a school's program continues through the IBO's moderation of sample laboratory reports and teachers' PSOWs that are submitted annually. Feedback is provided to the schools and teachers to promote improvements.

Students cannot take the IB examination without having taken the course. In contrast, students can register to take the AP chemistry exam without ever having taken an AP course, although this is not typically the case. The obverse is also true: students who take an AP chemistry course are not required by the College Board to take the examination. The College Board tracks only those students who take the examination. Although it does not have precise data about the number of students enrolled in AP courses, the College Board estimates that approximately 63 percent of students who are taking a course designated as AP sit for the AP examination in that subject. This, however, is the estimate for AP courses *in toto*. Currently, data are not available from the College Board for individual subject areas, such as chemistry. Consequently, the percentage of those students taking an AP chemistry course who do not take the AP exam is not known.[21] Accordingly, the panel believes that statements by the College Board about the quality of AP chemistry courses are suspect because they fail to account for the many AP courses nationwide in which large numbers of students may not take the examination. In addition, the AP examination results are not available until after the end of the academic year. Thus the final grade received in an AP chemistry course is not specifically linked with the student's performance on the AP examination. Furthermore, since AP examination scores are not available until students have completed the course, there can be no grade-related consequence in the course from not taking the AP examination or, if taken, from doing poorly.

The panel also notes that commercial vendors, some of them linked with a university (e.g., the Michigan State University program), now offer AP courses on the Internet to individual students. This new development allows students who pay the necessary fees to take an AP course independently of whether their school offers an AP course in the same subject. Internet-based courses are self-pacing. The pace and calendar are established by the examination date, should the student choose to take the examination. In courses with a laboratory component, such as chemistry, arrangements for laboratory work may be irregular. In some situations, the laboratory work is done at a nearby campus or high school during weekends or other periods when several laboratory experiments are conducted in an intense burst of work. In these circumstances, the timing of laboratory activities may not correlate

[21] The College Board recently began to gather such data from school AP coordinators.

well with the chemical principles being studied at that point. Simulations of laboratory experiments are also used, although current simulations offer no opportunity for students to gain facility and dexterity in the proper manipulation and use of laboratory equipment.

COURSE CONTENT AND EXAMINATIONS

The 75 multiple-choice questions on the AP chemistry examination (Section I) match closely the objectives stated in the Acorn Book for an AP chemistry course. Despite the rather long list of chemical topics and concepts to be included in the AP curriculum, Section II of the examination asks questions evaluating a more limited set of topics. In addition, the panel finds that the topics tested in both parts of the examination are rather predictable from year to year and formulaic in the way in which the concepts are queried,[22] especially in Section II. Certain topics and the style of questions addressing them change little from year to year. One example is the standard question in Section II, Part B of the AP examination that is related to reactions and writing of their affiliated chemical equations. (Although this question could perhaps be described as a laboratory-based question, the panel believes that students can answer the question correctly by sheer rote memory without ever having done any of the laboratory work.) Given this type of predictability in the examination's coverage from year to year, together with teachers who are very familiar with the general content and structure of the test, students may be able to earn high scores on the examination without actually having mastered all the material. This is especially true when students are given a choice of which questions to answer in Section II.

Some of the IB questions are identical in content to the chemical systems described and covered in the syllabus, thus requiring only rote learning with little mastery or understanding. In fact, there is an injunction from the IBO to IB instructors against using chemical systems other than those on the examination when teaching a given topic.

AP examinations ask less than IB exams about the application of concepts, especially with respect to new contexts or chemical systems. There is heavy emphasis on algorithmic solutions, rather than the extension or application of concepts to new, unfamiliar but equivalent situations. Few of the questions test students' abilities to predict or explain observations. For example, students could successfully write and balance sets of chemical equations with little understanding of the principles of chemical reactivity involved and no knowledge of the associated phenomena. The tests assess

[22]In large part, this level of predictability is based on the Educational Testing Service's emphasis on and close monitoring of exams to maximize their reliability from year to year.

primarily the acquisition of information, as opposed to analyzing students' understanding, application, and extension of concepts. The examinations thus do little to encourage inquiry-based learning.

The chemistry panel drafted samples that demonstrate how questions taken from the 1999 AP chemistry examination could be modified to accomplish several objectives: requiring critical thinking, combining qualitative and quantitative aspects of a chemical system within a given question, and applying concepts to chemical systems and situations not previously encountered. The suggested modified questions are presented in Appendix D. By using the approaches illustrated by these types of questions, the AP and IB programs would encourage teachers to teach in less algorithmic ways and students to learn in a different, more inquiry-based manner as recommended by the *NSES*.

The AP examinations have yet to address the shift in increasing numbers of introductory college/university chemistry courses toward including applications in biochemistry, materials science, or environmental chemistry. The IB program and examinations include some applications in biochemistry and environmental chemistry but still lack attention to materials science.

6

Summary and Recommendations

The Advanced Placement (AP) and International Baccalaureate (IB) chemistry courses now being offered are taught effectively according to the expectations of the College Board and the International Baccalaureate Organisation (IBO) in some, but by no means all, schools. The content of the courses is bound inextricably to the nature and corpus of questions on the affiliated AP and IB examinations, which the chemistry panel finds to be flawed, as described in previous chapters. It should be noted that there is a growing tendency for IB chemistry classes in the United States to be offered as 1-year courses, in order to conform to U.S. high school timetables. This practice contrasts with that of other countries, where virtually all IB chemistry classes are taught over 2 years. Thus, in many IB chemistry courses offered in the United States, too much information may be crammed into the course for the time available. The following sections summarize the panel's findings and recommendations regarding the AP and IB chemistry courses and examinations and the qualifications and professional development of those who teach the courses.

FINDINGS AND RECOMMENDATIONS REGARDING THE AP AND IB COURSES AND EXAMINATIONS

1. The chemistry panelists agree that advanced study options in high school chemistry should not necessarily be tied to the potential for earning college/university credit. The chemistry panel views these as two separate issues:

(a) The panel members are unanimous in agreeing that advanced study of chemistry at the high school level should provide students with a coherent, rigorous course that promotes further scientific lit-

eracy and prepares students to become part of a highly technological workforce, regardless of whether they continue studying chemistry at the tertiary level.

(b) An advanced chemistry course that meets criterion (a) should be organized and delivered such that it would be equivalent to the two-course college/university general chemistry sequence and such that college credit could be sought based on passing the placement examination that is administered by college or university departments of chemistry. That is to say, advanced study in chemistry need not be based on AP or IB. Indeed, many of the nation's top high schools for mathematics and science offer advanced courses that are neither AP nor IB based. Other legitimate alternatives should be explored.

2. Institutions awarding AP examination–based course credit or advanced placement should consider doing so only for a grade of 4 or 5, not for a grade of 3. The College Board is currently conducting studies on the validity of a grade of 3 for the awarding of college credit, and the panel applauds this effort. However, until that study is complete, it remains unclear whether students who have earned a score of 3 have achieved sufficient understanding of the subject matter at a level comparable to college courses to merit credit and placement out of the introductory course.

3. The chemistry panel recommends that to be effective, advanced courses in chemistry must reflect recommendations in the areas of content, pedagogy, and assessment contained in the *National Science Education Standards* (National Research Council [NRC], 1996).

FINDINGS AND RECOMMENDATIONS REGARDING THOSE WHO TEACH AP AND IB CHEMISTRY COURSES

1. The chemistry panel recommends that to be a qualified AP or IB teacher the teacher must have a B.S. or B.A. degree in chemistry (which includes a two-semester physical chemistry course sequence with laboratories) and preferably an M.A. or M.S. degree in chemistry. The chemistry panel does not view a B.S. in science education as being adequate preparation for these teachers, nor does the College Board.

2. A qualified advanced study chemistry instructor should have experience with effective current and emerging approaches to chemistry teaching and assessment in the subject and their applications to the AP and IB chemistry courses.

3. The qualified AP or IB chemistry teacher should have a working familiarity with teaching technologies (e.g., Web, electronic media, laboratory instrumentation) and their appropriate uses.

4. There should be required periodic, funded professional development opportunities, including content instruction, research participation, and pedagogy workshops, for teachers of advanced courses in chemistry. This recommendation is consonant with the Glenn Commission's description of what constitutes professional development: "a planned, collaborative, educational process of continuous improvement for teachers that helps them to do five things: (1) deepen their knowledge of the subject(s) they are teaching; (2) sharpen their teaching skills in the classroom; (3) keep up with developments in their fields, and in education generally; (4) generate and contribute new knowledge to the profession; and (5) increase their ability to monitor students' work, so they can provide constructive feedback to students and appropriately redirect their own teaching" (National Commission on Mathematics and Science Teaching for the 21st Century, 2000, p. 18).

5. Professional development opportunities, such as the experience of teaching courses or laboratories at colleges or universities and undertaking original research in industry, at government laboratories, or in collaboration with college faculty, would be particularly valuable for AP and IB chemistry teachers. High-school system personnel policies should encourage rather than inhibit such professional development activities during the academic year.

6. AP and IB chemistry teachers can profit from discussions with each other. School districts and schools should find ways to initiate and sustain such conversations and to share them with a wider audience. Communication about areas of common interest between chemistry faculties in high schools and those teaching general chemistry in institutions of higher education would be extremely helpful for both communities (see also the recommendations under Vision 4 in *Transforming Undergraduate Education in Science, Mathematics, Engineering, and Technology* [NRC, 1999]).

7. AP and IB chemistry teachers should be participating members of professional organizations such as the National Science Teachers Association and the American Chemical Society's Division of Chemical Education. Through such participation, teachers gain a sense of belonging to a community of professionals who are similarly inclined to excel in their teaching. They gain access to colleagues and resources that would have been largely inaccessible without membership.

Appendix B

Biographical Sketches of Chemistry Content Panel Members

Conrad L. Stanitski (committee liaison and chair) is professor of chemistry and chair of the Chemistry Department at the University of Central Arkansas. His principal focus is inorganic chemistry and general chemistry for science and nonscience majors. He is currently chair of the American Chemical Society (ACS) Division of Chemical Education, was a member of the ACS Committee on Education, has directed numerous ACS teacher-training workshops, is a (National Science Foundation) NSF proposal reviewer, and has been an invited speaker and workshop leader in seven foreign countries. Dr. Stanitski has authored or coauthored several highly regarded textbooks in the field, including *Chemistry in Context: Applying Chemistry to Society; The Chemical World: Concepts and Applications; Chemical Principles; Chemistry in the Community*; and *Chemistry for Health-Related Sciences: Concepts and Applications.* He received his B.S. in science education from Bloomsburg State College, his M.A. in chemistry education from the University of Northern Iowa, and his Ph.D. in inorganic chemistry from the University of Connecticut.

Arthur B. Ellis is Meloche-Bascom Professor of Chemistry at the University of Wisconsin at Madison. In addition to receiving numerous teaching awards, including the NSF's Director's Award for Distinguished Teaching Scholars, Dr. Ellis is currently involved in the creation of innovative instructional materials that integrate materials science into the chemistry curriculum. His research on the electro-optical properties of semiconductor interfaces has led to the development of new classes of on-line chemical sensors. He is currently serving a 2-year appointment to the National Research Council's (NRC) Committee on Undergraduate Science Education. Dr. Ellis received his Ph.D. from the Massachusetts Institute of Technology in inorganic chemistry. In July 2002, he will join the NSF as director of the chemistry division.

Patricia A. Metz is an assistant professor of chemistry at the United States Naval Academy. She specializes in the teaching and learning of chemistry and conducts research on curriculum development, instructional design, conceptual understanding, and assessment. She is responsible for the development of original guided-inquiry biochemistry and general chemistry laboratory classes for both chemistry and nonchemistry majors. Dr. Metz has published several articles related to instructional methods and diagnostic techniques. She received her Ph.D. from Purdue University in chemistry education.

John C. Oliver is a science teacher and department chair at Lindbergh High School in Saint Louis, Missouri, where he has taught a range of biology and chemistry classes, including both AP and IB chemistry. His teaching efforts have been recognized by awards, such as the Woodrow Wilson National Fellowship and local and regional high school teaching awards from ACS. Mr. Oliver actively pursues a variety of enrichment coursework in such fields as physics, chemistry, laboratory techniques, and chemistry education and is a member of numerous professional organizations. He received his M.A.T. in science education from Webster College in Saint Louis and an A.B. in zoology from the University of Missouri at Columbia, with a minor in chemistry.

David Pysnik is a chemistry instructor at Sidney Central Schools in Sydney, New York. He teaches the New York Board of Regents Chemistry, which is similar in content to the AP program, but he does not teach AP chemistry. Mr. Pysnik focuses on teaching through a research-based approach and has worked as a research associate at Ithaca College for the last 20 summers. He has developed mobile laboratory programs and has won the Catalyst Award from the Chemical Manufacturers Association, the Tandy Technology Scholars Award, the ACS Northeast Regional Award in High School Chemistry Teaching, and the Presidential Award for Excellence in Science and Mathematics Teaching. Mr. Pysnik received his B.S. from Juniata College and his M.S. from Indiana University.

A. Truman Schwartz is DeWitt Wallace Professor of Chemistry at Macalester College, where he previously served as chair of the chemistry department and dean of faculty. His research interests include chemical education, the history of science, and the physical chemistry of macromolecules. Professor Schwartz has contributed to several national curriculum reform projects, including the first two editions of *Chemistry in Context: Applying Chemistry to Society* and *ChemConnections*. On temporary assignment, he served as deputy director of the Teacher Preparation and Enhancement Division of the NSF. He has been honored with numerous teaching awards at the college, state, and national levels. Professor Schwartz received a B.A. from the University of South Dakota, M.A. at Oxford University as a Rhodes Scholar and a Ph.D. in physical chemistry from the Massachusetts Institute of Technology.

Glenda M. Torrence is a science resource teacher at Montgomery Blair High School in Maryland, where she is actively involved with curriculum development for new and pre-existing courses, interdisciplinary cooperation with the mathematics and technology departments, and the implementation of assessment methodologies for the chemistry department. She has taught chemistry courses at the University of Maryland at College Park and was nominated for the Presidential Teaching Award. Dr. Torrence received her Ph.D. in physical chemistry from the State University of New York at Buffalo.

Appendix D

Suggested Modifications of Examination Questions

This appendix presents examples of the chemistry panel's suggested modifications to the questions on the Advanced Placement (AP) chemistry 1999 examination, Section II, to make the questions more contextual; to probe more carefully the depth of student understanding; to seek to assess higher-order thinking skills; to require the applications of chemistry principles in an enlarged or new context; and to enjoin students to link concepts to chemical systems and macroscale phenomena, not merely see chemistry principles as isolated facts. In particular cases below, the original question is given, followed by its suggested modification.

AP CHEMISTRY 1999, SECTION II, PART A, QUESTION 1

Original Question

$NH_3(aq) + H_2O(l) \leftrightarrow NH_4^+(aq) + OH^-(aq)$

In aqueous solution, ammonia reacts as represented above. In 0.0180 M $NH_3(aq)$ at 25°C, the hydroxide ion concentration $[OH^-]$ is 5.60×10^{-4} *M*. In answering the following, assume that temperature is constant at 25°C and that volumes are additive.

(a) Write the equilibrium-constant expression for the reaction represented above.

(b) Determine the pH of 0.0180 *M* $NH_3(aq)$.

(c) Determine the value of the base ionization constant, K_b, for $NH_3(aq)$.

(d) Determine the percent ionization of NH_3 in 0.0180 *M* $NH_3(aq)$.

(e) In an experiment, a 20.0 mL sample of 0.0180 *M* $NH_3(aq)$ was placed in a flask and titrated to the equivalence point and beyond using 0.0120 *M* $HCl(aq)$.

(i) Determine the volume of 0.0120 *M* HCl(*aq*) that was added to reach the equivalence point.

(ii) Determine the pH of the solution in the flask after a total of 15.0 mL of 0.0120 *M* HCl(*aq*) was added.

(iii) Determine the pH of the solution in the flask after a total of 40.0 mL of 0.0120 *M* HCl(*aq*) was added.

(SOURCE: CEEB, 1999b, p. 42)

Suggested Modification

The panel would suggest leaving much of question 1 alone, although it could stand to be condensed somewhat. As written, it tests the student's fundamental understanding of K_b, buffers, and titration stoichiometry. One or more of the following additional questions might be added:

Sketch a titration curve for part (c) using the information from (b), (c), and (d)

and/or

compare the base strength and give the rationale for strength based on the type of site and associated structure for one or two other more obscure bases, given their respective K_b's.

AP CHEMISTRY 1999, SECTION II, PART A, QUESTION 2

Original Question

Answer the following questions regarding light and its interactions with molecules, atoms, and ions.

(a) The longest wavelength of light with enough energy to break the Cl-Cl bond in $Cl_2(g)$ is 495 nm.

(i) Calculate the frequency, in s^{-1}, of the light.

(ii) Calculate the energy, in J, of a photon of the light.

(iii) Calculate the minimum energy, in kJ mol^{-1}, of the Cl-Cl bond.

(b) A certain line in the spectrum of atomic hydrogen is associated with the electronic transition in the H atom from the sixth energy level ($n = 6$) to the second energy level ($n = 2$).

(i) Indicate whether the H atom emits energy or whether it absorbs energy during the transition. Justify your answer.

(ii) Calculate the wavelength, in nm, of the radiation associated with the spectral line.

(iii) Account for the observation that the amount of energy associated with the same electronic transition ($n = 6$ to $n = 2$) in the He^+ ion is greater than that associated with the corresponding transition in the H atom.

(SOURCE: CEEB, 1999b, p. 43)
(NOTE: On the exam, students were asked to answer *either* this question *or* the next question concerning reaction rates, but not both.)

Suggested Modification

A question containing some of the information assessed in the original version of Question 2 but considerably extended might look like this. This question now relates to a chlorofluorocarbon compound known as CFC-12 or Freon-12.

The Lewis structure of the CFC-12 molecule is: [structure would be given]

(a) Give the correct chemical name for this compound.

(b) Describe the geometrical shape of the compound and estimate the Cl-C-Cl angle.

(c) Identify the type of hybridization exhibited by the central carbon atom.

(d) The energy of the C-Cl bond is 327 kJ/mol bonds; the energy of the C-F bond is 485 kJ/mol bonds. Explain this difference.

or alternatively

(e) The energy of the C-Cl bond is 327 kJ/mol bonds. Would you predict the energy of the C-F bond to be higher or lower? Explain your answer.

(f) Calculate the frequency, in s^{-1}, of the radiation required to break a C-Cl bond.

(g) Calculate the wavelength (in nm) of the radiation required to break a C-Cl bond.

(h) Radiation of this wavelength falls within which region of the spectrum?

(i) What is the practical significance of the fact that radiation breaks C-Cl bonds in CFCs?

PART 2—CHEMISTRY

NATURE OF THE SUBJECT

Chemistry is an experimental science that combines academic study with the acquisition of practical and investigational skills. It is called the central science as chemical principles underpin both the physical environment in which we live and all biological systems. Apart from being a subject worthy of study in its own right, chemistry is a prerequisite for many other courses in higher education, such as medicine, biological science and environmental science, and serves as useful preparation for employment.

The Diploma Programme chemistry course includes the essential principles of the subject but also, through selection of options, allows teachers some flexibility to tailor the course to meet the needs of their students. The course is available at both higher level and standard level, and therefore accommodates students who wish to study science in higher education and those who do not.

Teaching Approach

There are a variety of approaches to the teaching of chemistry. By its very nature chemistry lends itself to an experimental approach and it is expected that this will be reflected throughout the course.

The order in which the syllabus is arranged is **not** the order in which it should be taught and it is up to individual teachers to decide on an arrangement which suits their circumstances. Option material may be taught within the core or the additional higher level (AHL) material if desired.

SYLLABUS OVERVIEW

The syllabus for the Diploma Programme chemistry course is divided into three parts: the core, the additional higher level (AHL) material and the options. A syllabus overview is provided below.

Core [80h]

Topics

		Teaching hours
1	Stoichiometry	11
2	Atomic theory	4
3	Periodicity	6
4	Bonding	12
5	States of matter	5
6	Energetics	11
7	Kinetics	4
8	Equilibrium	5
9	Acids and bases	5
10	Oxidation and reduction	7
11	Organic chemistry	10

Additional Higher Level [55h]

Topics

		Teaching hours
12	Atomic theory	4
13	Periodicity	4
14	Bonding	6
15	Energetics	4
16	Kinetics	6
17	Equilibrium	4
18	Acids and bases	11
19	Oxidation and reduction	7
20	Organic chemistry	9

Options

Options Standard Level

		Teaching hours
A	Higher physical organic chemistry	15

Options Standard Level/Higher Level

B	Medicines and drugs	15/22
C	Human biochemistry	15/22
D	Environmental chemistry	15/22
E	Chemical industries	15/22
F	Fuels and energy	15/22

Options Higher Level

G	Modern analytical chemistry	22
H	Further organic chemistry	22

Standard level candidates are required to study any **two** options from A–F. The duration of each option is 15 hours.

Higher level candidates are required to study any **two** options from B–H. The duration of each option is 22 hours.

SYLLABUS OUTLINE

Core [80h]

			Teaching hours
Topic 1		**Stoichiometry**	**[11]**
	1.1	Mole concept and Avogadro's constant	2
	1.2	Formulas	3
	1.3	Chemical equations	1
	1.4	Mass and gaseous volume relationships in chemical reactions	3
	1.5	Solutions	2
Topic 2		**Atomic theory**	**[4]**
	2.1	The atom	2
	2.2	Electron arrangement	2
Topic 3		**Periodicity**	**[6]**
	3.1	The periodic table	1
	3.2	Physical properties	2
	3.3	Chemical properties	3
Topic 4		**Bonding**	**[12]**
	4.1	Ionic bond	2
	4.2	Covalent bond	6
	4.3	Intermolecular forces	1.5
	4.4	Metallic bond	0.5
	4.5	Physical properties	2
Topic 5		**States of matter**	**[5]**
	5.1	States of matter	5
Topic 6		**Energetics**	**[11]**
	6.1	Exothermic and endothermic reactions	2
	6.2	Calculation of enthalpy changes	3
	6.3	Hess's law	2
	6.4	Bond enthalpies	1
	6.5	Entropy	1
	6.6	Spontaneity	2
Topic 7		**Kinetics**	**[4]**
	7.1	Rates of reaction	2
	7.2	Collision theory	2

Core

Teaching hours

Topic 8 Equilibrium [5]

8.1	Dynamic equilibrium	1
8.2	The position of equilibrium	4

Topic 9 Acids and bases [5]

9.1	Properties of acids and bases	1
9.2	Strong and weak acids and bases	1
9.3	The pH scale	1
9.4	Buffer solutions	1
9.5	Acid–base titrations	1

Topic 10 Oxidation and reduction [7]

10.1	Oxidation and reduction	2
10.2	Reactivity	2.5
10.3	Electrolysis	2.5

Topic 11 Organic chemistry [10]

11.1	Homologous series	1
11.2	Hydrocarbons	2
11.3	Other functional groups	7

Additional Higher Level [55h]

Topic 12 Atomic theory [4]

12.1	The mass spectrometer	1
12.2	Electron configuration of atoms	3

Topic 13 Periodicity [4]

13.1	Periodic trends Na $\rightarrow$ Ar (the third period)	2
13.2	d-block elements (first row)	2

Topic 14 Bonding [6]

14.1	Shapes of molecules and ions	1
14.2	Hybridization	2
14.3	Delocalization of electrons	2
14.4	Structures of allotropes of carbon	1

Topic 15 Energetics [4]

15.1	Standard enthalpy changes of reaction	1
15.2	Lattice enthalpy	2
15.3	Spontaneity of a reaction	1

Additional Higher Level

		Teaching hours
Topic 16	**Kinetics**	**[6]**
16.1	Rate expression	3
16.2	Reaction mechanism	1
16.3	Activation energy	2
Topic 17	**Equilibrium**	**[4]**
17.1	Phase equilibrium	2
17.2	The equilibrium law	2
Topic 18	**Acids and bases**	**[11]**
18.1	Brønsted–Lowry acids and bases	2
18.2	Lewis theory	1
18.3	Calculations involving acids and bases	5
18.4	Salt hydrolysis	1
18.5	Acid–base titrations	1
18.6	Indicators	1
Topic 19	**Oxidation and reduction**	**[7]**
19.1	Redox equations	2
19.2	Standard electrode potentials	3
19.3	Electrolysis	2
Topic 20	**Organic chemistry**	**[9]**
20.1	Determination of structure	4
20.2	Hydrocarbons	2
20.3	Nucleophilic substitution reactions	2
20.4	Alcohols	1

Option Standard Level

Teaching hours

Option A Higher physical organic chemistry [15]

A.1	Determination of structure	5
A.2	Rate expression	3
A.3	Reaction mechanism	1
A.4	Nucleophilic substitution reactions	2
A.5	Acids, bases and buffers	4

Options Standard Level/Higher Level

Standard level students study the core of these options and higher level students study the whole option (ie the core and the extension material).

Option B Medicines and drugs

Teaching Hours

Core (SL + HL) [15]

B.1	Pharmaceutical products	2
B.2	Antacids	1
B.3	Analgesics	3
B.4	Depressants	3
B.5	Stimulants	2.5
B.6	Antibacterials	2
B.7	Antivirals	1.5

Extension (HL only) [7]

B.8	Stereochemistry in drug action and design	3
B.9	Anesthetics	2
B.10	Mind-altering drugs	2

Option C Human biochemistry

Core (SL + HL) [15]

C.1	Diet	2
C.2	Proteins	3
C.3	Carbohydrates	2.5
C.4	Fats	2.5
C.5	Vitamins	2.5
C.6	Hormones	2.5

Extension (HL only) [7]

C.7	Enzymes	3
C.8	Nucleic acids	2
C.9	Metal ions in biological systems	2

Option D Environmental chemistry

		Teaching Hours
Core (SL + HL)		**[15]**
D.1	Primary air pollution	3
D.2	Ozone depletion	2
D.3	Greenhouse effect and global warming	2
D.4	Acid rain	1.5
D.5	Water suitable for drinking	3
D.6	Dissolved oxygen in water	2
D.7	Waste water treatment	1.5
Extension (HL only)		**[7]**
D.8	Smog	2
D.9	Ozone depletion	2
D.10	Toxic substances in water	3

Option E Chemical industries

Core (SL + HL)		**[15]**
E.1	Initial overview	2
E.2	Principles of extraction and production of metals	2
E.3	Iron and aluminium	4
E.4	The oil industry	4
E.5	Polymers	3
Extension (HL only)		**[7]**
E.6	Silicon	1.5
E.7	Ellingham diagrams	1.5
E.8	Mechanisms in the organic chemicals industry	2
E.9	The chlor–alkali industry	2

Option F Fuels and energy

Core (SL + HL)		**[15]**
F.1	Energy sources	1
F.2	Fossil fuels	4
F.3	Nuclear energy	4
F.4	Solar energy	3
F.5	Electrochemical energy	3
Extension (HL only)		**[7]**
F.6	Storage of energy and limits of efficiency	1
F.7	Nuclear stability	2
F.8	Radioactive decay	2
F.9	Photovoltaics	2

Options Higher Level

		Teaching hours
Option G	**Modern analytical chemistry**	**[22]**
G.1	Analytical techniques	2
G.2	Principles of spectroscopy	2
G.3	Visible and ultraviolet spectroscopy	4
G.4	Infrared spectroscopy	3
G.5	Nuclear magnetic resonance (NMR) spectroscopy	4
G.6	Mass spectrometry	3
G.7	Chromatography	4
Option H	**Further organic chemistry**	**[22]**
H.1	Stereoisomerism	3
H.2	Free radical substitution reactions	3
H.3	Electrophilic addition reactions	4
H.4	Electrophilic substitution reactions	4
H.5	Nucleophilic addition reactions	1
H.6	Nucleophilic substitution reactions	2
H.7	Elimination reactions	2
H.8	Addition–elimination reactions	1
H.9	Acid–base reactions	2

SYLLABUS DETAILS

Topic 1: Stoichiometry

A.S.		Obj
	1.1 Mole Concept and Avogadro's Constant (2h)	
1.1.1	Describe the mole concept and apply it to substances. The mole concept applies to all kinds of particles: atoms, molecules, ions, formula units etc. The amount of substance is measured in units of moles. The approximate value of Avogadro's constant (L), 6.02×10^{23} mol^{-1}, should be known.	2
1.1.2	Calculate the number of particles and the amount of substance (in moles). Convert between the amount of substance (in moles) and the number of atoms, molecules or formula units.	2
	1.2 Formulas (3h)	
1.2.1	Define the term *molar mass* (M) and calculate the mass of one mole of a species.	1, 2
1.2.2	Distinguish between *atomic mass*, *molecular mass* and *formula mass*. The term *molar mass* (in g mol^{-1}) can be used for all of these.	2
1.2.3	Define the terms *relative molecular mass* (M_r) and *relative atomic mass* (A_r). The terms have no units.	1
1.2.4	State the relationship between the amount of substance (in moles) and mass, and carry out calculations involving amount of substance, mass and molar mass.	1, 2
1.2.5	Define the terms *empirical formula* and *molecular formula*. The molecular formula is a multiple of the empirical formula.	1

A.S.		Obj
1.2.6	Determine the empirical formula and/or the molecular formula of a given compound. Determine the: • empirical formula from the percentage composition or from other suitable experimental data • percentage composition from the formula of a compound • molecular formula when given both the empirical formula and the molar mass.	3

1.3 Chemical Equations (1 h)

1.3.1	Balance chemical equations when all reactants and products are given. Distinguish between coefficients and subscripts.	2
1.3.2	Identify the mole ratios of any two species in a balanced chemical equation. Use balanced chemical equations to obtain information about the amounts of reactants and products.	2
1.3.3	Apply the state symbols (s), (l), (g) and (aq). Encourage the use of state symbols in chemical equations.	2

1.4 Mass and Gaseous Volume Relationships in Chemical Reactions (3h)

1.4.1	Calculate stoichiometric quantities and use these to determine experimental and theoretical yields. Mass is conserved in all chemical reactions. Given a chemical equation and the mass or amount (in moles) of one species, calculate the mass or amount of another species.	2, 3
1.4.2	Determine the limiting reactant and the reactant in excess when quantities of reacting substances are given. Given a chemical equation and the initial amounts of two or more reactants: • identify the limiting reactant • calculate the theoretical yield of a product • calculate the amount(s) of the reactant(s) in excess remaining after the reaction is complete.	3
1.4.3	Apply Avogadro's law to calculate reacting volumes of gases.	2

A.S.		Obj

1.5 Solutions (2h)

1.5.1	Define the terms *solute*, *solvent*, *solution* and *concentration* (g dm^{-3} and mol dm^{-3}). Concentration in mol dm^{-3} is often represented by square brackets around the substance under consideration, eg [CH_3COOH].	1
1.5.2	Carry out calculations involving concentration, amount of solute and volume of solution.	2
1.5.3	Solve solution stoichiometry problems. Given the quantity of one species in a chemical reaction in solution (in grams, moles or in terms of concentration), determine the quantity of another species.	3

Topic 2: Atomic Theory

A.S.		Obj

2.1 The Atom (2h)

2.1.1 State the relative mass and relative charge of protons, electrons and neutrons. 1

The accepted values are:

	Relative Mass	Charge
proton	1	+1
neutron	1	0
electron	$\frac{1}{1840}$	−1

2.1.2 State the position of protons, neutrons and electrons in the atom. 1

2.1.3 Define the terms *mass number* (*A*), *atomic number* (*Z*) and *isotope*. 1

2.1.4 State the symbol for an isotope given its mass number and atomic number. 1

Use the notation $^{A}_{Z}X$, eg $^{12}_{6}C$.

2.1.5 Explain how the isotopes of an element differ. 3

Isotopes have the same chemical properties but different physical properties. Examples such as $^{1}_{1}H$, $^{2}_{1}H$, $^{3}_{1}H$; $^{12}_{6}C$, $^{14}_{7}C$; $^{35}_{17}Cl$ and $^{37}_{17}Cl$ should be considered.

2.1.6 Calculate and explain non-integer atomic masses from the relative abundance of isotopes. 2, 3

2.1.7 Calculate the number of protons, electrons and neutrons in atoms and ions from the mass number, atomic number and charge. 2

2.2 Electron Arrangement (2h)

2.2.1 Describe and explain the difference between a continuous spectrum and a line spectrum. 2, 3

2.2.2 Explain how the lines in the emission spectrum of hydrogen are related to the energy levels of electrons. 3

Students should be able to draw an energy-level diagram, show transitions between different energy levels and recognize that the lines in a line spectrum are directly related to these differences. An understanding of convergence is expected. Series should be considered in the ultraviolet, visible and infrared regions of the spectrum. Calculations, knowledge of quantum numbers and historical references are not required.

A.S.		Obj
2.2.3	Describe the electron arrangement of atoms in terms of main energy levels. Students should know the maximum number of electrons that can occupy a main energy level (up to $Z = 18$). No knowledge of sub-levels s, p, d and f is required. The term *valence electrons* is used to describe the electrons in the highest main energy level.	2
2.2.4	Determine the electron arrangement up to $Z = 20$. For example, 2.8.7 or 2,8,7 for $Z = 17$.	3

Topic 3: Periodicity

A.S.		Obj

3.1 The Periodic Table (1h)

3.1.1 Describe the arrangement of elements in the periodic table in order of increasing atomic number. 2

Names and symbols of the elements are given in the *Chemistry Data Booklet*. The history of the periodic table is not required.

3.1.2 Distinguish between the terms *group* and *period*. 2

The numbering system for groups in the periodic table is shown in the data booklet. Students should also be aware of the position of the transition metals in the periodic table.

3.1.3 Deduce the relationship between the electron configuration of elements and their position in the periodic table. 3

Explanations are only required for the first 20 elements, although general principles can extend to the whole of the periodic table. For example, students should know or be able to predict that K is in group 1 using $Z = 19$, but need only know that since Cs is in group 1, it has one electron in its outer shell.

3.2 Physical Properties (2h)

3.2.1 Describe and explain the periodic trends in atomic radii, ionic radii, ionization energies, electronegativity and melting points for the alkali metals (Li $\rightarrow$ Cs), halogens (F $\rightarrow$ I) and period 3 elements (Na $\rightarrow$ Ar). 2, 3

Cross reference with topics 2, 4 and 5. Data for all these properties are listed in the data booklet. Explanations for the first four trends should be given in terms of the balance between the attraction of the nucleus for the electrons and the repulsion between electrons. Explanations based on effective nuclear charge are not required.

Ionization energy is defined as the minimum energy required to remove one electron from an isolated gaseous atom.

3.3 Chemical Properties (3h)

3.3.1 Discuss the similarities in chemical nature of elements in the same group. 3

The following reactions should be covered:

- alkali metals (Li, Na and K) with water and with halogens (Cl_2 and Br_2)
- halogens (Cl_2, Br_2 and I_2) with halide ions (Cl^-, Br^- and I^-)
- halide ions (Cl^-, Br^- and I^-) with silver ions.

Reactions of the halogens with alkali and confirmation of the silver halide by reaction with ammonia solution are not required.

A.S.		Obj
3.3.2	Discuss the change in nature, from metallic to non-metallic, of the elements across period 3. Use the study of the period 3 oxides to illustrate, for example, the change from basic through amphoteric to acidic oxides and their reaction with water. Halides and hydrides are not required.	3

Topic 4: Bonding

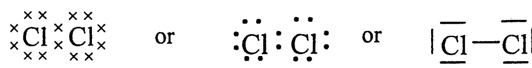
A.S.		Obj
	4.1 Ionic Bond (2h)	
4.1.1	Describe the ionic bond as the result of electron transfer leading to attraction between oppositely charged ions.	2
4.1.2	Determine which ions will be formed when metals in groups 1, 2 and 3 lose electrons.	3
4.1.3	Determine which ions will be formed when elements in groups 6 and 7 gain electrons.	3
4.1.4	State that transition metals can form more than one ion. Restrict examples to simple ions eg Fe^{2+} and Fe^{3+}.	1
4.1.5	Predict whether a compound of two elements would be mainly ionic or mainly covalent from the position of the elements in the periodic table, or from their electronegativity values.	3
4.1.6	Deduce the formula and state the name of an ionic compound formed from a group 1, 2 or 3 metal and a group 5, 6 or 7 non-metal.	3, 1
	4.2 Covalent Bond (6h)	
4.2.1	Describe the covalent bond as the result of electron sharing. The electron pair is attracted by both nuclei leading to a bond which is directional in nature. Both single and multiple bonds should be considered. Dative covalent bonds are not required.	2
4.2.2	Draw the electron distribution of single and multiple bonds in molecules. Examples should include O_2, N_2, CO_2, C_2H_4 (ethene) and C_2H_2 (ethyne).	1
4.2.3	State and explain the relationship between the number of bonds, bond length and bond strength. The comparison should include bond lengths and bond strengths of: • two carbon atoms joined by single, double and triple bonds • the carbon atom and the two oxygen atoms in the carboxyl group of a carboxylic acid.	1, 3
4.2.4	Compare the relative electronegativity values of two or more elements based on their positions in the periodic table. Precise values of electronegativity are not required.	2

A.S.		Obj
4.2.5	Identify the relative polarity of bonds based on electronegativity values.	2

In a covalent bond, electron distribution may not be symmetrical and the electron pair may not be equally shared.

4.2.6	Draw and deduce Lewis (electron dot) structures of molecules and ions for up to four electron pairs on each atom.	1, 3

A pair of electrons can be represented by dots, crosses, a combination of dots and crosses or by a line. For example, chlorine can be shown as:



Note: Cl – Cl is not a Lewis structure.

4.2.7	Predict the shape and bond angles for molecules with four charge centres on the central atom.	3

Use the valence shell electron pair repulsion (VSEPR) theory to predict the shapes and bond angles of molecules and ions having four pairs of electrons (charge centres) around the central atom. Suitable examples are NH_3, H_2O and alkanes (eg CH_4).

4.2.8	Identify the shape and bond angles for species with two and three negative charge centres.	2

Examples should include species with non-bonding as well as bonding electron pairs, eg CO_2, SO_2, C_2H_2, C_2H_4, CO_3^{2-} and NO_2^-.

4.2.9	Predict molecular polarity based on bond polarity and molecular shape.	3

The polarity of a molecule depends on its shape and on the electronegativities of its atoms, eg CO_2, H_2O.

4.3 Intermolecular Forces (1.5h)

4.3.1	Describe the types of intermolecular force (hydrogen bond, dipole–dipole attraction and van der Waals' forces) and explain how they arise from the structural features of molecules.	2, 3

All these intermolecular forces are weaker than covalent bonds. For substances of similar molar mass, hydrogen bonds are stronger than dipole–dipole attractions which are stronger than van der Waals' forces. Van der Waals' forces arise from the electrostatic attraction between temporary induced dipoles in both polar and non-polar molecules.

4.3.2	Describe and explain how intermolecular forces affect the boiling points of substances.	2, 3

The hydrogen bond can be illustrated by comparing physical properties of:

- H_2O and H_2S
- NH_3 and PH_3
- C_3H_8, CH_3CHO and C_2H_5OH.

A.S.		Obj

4.4 Metallic Bond (0.5h)

4.4.1 Describe metallic bond formation and explain the physical properties of metals. **2, 3**

> Metallic bonding is explained in terms of a lattice of positive ions surrounded by delocalized valence electrons. The delocalized electrons should be related to the high electrical conductivity, malleability and ductility of metals.

4.5 Physical Properties (2h)

4.5.1 Compare and explain the following properties of substances resulting from different types of bonding: melting and boiling points, volatility, conductivity and solubility. **2, 3**

> Consider melting points, boiling points and volatility of similar substances, such as F_2, Cl_2, Br_2 and I_2, and substances with different types of bonding and different intermolecular forces. Students should be aware of the effect of impurities on the melting point of a substance.
>
> The solubilities of compounds in non-polar and polar solvents should be compared and explained. Consider also the solubilities of alcohols in water as the length of the carbon chain increases.

4.5.2 Predict the relative values of melting and boiling points, volatility, conductivity and solubility based on the different types of bonding in substances. **3**

Topic 5: States of Matter

A.S.		Obj
	5.1 States of Matter (5h)	
5.1.1	Describe and compare solids, liquids and gases as the three states of matter. The movement of particles, the attractive forces between particles and interparticle spacing should be described. A molecular level description of what happens when evaporation, boiling, condensing, melting and freezing occur should be given. Students should understand what is meant by the term *diffusion*.	2
5.1.2	Describe kinetic theory in terms of the movement of particles whose average energy is proportional to absolute temperature. Kinetic theory should be interpreted in terms of ideal gases consisting of point masses in random motion whose energy is proportional to absolute temperature. Students should be able to describe what happens when the temperature is changed.	2
5.1.3	Describe the Maxwell–Boltzmann energy distribution curve.	2
5.1.4	Draw and explain qualitatively Maxwell–Boltzmann energy distribution curves for different temperatures.	1, 3
5.1.5	Describe qualitatively the effects of temperature, pressure and volume changes on a fixed mass of an ideal gas.	2
5.1.6	State the ideal gas equation, $PV = nRT$.	1
5.1.7	Apply the ideal gas equation in calculations. Use the relationship between P, V, n and T for gases. Students should be familiar with $\frac{P_1V_1}{T_1} = \frac{P_2V_2}{T_2}$ and be able to calculate molar volume.	2

Topic 6: Energetics

A.S.		Obj
	6.1 Exothermic and Endothermic Reactions (2h)	
6.1.1	Define the terms *exothermic reaction*, *endothermic reaction* and *standard enthalpy change of reaction* ($\Delta H^{\ominus}$). Standard enthalpy change is heat transferred under standard conditions—pressure 101.3 kPa, temperature 298 K. Only ΔH can be measured, not H for the initial or final state of a system.	1
6.1.2	State the relationship between temperature change, enthalpy change and whether a reaction is exothermic or endothermic. Combustion of organic compounds are good examples of exothermic reactions.	1
6.1.3	Deduce, from an enthalpy level diagram, the relative stabilities of reactants and products and the sign of the enthalpy change for the reaction. If the final state is more stable (lower on the enthalpy level diagram), this implies that $H_{\text{final}} < H_{\text{initial}}$ and ΔH must be negative. Energy must be released in going to a more stable state.	3
6.1.4	Describe and explain the changes which take place at the molecular level in chemical reactions. Relate bond formation to the release of energy and bond breaking to the absorption of energy.	2, 3
6.1.5	Suggest suitable experimental procedures for measuring enthalpy changes of reactions in aqueous solution. Explore different reactions operating at constant pressure (open containers). Use of the bomb calorimeter is not required.	3
	6.2 Calculation of Enthalpy Changes (3h)	
6.2.1	Calculate the heat change when the temperature of a pure substance is altered. Students should be able to calculate the heat change for a substance given the mass, specific heat and temperature change.	2
6.2.2	Explain that enthalpy changes of reaction relate to specific quantities of either reactants or products. Enthalpy changes are measured in joules (J) and are often quoted in kJ mol^{-1} of either a reactant or a product.	3
6.2.3	Analyse experimental data for enthalpy changes of reactions in aqueous solution.	3

A.S.		Obj
6.2.4	Calculate the enthalpy change for a reaction in aqueous solution using experimental data on temperature changes, quantities of reactants and mass of solution. Enthalpy change of an acid–base reaction could be investigated.	2

6.3 Hess's Law (2h)

6.3.1	Determine the enthalpy change of a reaction which is the sum of two or more reactions with known enthalpy changes. Use examples of simple two- and three-step processes. Students should be able to construct simple enthalpy cycles, but will not be required to state Hess's law.	3

6.4 Bond Enthalpies (1 h)

6.4.1	Define the term *average bond enthalpy*. Bond enthalpies are quoted for the gaseous state and should be recognized as average values obtained from a number of similar compounds. Cross reference with 11.2.6.	1
6.4.2	Calculate the enthalpy change of a reaction using bond enthalpies.	2

6.5 Entropy (1 h)

6.5.1	State and explain the factors which increase the disorder (entropy) in a system. An increase in disorder can result from the mixing of different types of particles, change of state (increased distance between particles), increased movement of particles or increased numbers of particles. An increase in the number of particles in the gaseous state usually has a greater influence than any other possible factor.	1, 3
6.5.2	Predict whether the entropy change (ΔS) for a given reaction or process would be positive or negative. From a given equation, identify a single factor which affects the value of ΔS and predict the sign of ΔS.	3

6.6 Spontaneity (2h)

6.6.1	Define *standard free energy change of reaction* ($\Delta G^{\ominus}$).	1
6.6.2	State whether a reaction or process will be spontaneous by using the sign of $\Delta G^{\ominus}$.	1
6.6.3	State and predict the effect of a change in temperature on the spontaneity of a reaction, given standard entropy and enthalpy changes. Use the equation $\Delta G^{\ominus} = \Delta H^{\ominus} - T\Delta S^{\ominus}$.	1, 3

Topic 7: Kinetics

A.S. Obj

7.1 Rates of Reaction (2h)

7.1.1 Define the term *rate of reaction* and describe the measurement of reaction rates. **1, 2**

Rate of reaction can be defined as the decrease in the concentration of reactants per unit time or the increase in the concentration of product per unit time.

7.1.2 Analyse data from rate experiments. **3**

Graphs of changes in concentration, volume or mass against time should be interpreted qualitatively.

7.2 Collision Theory (2h)

7.2.1 Describe and explain the collision theory. **2, 3**

Students should know that not all collisions lead to a reaction.

7.2.2 Define *activation energy* (E_a) and explain that reactions occur when reacting species have $E \geqslant E_a$. **1, 3**

Molecules must have a minimum energy and appropriate collision geometry in order to react. A simple treatment is all that is required. Cross reference with 5.1.3 and 5.1.4.

7.2.3 Predict and explain, using collision theory, the qualitative effect of particle size, temperature, concentration and catalysts on the rate of a reaction. **3**

Increasing the temperature increases the frequency of collisions but, more importantly, the proportion of molecules with $E \geqslant E_a$ increases.

7.2.4 Explain that reactions can occur by more than one step and that one step can determine the rate of reaction. **3**

Few reactions involve just one step although one step in the reaction, the *rate determining step*, determines the reaction rate. Orders of reactions and rate laws are not required.

Topic 8: Equilibrium

A.S. | | Obj

8.1 Dynamic Equilibrium (1h)

8.1.1 Outline the characteristics of a system in a state of equilibrium. 2

Many chemical reactions are reversible and never go to completion. Equilibrium can be approached from both directions. For a system in equilibrium the rate of the forward reaction equals the rate of the reverse reaction and the concentrations of all reactants and products remain constant. The system is closed and macroscopic properties remain constant.

Use phase equilibrium as an example of dynamic equilibrium involving physical changes.

8.2 The Position of Equilibrium (4h)

8.2.1 State the equilibrium constant expression (K_c) for a homogeneous reaction. 1

Consider equilibria involving one phase, gases or species in aqueous solution. The equilibrium constant is specific to a given system and varies with temperature. No calculations are required.

8.2.2 Deduce the extent of a reaction from the magnitude of the equilibrium constant. 3

When $K_c >> 1$, the reaction goes almost to completion.
When $K_c << 1$, the reaction hardly proceeds.

8.2.3 Describe and predict the qualitative effects of changes of temperature, pressure and concentration on the position of equilibrium and the value of the equilibrium constant. 2, 3

Use Le Chatelier's principle to predict the effects of these changes on the position of equilibrium. The value of the equilibrium constant (K_c) is only affected by temperature. The position of equilibrium may change without the value of K_c changing.

8.2.4 State and explain the effect of a catalyst on an equilibrium reaction. 1, 3

8.2.5 Describe and explain the application of equilibrium and kinetics concepts to the Haber process and the Contact process. 2, 3

Topic 9: Acids and Bases

A.S.		Obj
	9.1 Properties of Acids and Bases (1 h)	
9.1.1	Outline the characteristic properties of acids and bases in aqueous solution. The properties that must be considered are: effects on indicators and reactions of acids with bases, metals and carbonates. Bases which are not hydroxides, such as ammonia, soluble carbonates and hydrogencarbonates, should be included. Alkalis are bases that dissolve in water.	2
	9.2 Strong and Weak Acids and Bases (1 h)	
	Note: Brønsted-Lowry definitions of acids and bases are not required for this sub-topic.	
9.2.1	Describe and explain the differences between strong and weak acids and bases in terms of the extent of dissociation, reaction with water and conductivity. The term *ionization* can be used instead of *dissociation*. Solutions of equal concentration can be compared by pH and/or conductivity.	2, 3
9.2.2	State whether a given acid or base is strong or weak. Specified strong acids are hydrochloric acid, nitric acid and sulfuric acid. Specified weak acids are ethanoic acid and carbonic acid (aqueous carbon dioxide). Specified strong bases are all group 1 hydroxides and barium hydroxide. Specified weak bases are ammonia and ethylamine.	1
9.2.3	Describe and explain data from experiments to distinguish between strong and weak acids and bases, and to determine the relative acidities and basicities of substances.	2, 3
	9.3 The pH Scale (1 h)	
9.3.1	Distinguish between aqueous solutions that are acidic, neutral or basic using the pH scale.	2
9.3.2	Identify which of two or more aqueous solutions is more acidic or basic, using pH values. Measure pH using a pH meter or pH paper. Students should know that pH paper contains a mixture of indicators. The theory of pH meters is not required.	2

A.S.		Obj
9.3.3	State that each change of one pH unit represents a tenfold change in the hydrogen ion concentration $[H^+(aq)]$. Relate integral values of pH to $[H^+(aq)]$ expressed as powers of ten. Calculation of pH from $[H^+(aq)]$ is not required.	1
9.3.4	Deduce changes in $[H^+(aq)]$ when the pH of a solution changes by more than one pH unit.	3

9.4 Buffer Solutions (1 h)

9.4.1	Describe a buffer solution in terms of its composition and behaviour. A buffer resists change in pH when a small amount of a strong acid or base is added. Suitable examples include ammonium chloride/ammonia solution and ethanoic acid/sodium ethanoate. Blood is an example of a buffer solution.	2
9.4.2	Describe ways of preparing buffer solutions.	2

9.5 Acid-base Titrations (1 h)

9.5.1	Draw and explain a graph showing pH against volume of titrant for titrations involving strong acids and bases.	1, 3

Topic 10: Oxidation and Reduction

A.S.		Obj
	10.1 Oxidation and Reduction (2h)	
10.1.1	Define *oxidation* and *reduction* in terms of electron loss and gain. Introduce the concept of the half-equation.	1
10.1.2	Calculate the oxidation number of an element in a compound. Oxidation numbers should be shown by a sign (+ or -) and a number, eg +7 for Mn in $KMnO_4$.	2
10.1.3	State and explain the relationship between oxidation numbers and the names of compounds. Oxidation numbers in names of compounds are represented by Roman numerals, eg iron(II) oxide, iron(III) oxide.	1, 3
10.1.4	Identify whether an element is oxidized or reduced in simple redox reactions, using oxidation numbers. Appropriate reactions to illustrate this can be found in topics 3 and 11. Possible examples include: iron(II) and (III), manganese(II) and (VII), chromium(III) and (VI), copper(I) and (II), oxides of sulfur and oxyacids, halogens and halide ions.	2
10.1.5	Define the terms *oxidizing agent* and *reducing agent*.	1
	10.2 Reactivity (2.5h)	
10.2.1	Deduce a reactivity series based upon the chemical behaviour of a group of oxidizing and reducing agents. Displacement reactions of metals and halogens (see 3.3.1) provide a good experimental illustration of reactivity. Standard electrode potentials or reduction potentials are not required.	3
10.2.2	Deduce the feasibility of a redox reaction from a given reactivity series.	3
10.2.3	Describe and explain how a redox reaction is used to produce electricity in a voltaic cell. Students should be able to draw a diagram of a simple half-cell, and show how two half-cells can be connected by a salt bridge to form a whole cell. Suitable examples of half-cells are Mg, Zn, Fe and Cu in solutions of their ions.	2, 3

A.S.		Obj

10.3 Electrolysis (2.5h)

A.S.		Obj
10.3.1	Draw a diagram showing the essential components of an electrolytic cell. An electrolytic cell converts electrical energy to chemical energy. The diagram should include the source of electric current and conductors, positive and negative electrodes and the electrolyte.	1
10.3.2	Describe how current is conducted in an electrolytic cell.	2
10.3.3	Deduce the products for the electrolysis of a molten salt. Equations showing the formation of products at each electrode should be given.	3
10.3.4	Distinguish between the use of a spontaneous redox reaction to produce electricity in a voltaic cell and the use of electricity to carry out a non-spontaneous redox reaction in an electrolytic cell. Some teachers may wish to describe reactions at the electrodes in a cell in terms of reduction at the cathode and oxidation at the anode, but this is not required.	2
10.3.5	Describe and explain the use of electrolysis in electroplating. Restrict this to copper plating.	2, 3

Topic 11: Organic Chemistry

A.S. **Obj**

11.1 Homologous Series (1h)

11.1.1 Describe the features of a homologous series. 2

Features include a general formula and neighbouring members differing by CH_2, with similar chemical properties and with a gradation in physical properties.

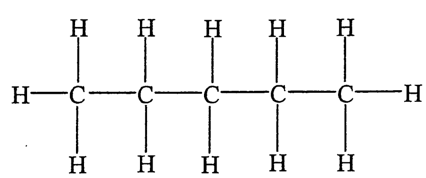
11.1.2 Predict and explain the trends in boiling points of members of a homologous series. 3

In a homologous series there is a gradual increase in boiling point as the number of carbon atoms increases. Cross reference with 4.3.

11.2 Hydrocarbons (2h)

11.2.1 Draw structural formulas for the isomers of the non-cyclic alkanes up to C_6. 1

Structural formulas should indicate clearly the bonding between atoms. For example, for pentane:



or $CH_3CH_2CH_2CH_2CH_3$

Or CH_3—$(CH_2)_3$—CH_3, but not C_5H_{12}.

11.2.2 State the names of alkanes up to C_6. 1

Name these using IUPAC rules. Consider both straight and branch-chained alkanes.

11.2.3 Explain the relative inertness of alkanes. 3

Refer to bond enthalpies. See 6.4.

11.2.4 Draw structural formulas and state the names for straight-chain alkenes (C_nH_{2n}, where n is between 2 and 5). 1

Geometric (*cis–trans*) isomers are not required.

11.2.5 Describe complete and incomplete combustion of hydrocarbons. 2

The formation of CO and C during incomplete combustion should be related to environmental impacts and oxidation–reduction.

11.2.6 State that the combustion of hydrocarbons is an exothermic process. 1

See 6.3 and 6.4.

AP Chemistry

> **Important Changes to This Course Description**
> - Changes to the exam starting in May 2007, pages 8–9
> - New sample free-response questions, pages 20–28

THE COURSE

The AP Chemistry course is designed to be the equivalent of the general chemistry course usually taken during the first college year. For some students, this course enables them to undertake, in their first year, second-year work in the chemistry sequence at their institution or to register in courses in other fields where general chemistry is a prerequisite. For other students, the AP Chemistry course fulfills the laboratory science requirement and frees time for other courses.

AP Chemistry should meet the objectives of a good college general chemistry course. Students in such a course should attain a depth of understanding of fundamentals and a reasonable competence in dealing with chemical problems. The course should contribute to the development of the students' abilities to think clearly and to express their ideas, orally and in writing, with clarity and logic. The college course in general chemistry differs qualitatively from the usual first secondary school course in chemistry with respect to the kind of textbook used, the topics covered, the emphasis on chemical calculations and the mathematical formulation of principles, and the kind of laboratory work done by students. Quantitative differences appear in the number of topics treated, the time spent on the course by students, and the nature and the variety of experiments done in the laboratory. *Secondary schools that wish to offer an AP Chemistry course must be prepared to provide a laboratory experience equivalent to that of a typical college course.*

Prerequisites

The AP Chemistry course is designed to be taken only after the successful completion of a first course in high school chemistry. Surveys of students who take the AP Chemistry Exam indicate that the probability of achieving a grade of 3 or higher is significantly greater for students who successfully complete a first course in high school chemistry prior to undertaking the AP course. *Thus it is strongly recommended that credit in a first-year high school chemistry course be a prerequisite for enrollment in an AP Chemistry class. In addition, the recommended mathematics prerequisite for an AP Chemistry class is the successful completion of a second-year algebra course.*

The advanced work in chemistry should not displace any other part of the student's science curriculum. It is highly desirable that a student have a course in secondary school physics and a four-year college-preparatory program in mathematics.

Time Allocations

Developing the requisite intellectual and laboratory skills required of an AP Chemistry student demands that adequate classroom and laboratory time be scheduled. Surveys of students taking the AP Chemistry Exam indicate that performance improved as both total instructional time and time devoted to laboratory work increased.

At least six class periods or the equivalent per week should be scheduled for an AP Chemistry course. Of the total allocated time, a minimum of one double period per week or the equivalent, preferably in a single session, should be spent engaged in laboratory work. Time devoted to class and laboratory demonstrations should not be counted as part of the laboratory period.

Students in an AP Chemistry course should spend at least five hours a week in individual study outside of the classroom.

Textbooks

Current college textbooks are probably the best indicators of the level of the college general chemistry course that AP Chemistry is designed to represent. A contemporary college chemistry text that stresses principles and concepts and their relation to the descriptive chemistry on which they are based should be selected. Even the more advanced secondary school texts cannot serve adequately as texts for an AP course that aims to achieve its objectives. A list of example textbooks appropriate for use in this course is available on the AP Chemistry Course Home Page at AP Central (apcentral.collegeboard.com/chemistry).

The Teachers' Resources section of AP Central (apcentral.collegeboard.com) has a searchable database of chemistry resources. Many of these resources have been reviewed and rated by experienced AP Chemistry teachers.

Topic Outline

The importance of the theoretical aspects of chemistry has brought about an increasing emphasis on these aspects of the content of general chemistry courses. Topics such as the structure of matter, kinetic theory of gases, chemical equilibria, chemical kinetics, and the basic concepts of thermodynamics are now being presented in considerable depth.

If the objectives of a college-level general chemistry course are to be achieved, instruction should be done by a teacher who has completed an undergraduate major program in chemistry including at least a year's work in physical chemistry. Teachers with such training are best able to present a course with adequate breadth and depth and to develop students' abilities to use the fundamental facts of the science in their reasoning. Because of the nature of the AP course, the teacher needs time for extra preparation for both class and laboratory and should have a teaching load that is adjusted accordingly.

Chemistry is broad enough to permit flexibility in its teaching, and college teachers exercise considerable freedom in methods and arrangements of topics in the effort to reach the objectives of their courses. The AP Chemistry Development Committee has no desire to impose greater uniformity on secondary schools than now exists in colleges.

The following list of topics for an AP course is intended to be a *guide* to the level and breadth of treatment expected rather than to be a syllabus. The percentage after each major topic indicates the approximate proportion of multiple-choice questions on the exam that pertain to the topic.

I. Structure of Matter (20%)

A. Atomic theory and atomic structure
   1. Evidence for the atomic theory
   2. Atomic masses; determination by chemical and physical means
   3. Atomic number and mass number; isotopes
   4. Electron energy levels: atomic spectra, quantum numbers, atomic orbitals
   5. Periodic relationships including, for example, atomic radii, ionization energies, electron affinities, oxidation states

B. Chemical bonding
   1. Binding forces
      a. Types: ionic, covalent, metallic, hydrogen bonding, van der Waals (including London dispersion forces)
      b. Relationships to states, structure, and properties of matter
      c. Polarity of bonds, electronegativities
   2. Molecular models
      a. Lewis structures
      b. Valence bond: hybridization of orbitals, resonance, sigma and pi bonds
      c. VSEPR
   3. Geometry of molecules and ions, structural isomerism of simple organic molecules and coordination complexes; dipole moments of molecules; relation of properties to structure

C. Nuclear chemistry: nuclear equations, half-lives, and radioactivity; chemical applications

II. States of Matter (20%)

A. Gases
   1. Laws of ideal gases
      a. Equation of state for an ideal gas
      b. Partial pressures
   2. Kinetic molecular theory
      a. Interpretation of ideal gas laws on the basis of this theory
      b. Avogadro's hypothesis and the mole concept
      c. Dependence of kinetic energy of molecules on temperature
      d. Deviations from ideal gas laws

B. Liquids and solids
   1. Liquids and solids from the kinetic-molecular viewpoint
   2. Phase diagrams of one-component systems
   3. Changes of state, including critical points and triple points
   4. Structure of solids; lattice energies

C. Solutions
   1. Types of solutions and factors affecting solubility
   2. Methods of expressing concentration (use of normalities is not tested)

3. Raoult's law and colligative properties (nonvolatile solutes); osmosis
4. Nonideal behavior (qualitative aspects)

III. Reactions (35–40%)

A. Reaction types
   1. Acid-base reactions; concepts of Arrhenius, Brønsted-Lowry, and Lewis; coordination complexes; amphoterism
   2. Precipitation reactions
   3. Oxidation-reduction reactions
      a. Oxidation number
      b. The role of the electron in oxidation-reduction
      c. Electrochemistry: electrolytic and galvanic cells; Faraday's laws; standard half-cell potentials; Nernst equation; prediction of the direction of redox reactions

B. Stoichiometry
   1. Ionic and molecular species present in chemical systems: net ionic equations
   2. Balancing of equations including those for redox reactions
   3. Mass and volume relations with emphasis on the mole concept, including empirical formulas and limiting reactants

C. Equilibrium
   1. Concept of dynamic equilibrium, physical and chemical; Le Chatelier's principle; equilibrium constants
   2. Quantitative treatment
      a. Equilibrium constants for gaseous reactions: K_p, K_c
      b. Equilibrium constants for reactions in solution
         (1) Constants for acids and bases; pK; pH
         (2) Solubility product constants and their application to precipitation and the dissolution of slightly soluble compounds
         (3) Common ion effect; buffers; hydrolysis

D. Kinetics
   1. Concept of rate of reaction
   2. Use of experimental data and graphical analysis to determine reactant order, rate constants, and reaction rate laws
   3. Effect of temperature change on rates
   4. Energy of activation; the role of catalysts
   5. The relationship between the rate-determining step and a mechanism

E. Thermodynamics
   1. State functions
   2. First law: change in enthalpy; heat of formation; heat of reaction; Hess's law; heats of vaporization and fusion; calorimetry
   3. Second law: entropy; free energy of formation; free energy of reaction; dependence of change in free energy on enthalpy and entropy changes
   4. Relationship of change in free energy to equilibrium constants and electrode potentials

IV. Descriptive Chemistry (10–15%)

Knowledge of specific facts of chemistry is essential for an understanding of principles and concepts. These descriptive facts, including the chemistry involved in environmental and societal issues, should not be isolated from the principles being studied but should be taught throughout the course to illustrate and illuminate the principles. The following areas should be covered:

1. Chemical reactivity and products of chemical reactions
2. Relationships in the periodic table: horizontal, vertical, and diagonal with examples from alkali metals, alkaline earth metals, halogens, and the first series of transition elements
3. Introduction to organic chemistry: hydrocarbons and functional groups (structure, nomenclature, chemical properties)

V. Laboratory (5–10%)

The differences between college chemistry and the usual secondary school chemistry course are especially evident in the laboratory work. The AP Chemistry Exam includes some questions based on experiences and skills students acquire in the laboratory:

- making observations of chemical reactions and substances
- recording data
- calculating and interpreting results based on the quantitative data obtained
- communicating effectively the results of experimental work

For information on the requirements for an AP Chemistry laboratory program, the *Guide for the Recommended Laboratory Program* is included on pages 29–39 of this book. The guide describes the general requirements for an AP Chemistry laboratory program and contains a list of recommended experiments. Also included in the guide are resources that AP Chemistry teachers should find helpful in developing a successful laboratory program.

Colleges have reported that some AP students, while doing well on the exam, have been at a serious disadvantage because of inadequate laboratory experience. Meaningful laboratory work is important in fulfilling the requirements of a college-level course of a laboratory science and in preparing a student for sophomore-level chemistry courses in college.

Because chemistry professors at some institutions ask to see a record of the laboratory work done by an AP student before making a decision about granting credit, placement, or both, in the chemistry program, students should keep a laboratory notebook that includes reports of their laboratory work in such a fashion that the reports can be readily reviewed.

Chemical Calculations

The following list summarizes types of problems either explicitly or implicitly included in the preceding material. Attention should be given to significant figures, precision of measured values, and the use of logarithmic and exponential relationships. Critical analysis of the reasonableness of results is to be encouraged.

1. Percentage composition
2. Empirical and molecular formulas from experimental data
3. Molar masses from gas density, freezing-point, and boiling-point measurements
4. Gas laws, including the ideal gas law, Dalton's law, and Graham's law
5. Stoichiometric relations using the concept of the mole; titration calculations
6. Mole fractions; molar and molal solutions
7. Faraday's laws of electrolysis
8. Equilibrium constants and their applications, including their use for simultaneous equilibria
9. Standard electrode potentials and their use; Nernst equation
10. Thermodynamic and thermochemical calculations
11. Kinetics calculations

THE EXAM

Starting in May 2007, the AP Chemistry Exam will have a new format. The two main parts of the exam, Section I and Section II, will contribute equally (50 percent each) toward the final grade. Section I (90 minutes) will still consist of 75 multiple-choice questions with broad coverage of topics.

Teachers should not try to prepare students to answer every question in Section I of the exam. To be broad enough in scope to give every student who has covered an adequate amount of material an opportunity to make a good showing, the exam must be so comprehensive that no student should be expected to make a perfect or near-perfect score.

There will be several changes in Section II of the exam starting in May 2007. The first change is that students will no longer choose between alternative questions. All students will answer the same six free-response questions. A second change relates to Question 4 of the exam, in which students are asked to write chemical equations for five reactions chosen from eight given sets of reactants. In the new Question 4 format, all students will write balanced chemical equations for several different sets of reactants. In addition, students will answer a short question about each reaction.

A third change in Section II relates to the timing of Part A (calculators permitted) and Part B (no calculators permitted). In Part A students will have 55 minutes to answer three problems—one problem involving chemical equilibrium and two other problems, one of which may involve quantitative analysis of data in a laboratory-based problem. In Part B students will have 40 minutes to answer a reactions question (Question 4, described above) and two essay questions, one of which will be based on laboratory in the case that no laboratory-based problem appears in Part A.

Calculators

The policy regarding the use of calculators on the AP Chemistry Exam was developed to address the rapid expansion of the capabilities of scientific calculators, which include not only programming and graphing functions but also the availability of stored equations and other data. For the section of the exam in which calculators are permitted, students should be allowed to use the calculators to which they are accustomed, except as noted below.* On the other hand, they should not have access to information in their calculators that is not available to other students, if that information is needed to answer the questions.

Therefore, calculators are not permitted on the *multiple-choice section* of the AP Chemistry Exam. The purpose of the multiple-choice section is to assess the breadth of students' knowledge and understanding of the basic concepts of chemistry. The multiple-choice questions emphasize conceptual understanding as well as qualitative and simple quantitative applications of principles. Many chemical and physical principles and relationships are quantitative by nature and can be expressed as equations. Knowledge of the underlying basic definitions and principles, expressed as equations, is a part of the content of chemistry that should be learned by chemistry students and will continue to be assessed in the multiple-choice section. However, any numeric calculations that require use of these equations in the multiple-choice section will be limited to simple arithmetic so that they can be done quickly, either mentally or with paper and pencil. Also, in some questions the answer choices differ by several orders of magnitude so that the questions can be answered by estimation. Refer to sample questions on pages 14–16 (#6, 8, 11, 12, 16, and 17), which can be answered using simple arithmetic or by estimation. Students should be encouraged to develop their skills not only in estimating answers but also in recognizing answers that are physically unreasonable or unlikely.

Calculators (with the exceptions previously noted) will be allowed only during the first 55 minutes (Part A) of the free-response section of the exam. During this time, students will work on three problems. **Any programmable or graphing calculator may be used, and students will NOT be required to erase their calculator memories before or after the exam.** Students will not be allowed to move on to the last portion of the free-response section until time is called and all calculators are put away. For the last 40 minutes (Part B) of the exam, students will work without calculators on the remaining portion of the free-response section.

Equation Tables

Tables containing equations commonly used in chemistry are printed both in the free-response (Section II) exam booklet and in the inserts provided with each exam for students to use when taking the free-response section. The equation tables are NOT permitted for use with the multiple-choice section. In general, the equations for each

* **Exceptions to calculator use.** Calculators that are not permitted are PowerBooks and portable/handheld computers; electronic writing pads or pen-input/stylus-driven devices (e.g., Palm, PDAs, Casio ClassPad 300); pocket organizers; models with QWERTY (i.e., typewriter) keypads (e.g., TI-92 Plus, Voyage 200); models with paper tapes; models that make noise or "talk"; models that require an electrical outlet; cell phone calculators. Students may not share calculators.

year's exam are printed and distributed with the Course Description at least a year in advance so that students can become accustomed to using them throughout the year. However, because the equation tables will be provided with the exam, students will NOT be allowed to bring their own copies to the exam room. The latest version of the equation tables is shown on pages 11–12 of this booklet.

One of the purposes of providing the tables of commonly used equations for use with the free-response section is to address the issue of equity for those students who do not have access to equations stored in their calculators. The availability of these equations to all students means that in the scoring of the free-response sections, little or no credit will be awarded for simply writing down equations or for answers unsupported by explanations or logical development.

The equations in the tables express relationships that are encountered most frequently in an AP Chemistry course and exam. However, they do not include all equations that might possibly be used. For example, they do not include many equations that can be derived by combining others in the tables. Nor do they include equations that are simply special cases of any that are in the tables. Students are responsible for understanding the physical principles that underlie each equation and for knowing the conditions for which each equation is applicable.

The equations are grouped in tables according to major content category. Within each table, the symbols used for the variables in that table are defined. However, in some cases the same symbol is used to represent different quantities in different tables. It should be noted that there is no uniform convention among textbooks for the symbols used in writing equations. The equation tables follow many common conventions, but in some cases consistency was sacrificed for the sake of clarity.

In summary, the purpose of minimizing numerical calculations in both sections of the exam and providing equations with the free-response section is to place greater emphasis on the understanding and application of fundamental chemical principles and concepts. For solving problems and writing essays, a sophisticated programmable or graphing calculator, or the availability of stored equations, is no substitute for a thorough grasp of the chemistry involved.

ADVANCED PLACEMENT CHEMISTRY EQUATIONS AND CONSTANTS

ATOMIC STRUCTURE

$E = h\nu \qquad c = \lambda\nu$

$\lambda = \dfrac{h}{mv} \qquad p = mv$

$E_n = \dfrac{-2.178 \times 10^{-18}}{n^2}$ joule

E = energy
ν = frequency
λ = wavelength
p = momentum
v = velocity
n = principal quantum number
m = mass

Speed of light, $c = 3.0 \times 10^{8}\ \text{m s}^{-1}$

Planck's constant, $h = 6.63 \times 10^{-34}$ J s

Boltzmann's constant, $k = 1.38 \times 10^{-23}\ \text{J K}^{-1}$

Avogadro's number $= 6.022 \times 10^{23}\ \text{mol}^{-1}$

Electron charge, $e = -1.602 \times 10^{-19}$ coulomb

1 electron volt per atom $= 96.5\ \text{kJ mol}^{-1}$

EQUILIBRIUM

$K_a = \dfrac{[H^+][A^-]}{[HA]}$

$K_b = \dfrac{[OH^-][HB^+]}{[B]}$

$K_w = [OH^-][H^+] = 1.0 \times 10^{-14}$ @ 25°C
$\quad = K_a \times K_b$

$pH = -\log[H^+],\ pOH = -\log[OH^-]$

$14 = pH + pOH$

$pH = pK_a + \log\dfrac{[A^-]}{[HA]}$

$pOH = pK_b + \log\dfrac{[HB^+]}{[B]}$

$pK_a = -\log K_a,\ pK_b = -\log K_b$

$K_p = K_c(RT)^{\Delta n}$,
where Δn = moles product gas − moles reactant gas

Equilibrium Constants

K_a (weak acid)
K_b (weak base)
K_w (water)
K_p (gas pressure)
K_c (molar concentrations)

THERMOCHEMISTRY/KINETICS

$\Delta S^\circ = \sum S^\circ \text{ products} - \sum S^\circ \text{ reactants}$

$\Delta H^\circ = \sum \Delta H_f^\circ \text{ products} - \sum \Delta H_f^\circ \text{ reactants}$

$\Delta G^\circ = \sum \Delta G_f^\circ \text{ products} - \sum \Delta G_f^\circ \text{ reactants}$

$\Delta G^\circ = \Delta H^\circ - T\Delta S^\circ$
$\quad = -RT\ln K = -2.303\,RT\log K$
$\quad = -n\mathcal{F}E^\circ$

$\Delta G = \Delta G^\circ + RT\ln Q = \Delta G^\circ + 2.303\,RT\log Q$

$q = mc\Delta T$

$C_p = \dfrac{\Delta H}{\Delta T}$

$\ln[A]_t - \ln[A]_0 = -kt$

$\dfrac{1}{[A]_t} - \dfrac{1}{[A]_0} = kt$

$\ln k = \dfrac{-E_a}{R}\left(\dfrac{1}{T}\right) + \ln A$

S° = standard entropy
H° = standard enthalpy
G° = standard free energy
E° = standard reduction potential
T = temperature
n = moles
m = mass
q = heat
c = specific heat capacity
C_p = molar heat capacity at constant pressure
E_a = activation energy
k = rate constant
A = frequency factor

Faraday's constant, $\mathcal{F}$ = 96,500 coulombs per mole of electrons

Gas constant, $R = 8.31\ \text{J mol}^{-1}\ \text{K}^{-1}$
$\quad = 0.0821\ \text{L atm mol}^{-1}\ \text{K}^{-1}$
$\quad = 8.31\ \text{volt coulomb mol}^{-1}\ \text{K}^{-1}$

GASES, LIQUIDS, AND SOLUTIONS

$$PV = nRT$$

$$\left(P + \frac{n^2a}{V^2}\right)(V - nb) = nRT$$

$$P_A = P_{total} \times X_A, \text{ where } X_A = \frac{\text{moles A}}{\text{total moles}}$$

$$P_{total} = P_A + P_B + P_C + \ldots$$

$$n = \frac{m}{M}$$

$$K = {}^\circ C + 273$$

$$\frac{P_1V_1}{T_1} = \frac{P_2V_2}{T_2}$$

$$D = \frac{m}{V}$$

$$u_{rms} = \sqrt{\frac{3kT}{m}} = \sqrt{\frac{3RT}{M}}$$

$$KE \text{ per molecule} = \frac{1}{2}mv^2$$

$$KE \text{ per mole} = \frac{3}{2}RT$$

$$\frac{r_1}{r_2} = \sqrt{\frac{M_2}{M_1}}$$

molarity, M = moles solute per liter solution

molality = moles solute per kilogram solvent

$$\Delta T_f = iK_f \times \text{molality}$$

$$\Delta T_b = iK_b \times \text{molality}$$

$$\pi = iMRT$$

$$A = abc$$

P = pressure
V = volume
T = temperature
n = number of moles
D = density
m = mass
v = velocity

u_{rms} = root-mean-square speed
KE = kinetic energy
r = rate of effusion
M = molar mass
π = osmotic pressure
i = van't Hoff factor
K_f = molal freezing-point depression constant
K_b = molal boiling-point elevation constant
A = absorbance
a = molar absorptivity
b = path length
c = concentration
Q = reaction quotient
I = current (amperes)
q = charge (coulombs)
t = time (seconds)
E° = standard reduction potential
K = equilibrium constant

OXIDATION-REDUCTION; ELECTROCHEMISTRY

$$Q = \frac{[C]^c\,[D]^d}{[A]^a\,[B]^b}, \text{ where } a\,A + b\,B \rightarrow c\,C + d\,D$$

$$I = \frac{q}{t}$$

$$E_{cell} = E^\circ_{cell} - \frac{RT}{n\mathcal{F}}\ln Q = E^\circ_{cell} - \frac{0.0592}{n}\log Q \text{ @ } 25^\circ C$$

$$\log K = \frac{nE^\circ}{0.0592}$$

Gas constant, $R = 8.31 \text{ J mol}^{-1}\text{ K}^{-1}$
$= 0.0821 \text{ L atm mol}^{-1}\text{ K}^{-1}$
$= 8.31 \text{ volt coulomb mol}^{-1}\text{ K}^{-1}$
Boltzmann's constant, $k = 1.38 \times 10^{-23}\text{ J K}^{-1}$
K_f for H_2O = $1.86 \text{ K kg mol}^{-1}$
K_b for H_2O = $0.512 \text{ K kg mol}^{-1}$
1 atm = 760 mm Hg
= 760 torr
STP = 0.000°C and 1.000 atm
Faraday's constant, $\mathcal{F}$ = 96,500 coulombs per mole of electrons

Thomas Jefferson High School for Science and Technology

Thomas Jefferson Governor's School (VA)

Academics

Science/Tech | Math/CS | Humanities | Foreign Language/Fine Arts/P.E

Science and Technology

Science

Each student will complete four years of laboratory science beginning with Molecular Biology integrated with English and technology, followed by Analytical Chemistry, Physics, and Geoscience. Each science course is supported by extended periods of time for participation in required laboratories and in relevant technology laboratory experiences. The extensive elective program includes advanced placement courses and courses such as Human Anatomy and Physiology, Marine Biology, Human Genetics, DNA-Biotechnology, and Quantum Mechanics.

Technology

Ninth graders enroll in Technology and Engineering Concepts (TEC) integrated with biology and English. This required course provides experiences in basic electronics, robotics, engineering graphics, mechanical design, and biotechnology. During the 10th and 11th grades, students are expected to prepare for senior research through coursework in technology, science and computer science electives. Twelfth graders select one technology laboratory for research, experimentation, and independent study. Mentorship opportunities off-campus are available for qualified students.

Student Webmaster: Martin Elthon
Faculty Curator: Richard Washer
Last Modified: 4.11.2003

For non-technical questions, please visit our contact page in order to contact the correct party.

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Thomas Jefferson High School for Science and Technology

Academics

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Introduction

A distinguishing characteristic of Thomas Jefferson High School for Science and Technology is its specialized science and technology research laboratories. They are designed to enhance the academic curriculum as well as provide students with unique learning experiences in technological environments, opportunities for independent research, experimentation, and interaction with professionals from the scientific, engineering, technological, and industrial communities. Through a mentorship coordinator, each laboratory maintains contact with local government, private research laboratories, and technical facilities for information exchange and off-campus student mentorship opportunities.

Research Laboratories

Astronomy (Lee Ann Hennig)

Students in the Astronomy Laboratory are involved in projects related to planetary geology, deep space image processing, and telescopic observations. Students are able to investigate astronomical images on CD ROM for their planetary projects. The Astronomy Laboratory participates in the Telescopes in Education program based on Mount Wilson in California. Students are permitted to remotely control Mt. Wilson's 24-inch telescope. Students access the telescope by modem and download the images in real time. Using "The Sky" software enables the students to do image processing. Other projects center on analyzing data provided by astronomers who are doing fundamental research on topics such as: light curves of variable stars, spectroscopic analysis, and investigating planetary features.

Automation and Robotics (Dave Bell)

In the Automation and Robotics Laboratory students apply engineering concepts to the design and fabrication of automated and robotic systems. They investigate the building blocks of those systems including sensors, analyzers, actuators, drivers, controllers, and power supplies. Students identify and solve problems aimed at integrating the concepts of automation and robotic systems, with a view to electronics, computer programming, and manufacturing. Applications are viewed with consideration of their social, cultural and ethical impacts.

Biotechnology (Fred Lampazzi)

The Biotechnology Laboratory provides a unique technology experience for a large portion of the Jefferson student body. The program offers a biotechnology training and research program designed to transform traditional secondary molecular biology studies into an applications program that helps students experience the power of newly discovered research tools associated with recombinant DNA technologies. The laboratory's primary mission is to supply a laboratory research-based program that allows its students to experience topics from bacterial transformation to DNA mapping. In addition, the program provides students with the experience of new, leading-edge technologies including bioinformatics, western blotting, rtPCR and DNA sequencing.

Chemical Analysis (Brian Kennedy)

In the Chemical Analysis Laboratory students take three years of chemistry from basic chemistry to more advanced topics which allow them to pursue independent research. For some students their chemistry experience culminates in an introductory organic chemistry with instrumental analysis course. For others, an independent research project rounds out their chemistry study.

Computer Assisted Design (Ken Domina)

The Computer Assisted Design Laboratory allows students to interact with the computer to produce various three dimensional designs. Seniors conducting research projects in CAD are free to pursue their interests through independent studies in a variety of technical fields. Students have access to various AutoDesk software packages, from CAD 2000i to 3D Studio Max and 3D Studio VIZ to turn their ideas into reality.

Computer Systems (Randy Latimer)

The Computer Systems Laboratory supports advanced studies in applied computer science, computer architecture, artificial intelligence and supercomputing applications. Working in a UNIX environment with full Internet access, students are able to investigate a broad range of pure and applied research topics which emphasize high performance computing and graphics visualization techniques.

Energy Systems (Rick Buxton)

In the Energy Systems Laboratory students apply the knowledge, problem-solving skills and project management skills acquired during their previous three years. Students may pursue projects of interest in a wide range of engineering disciplines, such as heat transfer, fluid dynamics, direct and indirect energy conversion, and mechanical systems. The laboratory accommodates both individual and team projects requiring specific knowledge in such diversified subjects as design, materials, testing, computer interfacing and planning.

Microelectronics (Dave Bell)

The Microelectronics Laboratory provides the opportunity for students to develop research and engineering projects involving the design of electronic circuitry. Areas of focus include digital signal processing, digital control, instrumentation, analog and digital audio, and communications. The various elective courses offered through this laboratory provide a technological foundation which prepares students for senior research both in this and in other technology laboratories.

Oceanography and Geophysics (Lisa Wu)

The Oceanography and Geophysics Research Laboratory focuses on the biological and physical aspects of oceanography and the geophysical systems. Biological oceanography students work on projects in taxonomy, morphology, ecology, biogeography and evolutionary biology. Physical Oceanography students work on projects in tidal dynamics, ocean currents and ocean acoustics. Geophysical students work on projects in hydrology, geographical mapping, sedimentation and geophysical fluid dynamics. Students are expected to collect their own data from the marine environment on research vessels. Assistance in the form of ship-time and technical advice has come from the Oceanography Department of the United States Naval Academy, the Smithsonian Environmental Research Center, the Department of Systemic Biology of the National Museum of Natural History, and the Center for Coastal Physical Oceanography of Old Dominion University.

Optics and Modern Physics (Robert Latham)

The Optics and Modern Physics Laboratory provides exciting opportunities for students to develop research and engineering projects in the areas of pure and applied physics that include lens systems, fiber optics, human vision, interferometry, photography, color science, holography, optical computing, or other laser and optical systems. Research projects in modern physics explore areas of nuclear, atomic, electromagnetic, solid state, wave and quantum physics. Other students regularly make use of the laboratory's specialized technologies to develop projects with applications in a variety of other scientific and engineering areas. In addition to research, the laboratory supports elective courses in optics and quantum physics.

Prototyping and Engineering Materials (Rick Buxton)

The Prototyping and Engineering Materials Laboratory allows students, through research, to increase their understanding of the nature of a wide range of engineering materials. Students can also explore processes that are used to fabricate these materials. In addition to the research classes, two elective classes are taught through this laboratory. One, the Nature of Materials, is designed to introduce students to the families of engineering materials and to expose them to the physical properties of each. The second elective is Materials Processing. As Nature of Materials is designed to introduce students to the characteristics of materials, Materials Processing is designed to allow students to explore the various ways engineering materials can be fabricated. These electives are designed to lay a foundation for students who will be conducting research in the Prototyping and Engineering Materials Laboratory.

Videotechnology and Communications (Ed Montgomery)

Students in the Videotechnology and Communications Laboratory are involved in the technical side of developing video projects which inform or entertain the viewer. They adapt video technology to convert ideas into a finished visual product, including videos for Fairfax County Public Schools, promotional videos for community agencies and programs that cable-cast throughout the school. Serving as a resource facility, the Television Studio is used in a variety of interdisciplinary activities throughout the school. Students are given instruction on equipment operation and ongoing guidance as the projects progress. A study of the fundamentals of audio and video telecommunications equipment is incorporated.

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Last Modified: 11.2.2006

For non-technical questions, please visit our contact page in order to contact the correct party.

Thomas Jefferson High School for Science and Technology

IBET

IBET Showcase | Teams | Program Overview | Book Talks | Symposium | Resources

IBET Program Overview

The 9th Grade Integrated Biology, English and Technology Program is comprised of six teams of approximately seventy to eighty students each. Three teachers from each required subject (Biology, English 9 and Principles of Engineering and Technology) are teamed together with a counselor. The curriculum units of each discipline may be re-sequenced to complement the interdisciplinary focus. Approximately 80% of instruction is discipline-specific, with 20% focused on integrated environmental projects. As the school year progresses teachers become facilitators of learning as projects shift from teacher-directed to student-directed.

Each team's three classes are scheduled back to back in a block schedule format, providing teachers and students with the flexibility to manage their time according to the needs of projects, group meetings or frequent field trips. At the heart of this program is the opportunity to forge and nurture community partnerships where students learn about local issues by becoming active partners with community agencies and teachers while conducting authentic research. One example is field work done at Mason Neck National Wildlife Refuge where students are introduced to wetlands ecology and classification in Biology, library research and informational writing and reading in English, and survey methodologies, electronics and materials processing in Technology.

Student Webmaster: Andrew Deason
Faculty Curator: Richard Washer
Last Modified: 2.3.2006

For non-technical questions, please visit our contact page in order to contact the correct party.

Science Standards of Learning

for Virginia Public Schools

Adopted in January 2003 by the
Board of Education

Superintendent of Public Instruction
Jo Lynne DeMary

Commonwealth of Virginia
Board of Education
Post Office Box 2120
Richmond, VA 23218-2120

Table of Contents

Introduction

The Science Standards of Learning for Virginia's Public Schools identify academic content for essential components of the science curriculum at different grade levels. Standards are identified for kindergarten through grade five, for middle school, and for a core set of high school courses — Earth Science, Biology, Chemistry, and Physics. Throughout a student's science schooling from kindergarten through grade six, specific content strands, or topics, are included. These strands are

- Scientific Investigation, Reasoning, and Logic;
- Force, Motion, and Energy;
- Matter;
- Life Processes;
- Living Systems;
- Interrelationships in Earth/Space Systems;
- Earth Patterns, Cycles, and Change; and
- Resources.

The Standards of Learning in each strand progress in complexity at each grade level K-6 and are represented indirectly throughout the high school courses.

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 to select instructional strategies and assessment methods appropriate for their students.

Four key components of the science standards that are critical to implementation and necessary for student success in achieving science literacy are described below. It is imperative to science instruction that the local curriculum consider and address how these components are incorporated in the design of the kindergarten through high school science program.

Goals

The purposes of scientific investigation and discovery are to satisfy humankind's quest for knowledge and understanding and to preserve and enhance the quality of the human experience. Therefore, as a result of science instruction, students will be able to achieve the following objectives:

1. Develop and use an experimental design in scientific inquiry.
2. Use the language of science to communicate understanding.
3. Investigate phenomena, using technology.
4. Apply scientific concepts, skills, and processes to everyday experiences.
5. Experience the richness and excitement of scientific discovery of the natural world through the collaborative quest for knowledge and understanding.

6. Make informed decisions regarding contemporary issues, taking into account the following:
   - public policy and legislation;
   - economic costs/benefits;
   - validation from scientific data and the use of scientific reasoning and logic;
   - respect for living things;
   - personal responsibility; and
   - history of scientific discovery.
7. Develop scientific dispositions and habits of mind including:
   - curiosity;
   - demand for verification;
   - respect for logic and rational thinking;
   - consideration of premises and consequences;
   - respect for historical contributions;
   - attention to accuracy and precision; and
   - patience and persistence.
8. Explore science-related careers and interests.

K-12 Safety

In implementing the Science Standards of Learning, teachers must be certain that students know how to follow safety guidelines, demonstrate appropriate laboratory safety techniques, and use equipment safely while working individually and in groups.

Safety must be given the highest priority in implementing the K–12 instructional program for science. Correct and safe techniques, as well as wise selection of experiments, resources, materials, and field experiences appropriate to age levels, must be carefully considered with regard to the safety precautions for every instructional activity. Safe science classrooms require thorough planning, careful management, and constant monitoring of student activities. Class enrollment should not exceed the designed capacity of the room.

Teachers must be knowledgeable of the properties, use, and proper disposal of all chemicals that may be judged as hazardous prior to their use in an instructional activity. Such information is referenced through Materials Safety Data Sheets (MSDS). The identified precautions involving the use of goggles, gloves, aprons, and fume hoods must be followed as prescribed.

While no comprehensive list exists to cover all situations, the following should be reviewed to avoid potential safety problems. Appropriate safety procedures should be used in the following situations:

- observing wildlife; handling living and preserved organisms; and coming in contact with natural hazards, such as poison ivy, ticks, mushrooms, insects, spiders, and snakes;
- engaging in field activities in, near, or over bodies of water;

- handling glass tubing and other glassware, sharp objects, and labware;
- handling natural gas burners, Bunsen burners, and other sources of flame/heat;
- working in or with direct sunlight (sunburn and eye damage);
- using extreme temperatures and cryogenic materials;
- handling hazardous chemicals including toxins, carcinogens, and flammable and explosive materials;
- producing acid/base neutralization reactions/dilutions;
- producing toxic gases;
- generating/working with high pressures;
- working with biological cultures including their appropriate disposal and recombinant DNA;
- handling power equipment/motors;
- working with high voltage/exposed wiring; and
- working with laser beam, UV, and other radiation.

The use of human body fluids or tissues is generally prohibited for classroom lab activities. Further guidance from the following sources may be referenced:

- OSHA (Occupational Safety and Health Administration);
- ISEF (International Science and Engineering Fair Rules); and
- public health departments and local school division protocols.

Instructional Technology

The use of current and emerging technologies is essential to the K–12 science instructional program. Specifically, technology must accomplish the following:

- Assist in improving every student's functional literacy. This includes improved communication through reading/information retrieval (the use of telecommunications), writing (word processing), organization and analysis of data (databases, spreadsheets, and graphics programs), presentation of one's ideas (presentation software), and resource management (project management software).
- Be readily available and regularly used as an integral and ongoing part of the delivery and assessment of instruction.
- Include instrumentation oriented toward the instruction and learning of science concepts, skills, and processes. Technology, however, should not be limited to traditional instruments of science, such as microscopes, labware, and data-collecting apparatus, but should also include computers, robotics, interactive-optical laser discs, video-microscopes, graphing calculators, CD-ROMs, probeware, global positioning systems (GPS), online telecommunication, software and appropriate hardware, as well as other emerging technologies.
- Be reflected in the "instructional strategies" generally developed at the local school division level.

In most cases, the application of technology in science should remain "transparent" unless it is the actual focus of the instruction. One must expect students to "do as a scientist does" and not simply hear about science if they are truly expected to explore, explain, and apply scientific concepts, skills, and processes.

As computer/technology skills are essential components of every student's education, it is important that teaching these skills is a shared responsibility of teachers of all disciplines and grade levels.

Investigate and Understand

Many of the standards in the Science Standards of Learning begin with the phrase "Students will investigate and understand." This phrase was chosen to communicate the range of rigorous science skills and knowledge levels embedded in each standard. Limiting a standard to one observable behavior, such as "describe" or "explain," would have narrowed the interpretation of what was intended to be a rich, highly rigorous, and inclusive content standard.

"Investigate" refers to scientific methodology and implies systematic use of the following inquiry skills:

- observing;
- classifying and sequencing;
- communicating;
- measuring;
- predicting;
- hypothesizing;
- inferring;
- defining, controlling, and manipulating variables in experimentation;
- designing, constructing, and interpreting models; and
- interpreting, analyzing, and evaluating data.

"Understand" refers to various levels of knowledge application. In the Science Standards of Learning, these knowledge levels include the ability to

- recall or recognize important information, key definitions, terminology, and facts;
- explain the information in one's own words, comprehend how the information is related to other key facts, and suggest additional interpretations of its meaning or importance;
- apply the facts and principles to new problems or situations, recognizing what information is required for a particular situation, using the information to explain new phenomena, and determining when there are exceptions;
- analyze the underlying details of important facts and principles, recognizing the key relations and patterns that are not always readily visible;
- arrange and combine important facts, principles, and other information to produce a new idea, plan, procedure, or product; and
- make judgments about information in terms of its accuracy, precision, consistency, or effectiveness.

Therefore, the use of "investigate and understand" allows each content standard to become the basis for a broad range of teaching objectives, which the local school division will develop and refine to meet the intent of the Science Standards of Learning.

Kindergarten

The kindergarten standards stress the use of basic science skills to explore common materials, objects, and living things. Emphasis is placed on using the senses to gather information. Students are expected to develop skills in posing simple questions, measuring, sorting, classifying, and communicating information about the natural world. The science skills are an important focus as students learn about life processes and properties of familiar materials, such as magnets and water. Through phenomena including shadows, patterns of weather, and plant growth, students are introduced to the concept of change. The significance of natural resources and conservation is introduced in the kindergarten standards.

Scientific Investigation, Reasoning, and Logic

K.1 The student will conduct investigations in which
- a) basic properties of objects are identified by direct observation;
- b) observations are made from multiple positions to achieve different perspectives;
- c) objects are described both pictorially and verbally;
- d) a set of objects is sequenced according to size;
- e) a set of objects is separated into two groups based on a single physical attribute;
- f) nonstandard units are used to measure common objects;
- g) a question is developed from one or more observations;
- h) picture graphs are constructed using 10 or fewer units;
- i) an unseen member in a sequence of objects is predicted; and
- j) unusual or unexpected results in an activity are recognized.

K.2 Students will investigate and understand that humans have senses that allow one to seek, find, take in, and react or respond to information in order to learn about one's surroundings. Key concepts include
- a) five senses and corresponding sensing organs (taste – tongue, touch – skin, smell – nose, hearing – ears, and sight – eyes); and
- b) sensory descriptors (sweet, sour, bitter, salty, rough/smooth, hard/soft, cold, warm, hot, loud/soft, high/low, bright/dull).

Force, Motion, and Energy

K.3 The student will investigate and understand that magnets have an effect on some materials, make some things move without touching them, and have useful applications. Key concepts include
- a) attraction/nonattraction, push/pull, attract/repel, and metal/nonmetal; and
- b) useful applications (refrigerator magnet, can opener, magnetized screwdriver, and magnetic games).

Matter

K.4 The student will investigate and understand that the position, motion, and physical properties of an object can be described. Key concepts include
- a) colors (red, orange, yellow, green, blue, purple), white, and black;
- b) shapes (circle, triangle, square, and rectangle) and forms (flexible/stiff, straight/curved);
- c) textures (rough/smooth) and feel (hard/soft);
- d) relative size and weight (big/little, large/small, heavy/light, wide/thin, long/short); and
- e) position (over/under, in/out, above/below, left/right) and speed (fast/slow).

K.5 The student will investigate and understand that water flows and has properties that can be observed and tested. Key concepts include
a) water occurs in different states (solid, liquid, gas);
b) the natural flow of water is downhill; and
c) some materials float in water, while others sink.

Life Processes

K.6 The student will investigate and understand basic needs and life processes of plants and animals. Key concepts include
a) living things change as they grow, and they need food, water, and air to survive;
b) plants and animals live and die (go through a life cycle); and
c) offspring of plants and animals are similar but not identical to their parents and to one another.

Interrelationships in Earth/Space Systems

K.7 The student will investigate and understand that shadows occur when light is blocked by an object. Key concepts include
a) shadows occur in nature when sunlight is blocked by an object; and
b) shadows can be produced by blocking artificial light sources.

Earth Patterns, Cycles, and Change

K.8 The student will investigate and understand simple patterns in his/her daily life. Key concepts include
a) weather observations;
b) the shapes and forms of many common natural objects including seeds, cones, and leaves;
c) animal and plant growth; and
d) home and school routines.

K.9 The student will investigate and understand that change occurs over time and rates may be fast or slow. Key concepts include
a) natural and human-made things may change over time; and
b) changes can be noted and measured.

Resources

K.10 The student will investigate and understand that materials can be reused, recycled, and conserved. Key concepts include
a) materials and objects can be used over and over again;
b) everyday materials can be recycled; and
c) water and energy conservation at home and in school helps preserve resources for future use.

Grade One

The first-grade standards continue to stress basic science skills in understanding familiar objects and events. Students are expected to begin conducting simple experiments and be responsible for some of the planning. Students are introduced to the concept of classifying plants and animals based on simple characteristics. Emphasis is placed on the relationships among objects and their interactions with one another. Students are expected to know the basic relationships between the sun and Earth and between seasonal changes and plant and animal activities. Students will also begin to develop an understanding of moving objects, simple solutions, and important natural resources.

Scientific Investigation, Reasoning, and Logic

1.1 The student will conduct investigations in which
- a) differences in physical properties are observed using the senses;
- b) simple tools are used to enhance observations;
- c) objects or events are classified and arranged according to attributes or properties;
- d) observations and data are communicated orally and with simple graphs, pictures, written statements, and numbers;
- e) length, mass, and volume are measured using standard and nonstandard units;
- f) predictions are based on patterns of observation rather than random guesses;
- g) simple experiments are conducted to answer questions; and
- h) inferences are made and conclusions are drawn about familiar objects and events.

Force, Motion, and Energy

1.2 The student will investigate and understand that moving objects exhibit different kinds of motion. Key concepts include
- a) objects may have straight, circular, and back-and-forth motions;
- b) objects may vibrate and produce sound;
- c) pushes or pulls can change the movement of an object; and
- d) the motion of objects may be observed in toys and in playground activities.

Matter

1.3 The student will investigate and understand how different common materials interact with water. Key concepts include
- a) some liquids will separate when mixed with water, but others will not;
- b) some common solids will dissolve in water, but others will not; and
- c) some substances will dissolve more readily in hot water than in cold water.

Life Processes

1.4 The student will investigate and understand that plants have life needs and functional parts and can be classified according to certain characteristics. Key concepts include
- a) needs (food, air, water, light, and a place to grow);
- b) parts (seeds, roots, stems, leaves, blossoms, fruits); and
- c) characteristics (edible/nonedible, flowering/nonflowering, evergreen/deciduous).

1.5 The student will investigate and understand that animals, including people, have life needs and specific physical characteristics and can be classified according to certain characteristics. Key concepts include

a) life needs (air, food, water, and a suitable place to live);
b) physical characteristics (body coverings, body shape, appendages, and methods of movement); and
c) other characteristics (wild/tame, water homes/land homes).

Interrelationships in Earth/Space Systems

1.6 The student will investigate and understand the basic relationships between the sun and the Earth. Key concepts include

a) the sun is the source of heat and light that warms the land, air, and water; and
b) night and day are caused by the rotation of the Earth.

Earth Patterns, Cycles, and Change

1.7 The student will investigate and understand the relationship of seasonal change and weather to the activities and life processes of plants and animals. Key concepts include how temperature, light, and precipitation bring about changes in

a) plants (growth, budding, falling leaves, and wilting);
b) animals (behaviors, hibernation, migration, body covering, and habitat); and
c) people (dress, recreation, and work).

Resources

1.8 The student will investigate and understand that natural resources are limited. Key concepts include

a) identification of natural resources (plants and animals, water, air, land, minerals, forests, and soil);
b) factors that affect air and water quality; and
c) recycling, reusing, and reducing consumption of natural resources.

Grade Two

The second-grade standards continue to focus on using a broad range of science skills in understanding the natural world. Making detailed observations, drawing conclusions, and recognizing unusual or unexpected data are stressed as skills needed for using and validating information. Measurement in both English and metric units is stressed. The idea of living systems is introduced through habitats and the interdependence of living and nonliving things. The concept of change is explored in states of matter, life cycles, weather patterns, and seasonal effects on plants and animals.

Scientific Investigation, Reasoning, and Logic

2.1 The student will conduct investigations in which
- a) observation is differentiated from personal interpretation, and conclusions are drawn based on observations;
- b) observations are repeated to ensure accuracy;
- c) two or more attributes are used to classify items;
- d) conditions that influence a change are defined;
- e) length, volume, mass, and temperature measurements are made in metric units (centimeters, meters, liters, degrees Celsius, grams, kilograms) and standard English units (inches, feet, yards, cups, pints, quarts, gallons, degrees Fahrenheit, ounces, pounds);
- f) pictures and bar graphs are constructed using numbered axes;
- g) unexpected or unusual quantitative data are recognized; and
- h) simple physical models are constructed.

Force, Motion, and Energy

2.2 The student will investigate and understand that natural and artificial magnets have certain characteristics and attract specific types of metals. Key concepts include
- a) magnetism, iron, magnetic/nonmagnetic, poles, attract/repel; and
- b) important applications of magnetism including the magnetic compass.

Matter

2.3 The student will investigate and understand basic properties of solids, liquids, and gases. Key concepts include
- a) mass and volume; and
- b) processes involved with changes in matter from one state to another (condensation, evaporation, melting, and freezing).

Life Processes

2.4 The student will investigate and understand that plants and animals undergo a series of orderly changes in their life cycles. Key concepts include
- a) some animals (frogs and butterflies) undergo distinct stages during their lives, while others generally resemble their parents; and
- b) flowering plants undergo many changes, from the formation of the flower to the development of the fruit.

Living Systems

2.5 The student will investigate and understand that living things are part of a system. Key concepts include
- a) living organisms are interdependent with their living and nonliving surroundings; and
- b) habitats change over time due to many influences.

Interrelationships in Earth/Space Systems

2.6 The student will investigate and understand basic types, changes, and patterns of weather. Key concepts include
- a) temperature, wind, precipitation, drought, flood, and storms; and
- b) the uses and importance of measuring and recording weather data.

Earth Patterns, Cycles, and Change

2.7 The student will investigate and understand that weather and seasonal changes affect plants, animals, and their surroundings. Key concepts include
- a) effects on growth and behavior of living things (migration, hibernation, camouflage, adaptation, dormancy); and
- b) weathering and erosion of the land surface.

Resources

2.8 The student will investigate and understand that plants produce oxygen and food, are a source of useful products, and provide benefits in nature. Key concepts include
- a) important plant products (fiber, cotton, oil, spices, lumber, rubber, medicines, and paper);
- b) the availability of plant products affects the development of a geographic area; and
- c) plants provide homes and food for many animals and prevent soil from washing away.

Grade Three

The third-grade standards place increasing emphasis on conducting investigations. Students are expected to be able to develop questions, formulate simple hypotheses, make predictions, gather data, and use the metric system with greater precision. Using information to make inferences and draw conclusions becomes more important. In the area of physical science, the standards focus on simple and compound machines, energy, and a basic understanding of matter. Behavioral and physical adaptations are examined in relation to the life needs of animals. The notion of living systems is further explored in aquatic and terrestrial food chains and diversity in environments. Patterns in the natural world are demonstrated in terms of the phases of the moon, tides, seasonal changes, the water cycle, and animal life cycles. Geological concepts are introduced through the investigation of the components of soil.

Scientific Investigation, Reasoning, and Logic

3.1 The student will plan and conduct investigations in which
- a) predictions and observations are made;
- b) objects with similar characteristics are classified into at least two sets and two subsets;
- c) questions are developed to formulate hypotheses;
- d) volume is measured to the nearest milliliter and liter;
- e) length is measured to the nearest centimeter;
- f) mass is measured to the nearest gram;
- g) data are gathered, charted, and graphed (line plot, picture graph, and bar graph);
- h) temperature is measured to the nearest degree Celsius;
- i) time is measured to the nearest minute;
- j) inferences are made and conclusions are drawn; and
- k) natural events are sequenced chronologically.

Force, Motion, and Energy

3.2 The student will investigate and understand simple machines and their uses. Key concepts include
- a) types of simple machines (lever, screw, pulley, wheel and axle, inclined plane, and wedge);
- b) how simple machines function;
- c) compound machines (scissors, wheelbarrow, and bicycle); and
- d) examples of simple and compound machines found in the school, home, and work environment.

Matter

3.3 The student will investigate and understand that objects are made of materials that can be described by their physical properties. Key concepts include
- a) objects are made of one or more materials;
- b) materials are composed of parts that are too small to be seen without magnification; and
- c) physical properties remain the same as the material is reduced in size.

Life Processes

3.4 The student will investigate and understand that behavioral and physical adaptations allow animals to respond to life needs. Key concepts include
a) methods of gathering and storing food, finding shelter, defending themselves, and rearing young; and
b) hibernation, migration, camouflage, mimicry, instinct, and learned behavior.

Living Systems

3.5 The student will investigate and understand relationships among organisms in aquatic and terrestrial food chains. Key concepts include
a) producer, consumer, decomposer;
b) herbivore, carnivore, omnivore; and
c) predator and prey.

3.6 The student will investigate and understand that environments support a diversity of plants and animals that share limited resources. Key concepts include
a) water-related environments (pond, marshland, swamp, stream, river, and ocean environments);
b) dry-land environments (desert, grassland, rain forest, and forest environments); and
c) population and community.

Interrelationships in Earth/Space Systems

3.7 The student will investigate and understand the major components of soil, its origin, and importance to plants and animals including humans. Key concepts include
a) soil provides the support and nutrients necessary for plant growth;
b) topsoil is a natural product of subsoil and bedrock;
c) rock, clay, silt, sand, and humus are components of soils; and
d) soil is a natural resource and should be conserved.

Earth Patterns, Cycles, and Change

3.8 The student will investigate and understand basic patterns and cycles occurring in nature. Key concepts include
a) patterns of natural events (day and night, seasonal changes, phases of the moon, and tides); and
b) animal and plant life cycles.

3.9 The student will investigate and understand the water cycle and its relationship to life on Earth. Key concepts include
a) the energy from the sun drives the water cycle;
b) processes involved in the water cycle (evaporation, condensation, precipitation);
c) water is essential for living things; and
d) water supply and water conservation.

Resources

3.10 The student will investigate and understand that natural events and human influences can affect the survival of species. Key concepts include

a) the interdependency of plants and animals;
b) the effects of human activity on the quality of air, water, and habitat;
c) the effects of fire, flood, disease, and erosion on organisms; and
d) conservation and resource renewal.

3.11 The student will investigate and understand different sources of energy. Key concepts include

a) the sun's ability to produce light and heat energy;
b) sources of energy (sunlight, water, wind);
c) fossil fuels (coal, oil, natural gas) and wood; and
d) renewable and nonrenewable energy resources.

Grade Four

The fourth-grade standards stress the importance of using information, analyzing data, and validating experimental results. Defining variables in experimentation is emphasized, and making simple predictions from picture, bar, and basic line graphs is underscored. Questioning and hypothesizing become more detailed at this level. Students are introduced to basic principles of electricity and to the concept of motion. Relationships are investigated in the interactions among the Earth, moon, and sun and among plants and animals and their environments. In examining weather phenomena and conditions, students identify various factors, make predictions based on data, and evaluate the results. The importance of natural resources in Virginia is emphasized.

Scientific Investigation, Reasoning, and Logic

4.1 The student will plan and conduct investigations in which
- a) distinctions are made among observations, conclusions, inferences, and predictions;
- b) hypotheses are formulated based on cause-and-effect relationships;
- c) variables that must be held constant in an experimental situation are defined;
- d) appropriate instruments are selected to measure linear distance, volume, mass, and temperature;
- e) appropriate metric measures are used to collect, record, and report data;
- f) data are displayed using bar and basic line graphs;
- g) numerical data that are contradictory or unusual in experimental results are recognized; and
- h) predictions are made based on data from picture graphs, bar graphs, and basic line graphs.

Force, Motion, and Energy

4.2 The student will investigate and understand characteristics and interaction of moving objects. Key concepts include
- a) motion is described by an object's direction and speed;
- b) forces cause changes in motion;
- c) friction is a force that opposes motion; and
- d) moving objects have kinetic energy.

4.3 The student will investigate and understand the characteristics of electricity. Key concepts include
- a) conductors and insulators;
- b) basic circuits (open/closed, parallel/series);
- c) static electricity;
- d) the ability of electrical energy to be transformed into heat, light, and mechanical energy;
- e) simple electromagnets and magnetism; and
- f) historical contributions in understanding electricity.

Life Processes

4.4 The student will investigate and understand basic plant anatomy and life processes. Key concepts include
   a) the structures of typical plants (leaves, stems, roots, and flowers);
   b) processes and structures involved with reproduction (pollination, stamen, pistil, sepal, embryo, spore, and seed);
   c) photosynthesis (sunlight, chlorophyll, water, carbon dioxide, oxygen, and sugar); and
   d) dormancy.

Living Systems

4.5 The student will investigate and understand how plants and animals in an ecosystem interact with one another and the nonliving environment. Key concepts include
   a) behavioral and structural adaptations;
   b) organization of communities;
   c) flow of energy through food webs;
   d) habitats and niches;
   e) life cycles; and
   f) influence of human activity on ecosystems.

Interrelationships in Earth/Space Systems

4.6 The student will investigate and understand how weather conditions and phenomena occur and can be predicted. Key concepts include
   a) weather measurements and meteorological tools (air pressure – barometer, wind speed – anemometer, rainfall – rain gauge, and temperature – thermometer); and
   b) weather phenomena (fronts, clouds, and storms).

Earth Patterns, Cycles, and Change

4.7 The student will investigate and understand the relationships among the Earth, moon, and sun. Key concepts include
   a) the motions of the Earth, moon, and sun (revolution and rotation);
   b) the causes for the Earth's seasons and phases of the moon;
   c) the relative size, position, age, and makeup of the Earth, moon, and sun; and
   d) historical contributions in understanding the Earth-moon-sun system.

Resources

4.8 The student will investigate and understand important Virginia natural resources. Key concepts include
   a) watershed and water resources;
   b) animals and plants;
   c) minerals, rocks, ores, and energy sources; and
   d) forests, soil, and land.

Grade Five

The fifth-grade standards emphasize the importance of selecting appropriate instruments for measuring and recording observations. The organization, analysis, and application of data continue to be an important focus of classroom inquiry. Science skills from preceding grades, including questioning, using and validating evidence, and systematic experimentation, are reinforced at this level. Students are introduced to more detailed concepts of sound and light and the tools used for studying them. Key concepts of matter, including those about atoms, molecules, elements, and compounds, are studied, and the properties of matter are defined in greater detail. The cellular makeup of organisms and the distinguishing characteristics of groups of organisms are stressed. Students learn about the characteristics of the oceans and the Earth's changing surface.

The fifth-grade standards focus on student growth in understanding the nature of science. This scientific view defines the idea that explanations of nature are developed and tested using observation, experimentation, models, evidence, and systematic processes. The nature of science includes the concepts that scientific explanations are based on logical thinking; are subject to rules of evidence; are consistent with observational, inferential, and experimental evidence; are open to rational critique; and are subject to refinement and change with the addition of new scientific evidence. The nature of science includes the concept that science can provide explanations about nature, can predict potential consequences of actions, but cannot be used to answer all questions.

Scientific Investigation, Reasoning, and Logic

5.1 The student will plan and conduct investigations in which
- a) rocks, minerals, and organisms are identified using a classification key;
- b) estimations of length, mass, and volume are made;
- c) appropriate instruments are selected and used for making quantitative observations of length, mass, volume, and elapsed time;
- d) accurate measurements are made using basic tools (thermometer, meter stick, balance, graduated cylinder);
- e) data are collected, recorded, and reported using the appropriate graphical representation (graphs, charts, diagrams);
- f) predictions are made using patterns, and simple graphical data are extrapolated;
- g) manipulated and responding variables are identified; and
- h) an understanding of the nature of science is developed and reinforced.

Force, Motion, and Energy

5.2 The student will investigate and understand how sound is transmitted and is used as a means of communication. Key concepts include
- a) frequency, waves, wavelength, vibration;
- b) the ability of different media (solids, liquids, and gases) to transmit sound; and
- c) uses and applications (voice, sonar, animal sounds, and musical instruments).

5.3 The student will investigate and understand basic characteristics of visible light and how it behaves. Key concepts include
- a) the visible spectrum and light waves;
- b) refraction of light through water and prisms;
- c) reflection of light from reflective surfaces (mirrors);
- d) opaque, transparent, and translucent; and
- e) historical contributions in understanding light.

Matter

5.4 The student will investigate and understand that matter is anything that has mass, takes up space, and occurs as a solid, liquid, or gas. Key concepts include
- a) atoms, elements, molecules, and compounds;
- b) mixtures including solutions; and
- c) the effect of heat on the states of matter.

Living Systems

5.5 The student will investigate and understand that organisms are made of cells and have distinguishing characteristics. Key concepts include
- a) basic cell structures and functions;
- b) kingdoms of living things;
- c) vascular and nonvascular plants; and
- d) vertebrates and invertebrates.

Interrelationships in Earth/Space Systems

5.6 The student will investigate and understand characteristics of the ocean environment. Key concepts include
- a) geological characteristics (continental shelf, slope, rise);
- b) physical characteristics (depth, salinity, major currents); and
- c) biological characteristics (ecosystems).

Earth Patterns, Cycles, and Change

5.7 The student will investigate and understand how the Earth's surface is constantly changing. Key concepts include
- a) the rock cycle including identification of rock types;
- b) Earth history and fossil evidence;
- c) the basic structure of the Earth's interior;
- d) plate tectonics (earthquakes and volcanoes);
- e) weathering and erosion; and
- f) human impact.

Grade Six

The sixth-grade standards continue to emphasize data analysis and experimentation. Methods are studied for testing the validity of predictions and conclusions. Scientific methodology, focusing on precision in stating hypotheses and defining dependent and independent variables, is strongly reinforced. The concept of change is explored through the study of transformations of energy and matter. The standards present an integrated focus on the role of the sun's energy in the Earth's systems, on water in the environment, on air and atmosphere, and on basic chemistry concepts. A more detailed understanding of the solar system and space exploration becomes a focus of instruction. Natural resource management, its relation to public policy, and cost/benefit tradeoffs in conservation policies are introduced.

The sixth-grade standards continue to focus on student growth in understanding the nature of science. This scientific view defines the idea that explanations of nature are developed and tested using observation, experimentation, models, evidence, and systematic processes. The nature of science includes the concepts that scientific explanations are based on logical thinking; are subject to rules of evidence; are consistent with observational, inferential, and experimental evidence; are open to rational critique; and are subject to refinement and change with the addition of new scientific evidence. The nature of science includes the concept that science can provide explanations about nature, can predict potential consequences of actions, but cannot be used to answer all questions.

Scientific Investigation, Reasoning, and Logic

6.1 The student will plan and conduct investigations in which

a) observations are made involving fine discrimination between similar objects and organisms;
b) a classification system is developed based on multiple attributes;
c) precise and approximate measurements are recorded;
d) scale models are used to estimate distance, volume, and quantity;
e) hypotheses are stated in ways that identify the independent (manipulated) and dependent (responding) variables;
f) a method is devised to test the validity of predictions and inferences;
g) one variable is manipulated over time, using many repeated trials;
h) data are collected, recorded, analyzed, and reported using appropriate metric measurements;
i) data are organized and communicated through graphical representation (graphs, charts, and diagrams);
j) models are designed to explain a sequence; and
k) an understanding of the nature of science is developed and reinforced.

Force, Motion, and Energy

6.2 The student will investigate and understand basic sources of energy, their origins, transformations, and uses. Key concepts include

a) potential and kinetic energy;
b) the role of the sun in the formation of most energy sources on Earth;
c) nonrenewable energy sources (fossil fuels including petroleum, natural gas, and coal);
d) renewable energy sources (wood, wind, hydro, geothermal, tidal, and solar); and
e) energy transformations (heat/light to mechanical, chemical, and electrical energy).

6.3 The student will investigate and understand the role of solar energy in driving most natural processes within the atmosphere, the hydrosphere, and on the Earth's surface. Key concepts include

a) the Earth's energy budget;
b) the role of radiation and convection in the distribution of energy;
c) the motion of the atmosphere and the oceans;
d) cloud formation; and
e) the role of heat energy in weather-related phenomena including thunderstorms and hurricanes.

Matter

6.4 The student will investigate and understand that all matter is made up of atoms. Key concepts include

a) atoms are made up of electrons, protons, and neutrons;
b) atoms of any element are alike but are different from atoms of other elements;
c) elements may be represented by chemical symbols;
d) two or more atoms may be chemically combined;
e) compounds may be represented by chemical formulas;
f) chemical equations can be used to model chemical changes; and
g) a limited number of elements comprise the largest portion of the solid Earth, living matter, the oceans, and the atmosphere.

6.5 The student will investigate and understand the unique properties and characteristics of water and its roles in the natural and human-made environment. Key concepts include

a) water as the universal solvent;
b) the properties of water in all three states;
c) the action of water in physical and chemical weathering;
d) the ability of large bodies of water to store heat and moderate climate;
e) the origin and occurrence of water on Earth;
f) the importance of water for agriculture, power generation, and public health; and
g) the importance of protecting and maintaining water resources.

6.6 The student will investigate and understand the properties of air and the structure and dynamics of the Earth's atmosphere. Key concepts include

a) air as a mixture of gaseous elements and compounds;
b) air pressure, temperature, and humidity;
c) how the atmosphere changes with altitude;
d) natural and human-caused changes to the atmosphere;
e) the relationship of atmospheric measures and weather conditions;
f) basic information from weather maps including fronts, systems, and basic measurements; and
g) the importance of protecting and maintaining air quality.

Living Systems

6.7 The student will investigate and understand the natural processes and human interactions that affect watershed systems. Key concepts include
- a) the health of ecosystems and the abiotic factors of a watershed;
- b) the location and structure of Virginia's regional watershed systems;
- c) divides, tributaries, river systems, and river and stream processes;
- d) wetlands;
- e) estuaries;
- f) major conservation, health, and safety issues associated with watersheds; and
- g) water monitoring and analysis using field equipment including hand-held technology.

Interrelationships in Earth/Space Systems

6.8 The student will investigate and understand the organization of the solar system and the relationships among the various bodies that comprise it. Key concepts include
- a) the sun, moon, Earth, other planets and their moons, meteors, asteroids, and comets;
- b) relative size of and distance between planets;
- c) the role of gravity;
- d) revolution and rotation;
- e) the mechanics of day and night and the phases of the moon;
- f) the unique properties of Earth as a planet;
- g) the relationship of the Earth's tilt and the seasons;
- h) the cause of tides; and
- i) the history and technology of space exploration.

Resources

6.9 The student will investigate and understand public policy decisions relating to the environment. Key concepts include
- a) management of renewable resources (water, air, soil, plant life, animal life);
- b) management of nonrenewable resources (coal, oil, natural gas, nuclear power, mineral resources);
- c) the mitigation of land-use and environmental hazards through preventive measures; and
- d) cost/benefit tradeoffs in conservation policies.

Life Science

The Life Science standards emphasize a more complex understanding of change, cycles, patterns, and relationships in the living world. Students build on basic principles related to these concepts by exploring the cellular organization and the classification of organisms; the dynamic relationships among organisms, populations, communities, and ecosystems; and change as a result of the transmission of genetic information from generation to generation. Inquiry skills at this level include organization and mathematical analysis of data, manipulation of variables in experiments, and identification of sources of experimental error.

The Life Science standards continue to focus on student growth in understanding the nature of science. This scientific view defines the idea that explanations of nature are developed and tested using observation, experimentation, models, evidence, and systematic processes. The nature of science includes the concepts that scientific explanations are based on logical thinking; are subject to rules of evidence; are consistent with observational, inferential, and experimental evidence; are open to rational critique; and are subject to refinement and change with the addition of new scientific evidence. The nature of science includes the concept that science can provide explanations about nature, can predict potential consequences of actions, but cannot be used to answer all questions.

LS.1 The student will plan and conduct investigations in which
- a) data are organized into tables showing repeated trials and means;
- b) variables are defined;
- c) metric units (SI—International System of Units) are used;
- d) models are constructed to illustrate and explain phenomena;
- e) sources of experimental error are identified;
- f) dependent variables, independent variables, and constants are identified;
- g) variables are controlled to test hypotheses, and trials are repeated;
- h) continuous line graphs are constructed, interpreted, and used to make predictions;
- i) interpretations from a set of data are evaluated and defended; and
- j) an understanding of the nature of science is developed and reinforced.

LS.2 The student will investigate and understand that all living things are composed of cells. Key concepts include
- a) cell structure and organelles (cell membrane, cell wall, cytoplasm, vacuole, mitochondrion, endoplasmic reticulum, nucleus, and chloroplast);
- b) similarities and differences between plant and animal cells;
- c) development of cell theory; and
- d) cell division (mitosis and meiosis).

LS.3 The student will investigate and understand that living things show patterns of cellular organization. Key concepts include
- a) cells, tissues, organs, and systems; and
- b) life functions and processes of cells, tissues, organs, and systems (respiration, removal of wastes, growth, reproduction, digestion, and cellular transport).

LS.4 The student will investigate and understand that the basic needs of organisms must be met in order to carry out life processes. Key concepts include
- a) plant needs (light, water, gases, and nutrients);
- b) animal needs (food, water, gases, shelter, space); and
- c) factors that influence life processes.

LS.5 The student will investigate and understand how organisms can be classified. Key concepts include

a) the distinguishing characteristics of kingdoms of organisms;
b) the distinguishing characteristics of major animal and plant phyla; and
c) the characteristics of the species.

LS.6 The student will investigate and understand the basic physical and chemical processes of photosynthesis and its importance to plant and animal life. Key concepts include

a) energy transfer between sunlight and chlorophyll;
b) transformation of water and carbon dioxide into sugar and oxygen; and
c) photosynthesis as the foundation of virtually all food webs.

LS.7 The student will investigate and understand that organisms within an ecosystem are dependent on one another and on nonliving components of the environment. Key concepts include

a) the carbon, water, and nitrogen cycles;
b) interactions resulting in a flow of energy and matter throughout the system;
c) complex relationships within terrestrial, freshwater, and marine ecosystems; and
d) energy flow in food webs and energy pyramids.

LS.8 The student will investigate and understand that interactions exist among members of a population. Key concepts include

a) competition, cooperation, social hierarchy, territorial imperative; and
b) influence of behavior on a population.

LS.9 The student will investigate and understand interactions among populations in a biological community. Key concepts include

a) the relationships among producers, consumers, and decomposers in food webs;
b) the relationship between predators and prey;
c) competition and cooperation;
d) symbiotic relationships; and
e) niches.

LS.10 The student will investigate and understand how organisms adapt to biotic and abiotic factors in an ecosystem. Key concepts include

a) differences between ecosystems and biomes;
b) characteristics of land, marine, and freshwater ecosystems; and
c) adaptations that enable organisms to survive within a specific ecosystem.

LS.11 The student will investigate and understand that ecosystems, communities, populations, and organisms are dynamic and change over time (daily, seasonal, and long term). Key concepts include

a) phototropism, hibernation, and dormancy;
b) factors that increase or decrease population size; and
c) eutrophication, climate changes, and catastrophic disturbances.

LS.12 The student will investigate and understand the relationships between ecosystem dynamics and human activity. Key concepts include

a) food production and harvest;
b) change in habitat size, quality, or structure;
c) change in species competition;
d) population disturbances and factors that threaten or enhance species survival; and
e) environmental issues (water supply, air quality, energy production, and waste management).

LS.13 The student will investigate and understand that organisms reproduce and transmit genetic information to new generations. Key concepts include

a) the role of DNA;
b) the function of genes and chromosomes;
c) genotypes and phenotypes;
d) factors affecting the expression of traits;
e) characteristics that can and cannot be inherited;
f) genetic engineering and its applications; and
g) historical contributions and significance of discoveries related to genetics.

LS.14 The student will investigate and understand that organisms change over time. Key concepts include

a) the relationships of mutation, adaptation, natural selection, and extinction;
b) evidence of evolution of different species in the fossil record; and
c) how environmental influences, as well as genetic variation, can lead to diversity of organisms.

Physical Science

The Physical Science standards continue to build on skills of systematic investigation with a clear focus on variables and repeated trials. Validating conclusions using evidence and data becomes increasingly important at this level. Students will plan and conduct research involving both classroom experimentation and literature reviews from written and electronic resources. Research methods and skills highlight practical problems and questions. Students will share their work, using written reports and other presentations.

The Physical Science standards stress an in-depth understanding of the nature and structure of matter and the characteristics of energy. The standards place considerable emphasis on the technological application of physical science principles. Major areas covered by the standards include the organization and use of the periodic table; physical and chemical changes; nuclear reactions; temperature and heat; sound; light; electricity and magnetism; and work, force, and motion.

The Physical Science standards continue to focus on student growth in understanding the nature of science. This scientific view defines the idea that explanations of nature are developed and tested using observation, experimentation, models, evidence, and systematic processes. The nature of science includes the concepts that scientific explanations are based on logical thinking; are subject to rules of evidence; are consistent with observational, inferential, and experimental evidence; are open to rational critique; and are subject to refinement and change with the addition of new scientific evidence. The nature of science includes the concept that science can provide explanations about nature, can predict potential consequences of actions, but cannot be used to answer all questions.

PS.1 The student will plan and conduct investigations in which
- a) chemicals and equipment are used safely;
- b) length, mass, volume, density, temperature, weight, and force are accurately measured and reported using metric units (SI—International System of Units);
- c) conversions are made among metric units, applying appropriate prefixes;
- d) triple beam and electronic balances, thermometers, metric rulers, graduated cylinders, and spring scales are used to gather data;
- e) numbers are expressed in scientific notation where appropriate;
- f) research skills are utilized using a variety of resources;
- g) independent and dependent variables, constants, controls, and repeated trials are identified;
- h) data tables showing the independent and dependent variables, derived quantities, and the number of trials are constructed and interpreted;
- i) data tables for descriptive statistics showing specific measures of central tendency, the range of the data set, and the number of repeated trials are constructed and interpreted;
- j) frequency distributions, scattergrams, line plots, and histograms are constructed and interpreted;
- k) valid conclusions are made after analyzing data;
- l) research methods are used to investigate practical problems and questions;
- m) experimental results are presented in appropriate written form; and
- n) an understanding of the nature of science is developed and reinforced.

PS.2 The student will investigate and understand the basic nature of matter. Key concepts include
a) the particle theory of matter;
b) elements, compounds, mixtures, acids, bases, and salts;
c) solids, liquids, and gases;
d) characteristics of types of matter based on physical and chemical properties;
e) physical properties (shape, density, solubility, odor, melting point, boiling point, color); and
f) chemical properties (acidity, basicity, combustibility, reactivity).

PS.3 The student will investigate and understand the modern and historical models of atomic structure. Key concepts include
a) the contributions of Dalton, Thomson, Rutherford, and Bohr in understanding the atom; and
b) the modern model of atomic structure.

PS.4 The student will investigate and understand the organization and use of the periodic table of elements to obtain information. Key concepts include
a) symbols, atomic number, atomic mass, chemical families (groups), and periods;
b) classification of elements as metals, metalloids, and nonmetals; and
c) simple compounds (formulas and the nature of bonding).

PS.5 The student will investigate and understand changes in matter and the relationship of these changes to the Law of Conservation of Matter and Energy. Key concepts include
a) physical changes;
b) nuclear reactions (products of fusion and fission and the effect of these products on humans and the environment); and
c) chemical changes (types of reactions, reactants, and products; and balanced equations).

PS.6 The student will investigate and understand states and forms of energy and how energy is transferred and transformed. Key concepts include
a) potential and kinetic energy;
b) mechanical, chemical, and electrical energy; and
c) heat, light, and sound.

PS.7 The student will investigate and understand temperature scales, heat, and heat transfer. Key concepts include
a) Celsius and Kelvin temperature scales and absolute zero;
b) phase change, freezing point, melting point, boiling point, vaporization, and condensation;
c) conduction, convection, and radiation; and
d) applications of heat transfer (heat engines, thermostats, refrigeration, and heat pumps).

PS.8 The student will investigate and understand characteristics of sound and technological applications of sound waves. Key concepts include
a) wavelength, frequency, speed, and amplitude;
b) resonance;
c) the nature of mechanical waves; and
d) technological applications of sound.

PS.9 The student will investigate and understand the nature and technological applications of light. Key concepts include
a) the wave behavior of light (reflection, refraction, diffraction, and interference);
b) images formed by lenses and mirrors; and
c) the electromagnetic spectrum.

PS.10 The student will investigate and understand scientific principles and technological applications of work, force, and motion. Key concepts include

a) speed, velocity, and acceleration;
b) Newton's laws of motion;
c) work, force, mechanical advantage, efficiency, and power; and
d) applications (simple machines, compound machines, powered vehicles, rockets, and restraining devices).

PS.11 The student will investigate and understand basic principles of electricity and magnetism. Key concepts include

a) static electricity, current electricity, and circuits;
b) magnetic fields and electromagnets; and
c) motors and generators.

Earth Science

The Earth Science standards connect the study of the Earth's composition, structure, processes, and history; its atmosphere, fresh water, and oceans; and its environment in space. The standards emphasize historical contributions in the development of scientific thought about the Earth and space. The standards stress the interpretation of maps, charts, tables, and profiles; the use of technology to collect, analyze, and report data; and the utilization of science skills in systematic investigation. Problem solving and decision making are an integral part of the standards, especially as they relate to the costs and benefits of utilizing the Earth's resources. Major topics of study include plate tectonics, the rock cycle, Earth history, the oceans, the atmosphere, weather and climate, and the solar system and universe.

The Earth Science standards continue to focus on student growth in understanding the nature of science. This scientific view defines the idea that explanations of nature are developed and tested using observation, experimentation, models, evidence, and systematic processes. The nature of science includes the concepts that scientific explanations are based on logical thinking; are subject to rules of evidence; are consistent with observational, inferential, and experimental evidence; are open to rational critique; and are subject to refinement and change with the addition of new scientific evidence. The nature of science includes the concept that science can provide explanations about nature, can predict potential consequences of actions, but cannot be used to answer all questions.

ES.1 The student will plan and conduct investigations in which
- a) volume, area, mass, elapsed time, direction, temperature, pressure, distance, density, and changes in elevation/depth are calculated utilizing the most appropriate tools;
- b) technologies including computers, probeware, and global positioning systems (GPS), are used to collect, analyze, and report data and to demonstrate concepts and simulate experimental conditions;
- c) scales, diagrams, maps, charts, graphs, tables, and profiles are constructed and interpreted;
- d) variables are manipulated with repeated trials; and
- e) a scientific viewpoint is constructed and defended (the nature of science).

ES.2 The student will demonstrate scientific reasoning and logic by
- a) analyzing how science explains and predicts the interactions and dynamics of complex Earth systems;
- b) recognizing that evidence is required to evaluate hypotheses and explanations;
- c) comparing different scientific explanations for a set of observations about the Earth;
- d) explaining that observation and logic are essential for reaching a conclusion; and
- e) evaluating evidence for scientific theories.

ES.3 The student will investigate and understand how to read and interpret maps, globes, models, charts, and imagery. Key concepts include
- a) maps (bathymetric, geologic, topographic, and weather) and star charts;
- b) imagery (aerial photography and satellite images);
- c) direction and measurements of distance on any map or globe; and
- d) location by latitude and longitude and topographic profiles.

ES.4 The student will investigate and understand the characteristics of the Earth and the solar system. Key concepts include
a) position of the Earth in the solar system;
b) sun-Earth-moon relationships (seasons, tides, and eclipses);
c) characteristics of the sun, planets and their moons, comets, meteors, and asteroids; and
d) the history and contributions of the space program.

ES.5 The student will investigate and understand how to identify major rock-forming and ore minerals based on physical and chemical properties. Key concepts include
a) hardness, color and streak, luster, cleavage, fracture, and unique properties; and
b) uses of minerals.

ES.6 The student will investigate and understand the rock cycle as it relates to the origin and transformation of rock types and how to identify common rock types based on mineral composition and textures. Key concepts include
a) igneous (intrusive and extrusive) rocks;
b) sedimentary (clastic and chemical) rocks; and
c) metamorphic (foliated and unfoliated) rocks.

ES.7 The student will investigate and understand the differences between renewable and nonrenewable resources. Key concepts include
a) fossil fuels, minerals, rocks, water, and vegetation;
b) advantages and disadvantages of various energy sources;
c) resources found in Virginia;
d) making informed judgments related to resource use and its effects on Earth systems; and
e) environmental costs and benefits.

ES.8 The student will investigate and understand geologic processes including plate tectonics. Key concepts include
a) how geologic processes are evidenced in the physiographic provinces of Virginia including the Coastal Plain, Piedmont, Blue Ridge, Valley and Ridge, and Appalachian Plateau;
b) processes (faulting, folding, volcanism, metamorphism, weathering, erosion, deposition, and sedimentation) and their resulting features; and
c) tectonic processes (subduction, rifting and sea floor spreading, and continental collision).

ES.9 The student will investigate and understand how freshwater resources are influenced by geologic processes and the activities of humans. Key concepts include
a) processes of soil development;
b) development of karst topography;
c) identification of groundwater zones including the water table, zone of saturation, and zone of aeration;
d) identification of other sources of fresh water including rivers, springs, and aquifers, with reference to the hydrologic cycle;
e) dependence on freshwater resources and the effects of human usage on water quality; and
f) identification of the major watershed systems in Virginia including the Chesapeake Bay and its tributaries.

ES.10 The student will investigate and understand that many aspects of the history and evolution of the Earth and life can be inferred by studying rocks and fossils. Key concepts include

a) traces and remains of ancient, often extinct, life are preserved by various means in many sedimentary rocks;
b) superposition, cross-cutting relationships, index fossils, and radioactive decay are methods of dating bodies of rock;
c) absolute and relative dating have different applications but can be used together to determine the age of rocks and structures; and
d) rocks and fossils from many different geologic periods and epochs are found in Virginia.

ES.11 The student will investigate and understand that oceans are complex, interactive physical, chemical, and biological systems and are subject to long- and short-term variations. Key concepts include

a) physical and chemical changes (tides, waves, currents, sea level and ice cap variations, upwelling, and salinity variations);
b) importance of environmental and geologic implications;
c) systems interactions (density differences, energy transfer, weather, and climate);
d) features of the sea floor (continental margins, trenches, mid-ocean ridges, and abyssal plains) as reflections of tectonic processes; and
e) economic and public policy issues concerning the oceans and the coastal zone including the Chesapeake Bay.

ES.12 The student will investigate and understand the origin and evolution of the atmosphere and the interrelationship of geologic processes, biologic processes, and human activities on its composition and dynamics. Key concepts include

a) scientific evidence for atmospheric changes over geologic time;
b) current theories related to the effects of early life on the chemical makeup of the atmosphere;
c) comparison of the Earth's atmosphere to that of other planets;
d) atmospheric regulation mechanisms including the effects of density differences and energy transfer; and
e) potential atmospheric compositional changes due to human, biologic, and geologic activity.

ES.13 The student will investigate and understand that energy transfer between the sun and the Earth and its atmosphere drives weather and climate on Earth. Key concepts include

a) observation and collection of weather data;
b) prediction of weather patterns;
c) severe weather occurrences, such as tornadoes, hurricanes, and major storms; and
d) weather phenomena and the factors that affect climate including radiation and convection.

ES.14 The student will investigate and understand scientific concepts related to the origin and evolution of the universe. Key concepts include

a) nebulae;
b) the origin of stars and star systems;
c) stellar evolution;
d) galaxies; and
e) cosmology including the big bang theory.

Biology

The Biology standards are designed to provide students with a detailed understanding of living systems. Emphasis continues to be placed on the skills necessary to examine alternative scientific explanations, actively conduct controlled experiments, analyze and communicate information, and gather and use information in scientific literature. The history of biological thought and the evidence that supports it are explored, providing the foundation for investigating biochemical life processes, cellular organization, mechanisms of inheritance, dynamic relationships among organisms, and the change in organisms through time. The importance of scientific research that validates or challenges ideas is emphasized at this level. All students are expected to achieve the content of the biology standards.

The Biology standards continue to focus on student growth in understanding the nature of science. This scientific view defines the idea that explanations of nature are developed and tested using observation, experimentation, models, evidence, and systematic processes. The nature of science includes the concepts that scientific explanations are based on logical thinking; are subject to rules of evidence; are consistent with observational, inferential, and experimental evidence; are open to rational critique; and are subject to refinement and change with the addition of new scientific evidence. The nature of science includes the concept that science can provide explanations about nature, can predict potential consequences of actions, but cannot be used to answer all questions.

BIO.1 The student will plan and conduct investigations in which

- a) observations of living organisms are recorded in the lab and in the field;
- b) hypotheses are formulated based on direct observations and information from scientific literature;
- c) variables are defined and investigations are designed to test hypotheses;
- d) graphing and arithmetic calculations are used as tools in data analysis;
- e) conclusions are formed based on recorded quantitative and qualitative data;
- f) sources of error inherent in experimental design are identified and discussed;
- g) validity of data is determined;
- h) chemicals and equipment are used in a safe manner;
- i) appropriate technology including computers, graphing calculators, and probeware, is used for gathering and analyzing data and communicating results;
- j) research utilizes scientific literature;
- k) differentiation is made between a scientific hypothesis and theory;
- l) alternative scientific explanations and models are recognized and analyzed; and
- m) a scientific viewpoint is constructed and defended (the nature of science).

BIO.2 The student will investigate and understand the history of biological concepts. Key concepts include

- a) evidence supporting the cell theory;
- b) scientific explanations of the development of organisms through time (biological evolution);
- c) evidence supporting the germ theory of infectious disease;
- d) development of the structural model of DNA; and
- e) the collaborative efforts of scientists, past and present.

BIO.3 The student will investigate and understand the chemical and biochemical principles essential for life. Key concepts include

a) water chemistry and its impact on life processes;
b) the structure and function of macromolecules;
c) the nature of enzymes; and
d) the capture, storage, transformation, and flow of energy through the processes of photosynthesis and respiration.

BIO.4 The student will investigate and understand relationships between cell structure and function. Key concepts include

a) characteristics of prokaryotic and eukaryotic cells;
b) exploring the diversity and variation of eukaryotes;
c) similarities between the activities of a single cell and a whole organism; and
d) the cell membrane model (diffusion, osmosis, and active transport).

BIO.5 The student will investigate and understand life functions of archaebacteria, monerans (eubacteria), protists, fungi, plants, and animals including humans. Key concepts include

a) how their structures and functions vary between and within the kingdoms;
b) comparison of their metabolic activities;
c) analyses of their responses to the environment;
d) maintenance of homeostasis;
e) human health issues, human anatomy, body systems, and life functions; and
f) how viruses compare with organisms.

BIO.6 The student will investigate and understand common mechanisms of inheritance and protein synthesis. Key concepts include

a) cell growth and division;
b) gamete formation;
c) cell specialization;
d) prediction of inheritance of traits based on the Mendelian laws of heredity;
e) genetic variation (mutation, recombination, deletions, additions to DNA);
f) the structure, function, and replication of nucleic acids (DNA and RNA);
g) events involved in the construction of proteins;
h) use, limitations, and misuse of genetic information; and
i) exploration of the impact of DNA technologies.

BIO.7 The student will investigate and understand bases for modern classification systems. Key concepts include

a) structural similarities among organisms;
b) fossil record interpretation;
c) comparison of developmental stages in different organisms;
d) examination of biochemical similarities and differences among organisms; and
e) systems of classification that are adaptable to new scientific discoveries.

BIO.8 The student will investigate and understand how populations change through time. Key concepts include

a) evidence found in fossil records;
b) how genetic variation, reproductive strategies, and environmental pressures impact the survival of populations;
c) how natural selection leads to adaptations;
d) emergence of new species; and
e) scientific explanations for biological evolution.

BIO.9 The student will investigate and understand dynamic equilibria within populations, communities, and ecosystems. Key concepts include

a) interactions within and among populations including carrying capacities, limiting factors, and growth curves;
b) nutrient cycling with energy flow through ecosystems;
c) succession patterns in ecosystems;
d) the effects of natural events and human activities on ecosystems; and
e) analysis of the flora, fauna, and microorganisms of Virginia ecosystems including the Chesapeake Bay and its tributaries.

Chemistry

The Chemistry standards are designed to provide students with a detailed understanding of the interaction of matter and energy. This interaction is investigated through the use of laboratory techniques, manipulation of chemical quantities, and problem-solving applications. Scientific methodology is employed in experimental and analytical investigations, and concepts are illustrated with practical applications that should include examples from environmental, nuclear, organic, and biochemistry content areas.

Technology, including graphing calculators, computers, and probeware, are employed where feasible. Students will understand and use safety precautions with chemicals and equipment. The standards emphasize qualitative and quantitative study of substances and the changes that occur in them. In meeting the chemistry standards, students will be encouraged to share their ideas, use the language of chemistry, discuss problem-solving techniques, and communicate effectively.

The Chemistry standards continue to focus on student growth in understanding the nature of science. This scientific view defines the idea that explanations of nature are developed and tested using observation, experimentation, models, evidence, and systematic processes. The nature of science includes the concepts that scientific explanations are based on logical thinking; are subject to rules of evidence; are consistent with observational, inferential, and experimental evidence; are open to rational critique; and are subject to refinement and change with the addition of new scientific evidence. The nature of science includes the concept that science can provide explanations about nature, can predict potential consequences of actions, but cannot be used to answer all questions.

CH.1 The student will investigate and understand that experiments in which variables are measured, analyzed, and evaluated produce observations and verifiable data. Key concepts include

a) designated laboratory techniques;
b) safe use of chemicals and equipment;
c) proper response to emergency situations;
d) manipulation of multiple variables, using repeated trials;
e) accurate recording, organization, and analysis of data through repeated trials;
f) mathematical and procedural error analysis;
g) mathematical manipulations (SI units, scientific notation, linear equations, graphing, ratio and proportion, significant digits, dimensional analysis);
h) use of appropriate technology including computers, graphing calculators, and probeware, for gathering data and communicating results; and
i) construction and defense of a scientific viewpoint (the nature of science).

CH.2 The student will investigate and understand that the placement of elements on the periodic table is a function of their atomic structure. The periodic table is a tool used for the investigations of

a) average atomic mass, mass number, and atomic number;
b) isotopes, half lives, and radioactive decay;
c) mass and charge characteristics of subatomic particles;
d) families or groups;
e) series and periods;
f) trends including atomic radii, electronegativity, shielding effect, and ionization energy;
g) electron configurations, valence electrons, and oxidation numbers;
h) chemical and physical properties; and
i) historical and quantum models.

CH.3 The student will investigate and understand how conservation of energy and matter is expressed in chemical formulas and balanced equations. Key concepts include

a) nomenclature;
b) balancing chemical equations;
c) writing chemical formulas (molecular, structural, and empirical; and Lewis diagrams);
d) bonding types (ionic and covalent);
e) reaction types (synthesis, decomposition, single and double replacement, oxidation-reduction, neutralization, exothermic, and endothermic); and
f) reaction rates and kinetics (activation energy, catalysis, and degree of randomness).

CH.4 The student will investigate and understand that quantities in a chemical reaction are based on molar relationships. Key concepts include

a) Avogadro's principle and molar volume;
b) stoichiometric relationships;
c) partial pressure;
d) gas laws;
e) solution concentrations;
f) chemical equilibrium; and
g) acid/base theory: strong electrolytes, weak electrolytes, and nonelectrolytes; dissociation and ionization; pH and pOH; and the titration process.

CH.5 The student will investigate and understand that the phases of matter are explained by kinetic theory and forces of attraction between particles. Key concepts include

a) pressure, temperature, and volume;
b) vapor pressure;
c) phase changes;
d) molar heats of fusion and vaporization;
e) specific heat capacity; and
f) colligative properties.

NSTA

Organic + biochemistry?

Nuclear processes?

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Physics

The Physics standards emphasize a more complex understanding of experimentation, the analysis of data, and the use of reasoning and logic to evaluate evidence. The use of mathematics, including algebra and trigonometry, is important, but conceptual understanding of physical systems remains a primary concern. Students build on basic physical science principles by exploring in depth the nature and characteristics of energy and its dynamic interaction with matter. Key areas covered by the standards include force and motion, energy transformations, wave phenomena and the electromagnetic spectrum, light, electricity, fields, and non-Newtonian physics. The standards stress the practical application of physics in other areas of science and technology and how physics affects our world.

The Physics standards continue to focus on student growth in understanding the nature of science. This scientific view defines the idea that explanations of nature are developed and tested using observation, experimentation, models, evidence, and systematic processes. The nature of science includes the concepts that scientific explanations are based on logical thinking; are subject to rules of evidence; are consistent with observational, inferential, and experimental evidence; are open to rational critique; and are subject to refinement and change with the addition of new scientific evidence. The nature of science includes the concept that science can provide explanations about nature, can predict potential consequences of actions, but cannot be used to answer all questions.

PH.1 The student will plan and conduct investigations in which

a) the components of a system are defined;
b) instruments are selected and used to extend observations and measurements of mass, volume, temperature, heat exchange, energy transformations, motion, fields, and electric charge;
c) information is recorded and presented in an organized format;
d) metric units are used in all measurements and calculations;
e) the limitations of the experimental apparatus and design are recognized;
f) the limitations of measured quantities are recognized through the appropriate use of significant figures or error ranges;
g) data gathered from non-SI instruments are incorporated through appropriate conversions; and
h) appropriate technology including computers, graphing calculators, and probeware, is used for gathering and analyzing data and communicating results.

PH.2 The student will investigate and understand how to analyze and interpret data. Key concepts include

a) a description of a physical problem is translated into a mathematical statement in order to find a solution;
b) relationships between physical quantities are determined using the shape of a curve passing through experimentally obtained data;
c) the slope of a linear relationship is calculated and includes appropriate units;
d) interpolated, extrapolated, and analyzed trends are used to make predictions; and
e) analysis of systems employs vector quantities utilizing trigonometric and graphical methods.

PH.3 The student will investigate and understand how to demonstrate scientific reasoning and logic. Key concepts include
- a) analysis of scientific sources to develop and refine research hypotheses;
- b) analysis of how science explains and predicts relationships;
- c) evaluation of evidence for scientific theories;
- d) examination of how new discoveries result in modification of existing theories or establishment of new paradigms; and
- e) construction and defense of a scientific viewpoint (the nature of science).

PH.4 The student will investigate and understand how applications of physics affect the world. Key concepts include
- a) examples from the real world; and
- b) exploration of the roles and contributions of science and technology.

PH.5 The student will investigate and understand the interrelationships among mass, distance, force, and time through mathematical and experimental processes. Key concepts include
- a) linear motion;
- b) uniform circular motion;
- c) projectile motion;
- d) Newton's laws of motion;
- e) gravitation;
- f) planetary motion; and
- g) work, power, and energy.

PH.6 The student will investigate and understand that quantities including mass, energy, momentum, and charge are conserved. Key concepts include
- a) kinetic and potential energy;
- b) elastic and inelastic collisions; and
- c) electric power.

PH.7 The student will investigate and understand properties of fluids. Key concepts include
- a) density and pressure;
- b) variation of pressure with depth;
- c) Archimedes' principle of buoyancy;
- d) Pascal's principle;
- e) fluids in motion; and
- f) Bernoulli's principle.

PH.8 The student will investigate and understand that energy can be transferred and transformed to provide usable work. Key concepts include
- a) transformation of energy among forms including mechanical, thermal, electrical, gravitational, chemical, and nuclear; and
- b) efficiency of systems.

PH.9 The student will investigate and understand how to use models of transverse and longitudinal waves to interpret wave phenomena. Key concepts include
- a) wave characteristics (period, wavelength, frequency, amplitude, and phase);
- b) fundamental wave processes (reflection, refraction, diffraction, interference, polarization, Doppler effect); and
- c) light and sound in terms of wave models.

PH.10 The student will investigate and understand that different frequencies and wavelengths in the electromagnetic spectrum are phenomena ranging from radio waves through visible light to gamma radiation. Key concepts include

a) the properties and behaviors of radio waves, microwaves, infrared, visible light, ultraviolet, X-rays, and gamma rays; and
b) current applications based on the wave properties of each band.

PH.11 The student will investigate and understand, in describing optical systems, how light behaves in the fundamental processes of reflection, refraction, and image formation. Key concepts include

a) application of the laws of reflection and refraction;
b) construction and interpretation of ray diagrams;
c) development and use of mirror and lens equations; and
d) predictions of type, size, and position of real and virtual images.

PH.12 The student will investigate and understand how to use the field concept to describe the effects of gravitational, electric, and magnetic forces. Key concepts include

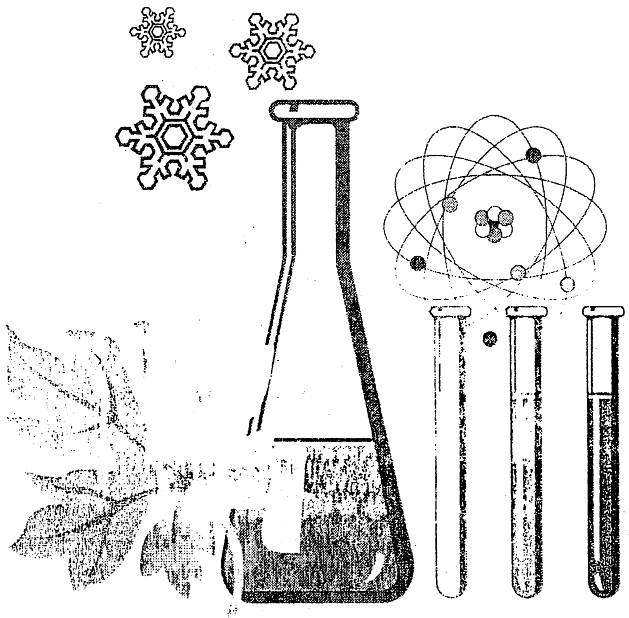
a) inverse square laws (Newton's law of universal gravitation and Coulomb's law); and
b) operating principles of motors, generators, transformers, and cathode ray tubes.

PH.13 The student will investigate and understand how to diagram and construct basic electrical circuits and explain the function of various circuit components. Key concepts include

a) Ohm's law;
b) series, parallel, and combined circuits; and
c) circuit components including resistors, batteries, generators, fuses, switches, and capacitors.

PH.14 The student will investigate and understand that extremely large and extremely small quantities are not necessarily described by the same laws as those studied in Newtonian physics. Key concepts include

a) wave/particle duality;
b) wave properties of matter;
c) matter/energy equivalence;
d) quantum mechanics and uncertainty;
e) relativity;
f) nuclear physics;
g) solid state physics;
h) superconductivity; and
i) radioactivity.



Science Standards of Learning Curriculum Framework

Chemistry

Commonwealth of Virginia
Board of Education
Richmond, Virginia

Standard CH.1 a, b, c

The student will investigate and understand that experiments in which variables are measured, analyzed, and evaluated produce observations and verifiable data. Key concepts include

a) designated laboratory techniques;
b) safe use of chemicals and equipment; and
c) proper response to emergency situations.

Essential Understandings	Essential Knowledge and Skills
• Measurements of quantity include length, volume, mass, temperature, time, and pressure to the correct number of significant digits. • Techniques for experimentation involve the identification and the proper use of chemicals, the description of equipment, and the recommended statewide framework for high school laboratory safety. • Measurements are useful in gathering data about chemicals and how they behave.	<u>Skills</u> • Make the following measurements, using the specified equipment: - volume: graduated cylinder, pipette, volumetric flask, buret - mass: electronic or dial-a-gram - temperature: thermometer and/or temperature probe - pressure: barometer or pressure probe. • Identify, locate, and know how to use laboratory safety equipment, including aprons, goggles, gloves, fire extinguishers, fire blanket, safety shower, eye wash, broken glass container, and fume hood. • Demonstrate the following basic lab techniques: filtering, decanting, using chromatography, and lighting a gas burner.

Standard CH.1 a, b, c (continued)

Essential Understandings	Essential Knowledge and Skills
	• Identify the following basic lab equipment: beaker, flask, graduated cylinder, test tube, test tube rack, test tube holder, ring stand, wire gauze, clay triangle, crucible with lid, evaporation dish, watch glass, wash bottle, and dropping pipette. • Understand Material Safety Data Sheet (MSDS) warnings, including handling chemicals, lethal dose (LD), hazards, disposal, and chemical spill cleanup. • Demonstrate safe laboratory practices, procedures, and techniques.

Standard CH.1 d, e

The student will investigate and understand that experiments in which variables are measured, analyzed, and evaluated produce observations and verifiable data. Key concepts include

d) manipulation of multiple variables, using repeated trials; and
e) accurate recording, organization, and analysis of data through repeated trials.

Essential Understandings	Essential Knowledge and Skills
• Repeated trials during experimentation ensure verifiable data. • Data tables are used to record and organize measurements. • Graphs are used to summarize the relationship between the independent and dependent variable.	<u>Skills</u> • Design and perform experiments to test predictions. • Identify variables. • Predict outcome(s) when a variable is changed. • Record data, using the significant digits of the measuring equipment. • Demonstrate precision (reproducibility) in measurement. • Recognize accuracy in terms of closeness to the true value of a measurement.

Standard CH.1 f, g

The student will investigate and understand that experiments in which variables are measured, analyzed, and evaluated produce observations and verifiable data. Key concepts include

f) mathematical and procedural error analysis; and
g) mathematical manipulations (SI units, scientific notation, linear equations, graphing, ratio and proportion, significant digits, dimensional analysis).

Essential Understandings	Essential Knowledge and Skills
• Measurements must be expressed in SI units. • Scientific notation is used to write very small and very large numbers. • Algebraic equations represent relationships between dependent and independent variables. • Graphed data give a picture of a relationship. • Ratios and proportions are used in calculations. • *Significant digits* of a measurement are the number of known digits together with one estimated digit. • The last digit of any valid measurement must be estimated and is therefore uncertain. • *Dimensional analysis* is a way of translating a measurement from one unit to another unit. • Graphing calculators can be used to manage the mathematics of chemistry. • Mathematical procedures are used to validate data.	<u>Skills</u> • Discover and eliminate procedural errors. • Know most frequently used SI prefixes and their values (milli-, centi-, deci-, kilo-). • Demonstrate the use of scientific notation, using the correct number of significant digits with powers of ten notation for the decimal place. • Correctly utilize the following when graphing data: - dependent variable (vertical axis) - independent variable (horizontal axis) - scale and units of a graph - regression line (best fit curve). • Calculate mole ratios, percent composition, conversions, and relative atomic mass. • Use the rules for performing operations with significant digits. • Utilize dimensional analysis.

Standard CH.1 f, g (continued)

Essential Understandings	Essential Knowledge and Skills
	• Use graphing calculators correctly. • Read a measurement from a graduated scale, stating measured digits plus the estimated digit. • Use data collected to calculate percent error. • Determine the mean of a set of measurements.

Standard CH.1 h, i

The student will investigate and understand that experiments in which variables are measured, analyzed, and evaluated produce observations and verifiable data. Key concepts include

h) use of appropriate technology including computers, graphing calculators, and probeware, for gathering data and communicating results; and

i) construction and defense of a scientific viewpoint (the nature of science).

Essential Understandings	Essential Knowledge and Skills
• Constant reevaluation in the light of new data is essential to keeping scientific knowledge current. In this fashion, all forms of scientific knowledge remain flexible and may be revised as new data and new ways of looking at existing data become available.	• Use appropriate technology for data collection and analysis, including probeware interfaced to a graphing calculator and/or computer. • Use probeware to gather data. • Explain the emergence of modern theories based on historical development. For example, students should be able to explain the origin of the atomic theory beginning with the Greek atomists and continuing through the most modern Quantum models.

Standard CH.2 a, b, c

The student will investigate and understand that the placement of elements on the periodic table is a function of their atomic structure. The periodic table is a tool used for the investigations of

a) average atomic mass, mass number, and atomic number;
b) isotopes, half lives, and radioactive decay; and
c) mass and charge characteristics of subatomic particles.

Essential Understandings	Essential Knowledge and Skills
• The periodic table is arranged in order of increasing atomic numbers. • The atomic number of an element is the same as the number of protons. • In a neutral atom, the number of electrons is the same as the number of protons. • All atoms of an element have the same number of protons. • The atomic mass for each element is the weighted average of that element's naturally occurring isotopes.	<u>Knowledge</u> • *Electrons* have little mass and a negative (–) charge. They are located in electron clouds or probability clouds outside the nucleus. • *Protons* have a positive (+) charge. *Neutrons* have no charge. Protons and neutrons are located in the nucleus of the atom and comprise most its mass. • An *isotope* is an atom that has the same number of protons as another atom of the same element but has a different number of neutrons. Some isotopes are radioactive; many are not. • *Half-life* is the length of time required for half of a given sample of a radioactive isotope to decay.

Standard CH.2 a, b, c (continued)

Essential Understandings	Essential Knowledge and Skills
	<u>Skills</u> • Using a periodic chart, determine the atomic number, atomic mass, the number of protons, the number of electrons, and the number of neutrons of any neutral atom of a particular element. • Determine the half-life of a radioactive substance. • Describe alpha, beta, and gamma radiation with respect to penetrating power, shielding, and composition.

Standard CH.2 d, e, f

The student will investigate and understand that the placement of elements on the periodic table is a function of their atomic structure. The periodic table is a tool used for the investigations of

d) families or groups;
e) series and periods; and
f) trends including atomic radii, electronegativity, shielding effect, and ionization energy.

Essential Understandings	Essential Knowledge and Skills
• *Periodicity* is regularly repeating patterns or trends in the chemical and physical properties of the elements arranged in the periodic table. • Horizontal rows called *periods* have predictable properties based on an increasing number of electrons in the outer orbitals. • Vertical columns called *groups* have similar properties because of their similar valence electron configurations.	<u>Knowledge</u> • The Periodic Law states that when elements are arranged in order of increasing atomic numbers, their physical and chemical properties show a periodic pattern. • The names of groups and periods on the periodic chart are alkali metals, alkaline earth metals, transition metals, halogens, noble gases, and metalloids. • Periods and groups are named by numbering columns and rows. • Some elements, such as oxygen, hydrogen, fluorine, chlorine, bromine, and nitrogen, naturally occur as diatomic molecules. • Electronegativity increases from left to right within a period and decreases from top to bottom within a group. • Shielding effect is constant within a given period and increases within given groups from top to bottom.

Standard CH.2 d, e, f (continued)

Essential Understandings	Essential Knowledge and Skills
	• Atomic radius decreases from left to right and increases from top to bottom within given groups. • Ionization energies generally increase from left to right and decrease from top to bottom of a given group. <u>Skills</u> • Use an element's electron configuration to determine the number of valence electrons and possible oxidation numbers.

Standard CH.2 g

The student will investigate and understand that the placement of elements on the periodic table is a function of their atomic structure. The periodic table is a tool used for the investigations of

g) electron configurations, valence electrons, and oxidation numbers.

Essential Understandings	Essential Knowledge and Skills
• Electron configuration is the arrangement of electrons around the nucleus of an atom based on their energy level. • Atoms can gain, lose, or share electrons within the outer energy level.	<u>Knowledge</u> • Electrons are added one at a time to the lowest energy levels first (Aufbau Principle). • An orbital can hold a maximum of two electrons (Pauli Exclusion Principle). • Electrons occupy equal-energy orbitals so that a maximum number of unpaired electrons results (Hund's Rule). • Energy levels are designated 1–7. Orbitals are designated s, p, d, and f according to their shapes • s, p, d, f orbitals relate to the regions of the Periodic Table. • Loss of electrons from neutral atoms results in the formation of an ion with a positive charge (cation). • Gain of electrons by a neutral atom results in the formation of an ion with a negative charge (anion). • Transition metals can have multiple oxidation states.

Standard CH.2 h

The student will investigate and understand that the placement of elements on the periodic table is a function of their atomic structure. The periodic table is a tool used for the investigations of

h) chemical and physical properties.

Essential Understandings	Essential Knowledge and Skills
• Matter is classified by its chemical and physical properties. • *Physical properties* refer to the condition or quality of a substance that can be observed or measured without changing the substance's composition. • *Chemical properties* refer to the ability of a substance to undergo chemical reaction and form a new substance.	<u>Knowledge</u> • Matter occurs as elements (pure), compounds (pure), and mixtures, which may be homogeneous (solutions) or heterogeneous. • Important physical properties are density, conductivity, melting point, boiling point, malleability, and ductility. • *Reactivity* is the tendency of an element to enter into a chemical reaction.

Standard CH.2 i

The student will investigate and understand that the placement of elements on the periodic table is a function of their atomic structure. The periodic table is a tool used for the investigations of

i) historical and quantum models.

Essential Understandings	Essential Knowledge and Skills
• Discoveries and insights related to the atom's structure have changed the model of the atom over time. • The modern atomic theory is called the Quantum Mechanical Model.	<u>Knowledge</u> • Major insights regarding the atomic model of the atom and principal scientists include: - particles – Democritus - first atomic theory of matter – John Dalton - discovery of the electron – J. J. Thompson - discovery of the nucleus – Ernest Rutherford - discovery of charge of electron – Robert Millikan - planetary model of atom – Niels Bohr - periodic table by atomic mass – Demitry Mendeleev - periodic table by atomic number – Henry Moseley - quantum nature of energy – Max Planck - uncertainty principle – Werner Heisenberg - wave theory – Louis de Broglie.

Standard CH.3 a, b, c, d

The student will investigate and understand how conservation of energy and matter is expressed in chemical formulas and balanced equations. Key concepts include

a) nomenclature;
b) balancing chemical equations;
c) writing chemical formulas (molecular, structural, and empirical; and Lewis diagrams); and
d) bonding types (ionic and covalent).

Essential Understandings	Essential Knowledge and Skills
• Conservation of matter is represented in balanced chemical equations. • Chemical formulas are used to represent compounds. • *Subscripts* represent the relative number of each type of atom in a molecule or formula unit. • A *coefficient* is a quantity that precedes a reactant or product symbol or formula in a chemical equation and indicates the relative number of particles involved in the reaction. • Bonds form between atoms to achieve stability.	<u>Knowledge</u> • When pairs of elements form two or more compounds, the masses of one element that combine with a fixed mass of the other element form simple, whole-number ratios (Law of Multiple Proportions). • The *empirical formula* shows the simplest whole-number ratio in which the atoms of the elements are present in the compound. • The *molecular formula* shows the actual number of atoms of each element in one molecule of the substance. • *Structural formulas* also show the arrangements of atoms and bonds. • *Covalent bonds* involve the sharing of electrons. • *Ionic bonds* involve the transfer of electrons.

Standard CH.3 a, b, c, d (continued)

Essential Understandings	Essential Knowledge and Skills
	• *Ionization energy* is the energy required to remove the most loosely held electron from a neutral atom. Elements with low ionization energy form positive ions (cations) easily. Elements with high ionization energy form negative ions (anions) easily. • *Electronegativity* is the measure of the attraction of an atom for electrons in a covalent bond. • *Polar molecules* result when a molecule behaves as if one end were positive and the other end negative. • The IUPAC system is used for naming compounds. <u>Skills</u> • Name binary covalent compounds. • Name binary ionic compounds (using the Roman numeral system where appropriate). • Predict, draw, and name molecular shapes (bent, linear, trigonal planar, tetrahedral, and trigonal pyramidal). • Determine formulas, write equations, and balance chemical equations. • Write the chemical formulas for certain common substances, such as ammonia, water, carbon monoxide, carbon dioxide, sulfur dioxide, and carbon tetraflouride.

Standard CH.3 a, b, c, d (continued)

Essential Understandings	Essential Knowledge and Skills
	• Recognize the formulas and names of certain polyatomic ions, such as carbonate, sulfate, nitrate, hydroxide, phosphate, and ammonium, and use these polyatomic ions for naming and writing the formulas of ionic compounds. • Draw Lewis Dot Diagrams to show covalent bonding.

Standard CH.3 e, f

The student will investigate and understand how conservation of energy and matter is expressed in chemical formulas and balanced equations. Key concepts include

e) reaction types (synthesis, decomposition, single and double replacement, oxidation-reduction, neutralization, exothermic, and endothermic); and

f) reaction rates and kinetics (activation energy, catalysis, and degree of randomness).

Essential Understandings	Essential Knowledge and Skills
• Elements and compounds react in different ways. • Spontaneous reactions may be fast or slow. • Randomness (entropy), heat content (enthalpy), and temperature affect spontaneity. • Reaction rates/kinetics are affected by activation energy, catalysis, and the degree of randomness (entropy).	Knowledge • Major types of chemical reactions are - synthesis **(A+B → AB)** - decomposition **(BC → B+C)** - single replacement **(A+BC → B+AC)** - double replacement **(AC+BD → AD+BC).** • Chemical reactions based on the net heat energy are exothermic reaction (heat producing) and endothermic reaction (heat absorbing). • Reactions can occur in two directions simultaneously. • Le Chatelier's Principle indicates the qualitative prediction of direction of change with temperature, pressure, and concentration. • Catalysts decrease the amount of activation energy needed.

Standard CH.3 e, f (continued)

Essential Understandings	Essential Knowledge and Skills
	<u>Skills</u> • Recognize equations for redox reactions and neutralization reactions. • Interpret reaction rate diagrams.

Standard CH.4 a, b

The student will investigate and understand that quantities in a chemical reaction are based on molar relationships. Key concepts include

a) Avogadro's principle and molar volume; and
b) stoichiometric relationships.

Essential Understandings	Essential Knowledge and Skills
• Atoms and molecules are too small to count by usual means. • A *mole* is a way of counting any type of particle (atoms, molecules, and formula units). • Stoichiometry involves quantitative relationships. • Stoichiometric relationships are based on mole quantities in a balanced equation.	<u>Knowledge</u> • Avogadro's number = 6.02×10^{23} particles per mole. • Molar volume = 22.4 dm^3/mole and/or 22.4 L/mole for any gas at STP. • Molar mass of a substance is its average atomic mass in grams from the Periodic Table. • Total grams of reactant(s) = total grams of product(s). <u>Skills</u> • Make calculations involving the following relationships: - mole-mole; - mass-mass; - mole-mass; - mass-volume; - mole-volume; and - volume-volume. • Identify the limiting reactant (reagent) in a reaction. • Calculate percent yield of a reaction.

Standard CH.4 c, d, e, f

The student will investigate and understand that quantities in a chemical reaction are based on molar relationships. Key concepts include

c) partial pressure;
d) gas laws;
e) solution concentrations; and
f) chemical equilibrium.

Essential Understandings	Essential Knowledge and Skills
• Gases have mass and occupy space. • Gas particles are in constant, rapid, random motion and exert pressure as they collide with the walls of their containers. • Gas molecules with the lightest mass travel fastest. • Relatively large distances separate gas particles from each other. • An Ideal Gas does not exist, but this concept is used to model gas behavior. • A Real Gas exists, has intermolecular forces and particle volume, and can change states. • Equal volumes of gases at the same temperature and pressure contain an equal number of particles. • Solutions can be a variety of solute/solvent combinations: gas/gas, gas/liquid, liquid/liquid, solid/liquid, gas/solid, liquid/solid, or solid/solid.	<u>Knowledge</u> • The pressure and volume of a sample of a gas at constant temperature are inversely proportional to each other (Boyle's Law). • At constant pressure, the volume of a fixed amount of gas is directly proportional to its absolute temperature (Charles' Law). • The sum of the partial pressures of all the components in a gas mixture is equal to the total pressure of a gas mixture (Dalton's law of partial pressures). • Ideal Gas Law states that $PV = nRT$. • Molarity = moles/dm^3 or moles/L of solution. • Pressure Units include K Pa and mm of Hg. <u>Skills</u> • Solve problems and interpret graphs involving the gas laws.

Standard CH.4 g

The student will investigate and understand that quantities in a chemical reaction are based on molar relationships. Key concepts include

g) acid/base theory: strong electrolytes, weak electrolytes, and nonelectrolytes; dissociation and ionization; pH and pOH; and the titration process.

Essential Understandings	Essential Knowledge and Skills
• Two important classes of compounds are acids and bases. • Acids and bases are defined by several theories. • Acids and bases dissociate in varying degrees.	Knowledge • Arrhenius acids are characterized by their sour taste, low pH, and the fact that they turn litmus paper red. Arrhenius bases are characterized by their bitter taste, slippery feel, high pH, and the fact that they turn litmus paper blue. • Bronsted-Lowry-acids are proton donors, whereas bases are proton acceptors. • The pH number denotes hydrogen (hydronium) ion concentration. The pOH number denotes hydroxide ion concentration. • $pH + pOH = 14$ • pH is a number scale ranging from 0 to 14 that represents the acidity of a solution. • [ ] refers to molar concentration. • Strong acid-strong base titration is the process that measures $[H^+]$ and $[OH^-]$. • Indicators show color changes at certain pH levels. • Strong electrolytes dissociate completely. Weak electrolytes dissociate partially.

Standard CH.5 a, b

The student will investigate and understand that the phases of matter are explained by kinetic theory and forces of attraction between particles. Key concepts include

a) pressure, temperature, and volume; and
b) vapor pressure.

Essential Understandings	Essential Knowledge and Skills
• Atoms and molecules are in constant motion. • The Kinetic Molecular Theory is a model for predicting and explaining gas behavior. • Forces of attraction between molecules determine the physical changes of state. • Vapor pressure is a property of a substance determined by intermolecular forces.	<u>Knowledge</u> • Pressure, temperature, and volume changes can cause a change in physical state. • Forces of attraction include hydrogen bonding, dipole-dipole attraction, and London dispersion (van der Waals) forces.

Standard CH.5 c, d, e, f

The student will investigate and understand that the phases of matter are explained by kinetic theory and forces of attraction between particles. Key concepts include

c) phase changes;
d) molar heats of fusion and vaporization;
e) specific heat capacity; and
f) colligative properties.

Essential Understandings	Essential Knowledge and Skills
• Solid, liquid, and gas phases of a substance have different energy content. • Specific amounts of energy are absorbed or released during phase changes. • Specific heat capacity is a property of a substance. • Polar substances dissolve ionic or polar substances; nonpolar substances dissolve nonpolar substances. • The number of solute particles changes the freezing point and boiling point of a pure substance.	<u>Knowledge</u> • A liquid's boiling point and freezing point are affected by changes in atmospheric pressure. • A liquid's boiling point and freezing point are affected by the presence of certain solutes. <u>Skills</u> • Graph and interpret a heating curve (temperature vs. time). • Calculate energy changes, using specific heat capacity. • Calculate energy changes, using molar heat of fusion and molar heat of vaporization. • Interpret a phase diagram of water. • Perform calorimetry calculations. • Recognize polar molecules and non-polar molecules.

CALIFORNIA

Science Content Standards

A Message from the State Board of Education and the State Superintendent of Public Instruction.

In 1998 California adopted academically rigorous content standards in science. The adoption of standards subject area marked a turning point in the education reform movement that began in 1983 with the report *A Risk: The Imperative for Educational Reform*, by the National Commission on Excellence in Education. Unt reform movement had focused on important but largely structural improvements, such as more instructiona minimum course requirements for high school diplomas, and an emphasis on local planning efforts to prom efficiency and effectiveness. The desire to improve student achievement was there, but the focus on conte comprehensive, specific vision of what students actually needed to know and be able to do-was lacking.

Standards are a bold initiative.

Through content standards in the core subjects, California began to redefine the state's role in public educ first time, the knowledge and skills that students needed to acquire were explicitly stated for the most part b level, although science standards at the high school level were organized by discipline. The standards are Students who master this content are on a par with those in the best educational systems in other states a The content is attainable by all students, given sufficient time, except for those few who have severe disabi continue to regard the standards as firm but not unyielding; they will be modified in future years to reflect n and scholarship.

Standards describe what to teach, not how to teach it.

Standards-based education maintains California's tradition of respect for local control of schools. To help s achieve at high levels, local educators-with the full support and cooperation of families, businesses, and co partners-have taken these standards and designed the specific curricular and instructional strategies that b the content to their students. Their efforts have been admirable.

Standards are here to stay.

Since the science content standards were adopted, much has been done to align all of the state's efforts in instruction, assessment, teacher preparation, and professional development to the standards. Educators n science content standards as the foundation for their work, not as an additional layer.

Standards are a continuing commitment to excellence.

The adoption of science content standards and the work to align the whole of the educational system to the placed our state on the path to success in science education. The standards have brought certainty of kno purpose to all. They are comprehensive and specific. They reflect our continuing commitment to excellence

Reed Hastings
President, State Board of Education

Jack O'Connell
State Superintendent of Public Instruction

Chemistry - Grades Nine Through Twelve

Science Content Standards.

Standards that all students are expected to achieve in the course of their studies are unmarked. Standards that all students should have the opportunity to learn are marked with an asterisk (*).

Atomic and Molecular Structure

1. The periodic table displays the elements in increasing atomic number and shows how periodicity of and chemical properties of the elements relates to atomic structure. As a basis for understanding th
   a. *Students know* how to relate the position of an element in the periodic table to its atomic nu atomic mass.
   b. *Students know* how to use the periodic table to identify metals, semimetals, nonmetals, and
   c. *Students know* how to use the periodic table to identify alkali metals, alkaline earth metals a metals, trends in ionization energy, electronegativity, and the relative sizes of ions and atom
   d. *Students know* how to use the periodic table to determine the number of electrons available
   e. *Students know* the nucleus of the atom is much smaller than the atom yet contains most of i
   f. * *Students know* how to use the periodic table to identify the lanthanide, actinide, and transa elements and know that the transuranium elements were synthesized and identified in labor experiments through the use of nuclear accelerators.
   g. * *Students know* how to relate the position of an element in the periodic table to its quantum configuration and to its reactivity with other elements in the table.
   h. * *Students know* the experimental basis for Thomson's discovery of the electron, Rutherford atom, Millikan's oil drop experiment, and Einstein's explanation of the photoelectric effect.
   i. * *Students know* the experimental basis for the development of the quantum theory of atomi and the historical importance of the Bohr model of the atom.
   j. * *Students know* that spectral lines are the result of transitions of electrons between energy that these lines correspond to photons with a frequency related to the energy spacing betwe using Planck's relationship ($E = hv$).

Chemical Bonds

2. Biological, chemical, and physical properties of matter result from the ability of atoms to form bonds electrostatic forces between electrons and protons and between atoms and molecules. As a basis f understanding this concept:
   a. *Students know* atoms combine to form molecules by sharing electrons to form covalent or m bonds or by exchanging electrons to form ionic bonds.
   b. *Students know* chemical bonds between atoms in molecules such as H_2 , CH_4 , NH_3 , H_2 C Cl_2 , and many large biological molecules are covalent.
   c. *Students know* salt crystals, such as NaCl, are repeating patterns of positive and negative io together by electrostatic attraction.
   d. *Students know*the atoms and molecules in liquids move in a random pattern relative to one because the intermolecular forces are too weak to hold the atoms or molecules in a solid fo
   e. *Students know* how to draw Lewis dot structures.
   f. * *Students know* how to predict the shape of simple molecules and their polarity from Lewis

structures.

g. * *Students know* how electronegativity and ionization energy relate to bond formation.
h. * *Students know* how to identify solids and liquids held together by van der Waals forces or bonding and relate these forces to volatility and boiling/ melting point temperatures.

Conservation of Matter and Stoichiometry

3. The conservation of atoms in chemical reactions leads to the principle of conservation of matter an(to calculate the mass of products and reactants. As a basis for understanding this concept:
   a. *Students know* how to describe chemical reactions by writing balanced equations.
   b. *Students know* the quantity one mole is set by defining one mole of carbon 12 atoms to hav exactly 12 grams.
   c. *Students know* one mole equals 6.02×10^{23} particles (atoms or molecules).
   d. *Students know* how to determine the molar mass of a molecule from its chemical formula ar atomic masses and how to convert the mass of a molecular substance to moles, number of volume of gas at standard temperature and pressure.
   e. *Students know* how to calculate the masses of reactants and products in a chemical reactio mass of one of the reactants or products and the relevant atomic masses.
   f. * *Students know* how to calculate percent yield in a chemical reaction.
   g. * *Students know* how to identify reactions that involve oxidation and reduction and how to ba oxidation-reduction reactions.

Gases and Their Properties

4. The kinetic molecular theory describes the motion of atoms and molecules and explains the propert As a basis for understanding this concept:
   a. *Students know* the random motion of molecules and their collisions with a surface create th(pressure on that surface.
   b. *Students know* the random motion of molecules explains the diffusion of gases.
   c. *Students know* how to apply the gas laws to relations between the pressure, temperature, a any amount of an ideal gas or any mixture of ideal gases.
   d. *Students know* the values and meanings of standard temperature and pressure (STP).
   e. *Students know* how to convert between the Celsius and Kelvin temperature scales.
   f. *Students know* there is no temperature lower than 0 Kelvin.
   g. * *Students know* the kinetic theory of gases relates the absolute temperature of a gas to the kinetic energy of its molecules or atoms.
   h. * *Students know* how to solve problems by using the ideal gas law in the form PV = nRT.
   i. * *Students know* how to apply Dalton's law of partial pressures to describe the composition (Graham's law to predict diffusion of gases.

Acids and Bases

5. Acids, bases, and salts are three classes of compounds that form ions in water solutions. As a basi understanding this concept:
   a. *Students know* the observable properties of acids, bases, and salt solutions.
   b. *Students know* acids are hydrogen-ion-donating and bases are hydrogen-ion-accepting sub
   c. *Students know* strong acids and bases fully dissociate and weak acids and bases partially d
   d. *Students know* how to use the pH scale to characterize acid and base solutions.
   e. * *Students know* the Arrhenius, Brønsted-Lowry, and Lewis acid-base definitions.
   f. * *Students know* how to calculate pH from the hydrogen-ion concentration.
   g. * *Students know* buffers stabilize pH in acid-base reactions.

Solutions

6. Solutions are homogeneous mixtures of two or more substances. As a basis for understanding this
   a. *Students know* the definitions of solute and solvent.
   b. *Students know* how to describe the dissolving process at the molecular level by using the cc random molecular motion.
   c. *Students know* temperature, pressure, and surface area affect the dissolving process.
   d. *Students know* how to calculate the concentration of a solute in terms of grams per liter, mo per million, and percent composition.
   e. * *Students know* the relationship between the molality of a solute in a solution and the soluti depressed freezing point or elevated boiling point.
   f. * *Students know* how molecules in a solution are separated or purified by the methods of chromatography and distillation.

Chemical Thermodynamics

7. Energy is exchanged or transformed in all chemical reactions and physical changes of matter. As a understanding this concept:
   a. *Students know* how to describe temperature and heat flow in terms of the motion of molecul atoms).
   b. *Students know* chemical processes can either release (exothermic) or absorb (endothermic energy.
   c. *Students know* energy is released when a material condenses or freezes and is absorbed w material evaporates or melts.
   d. *Students know* how to solve problems involving heat flow and temperature changes, using k values of specific heat and latent heat of phase change.
   e. * *Students know* how to apply Hess's law to calculate enthalpy change in a reaction.
   f. * *Students know* how to use the Gibbs free energy equation to determine whether a reactior spontaneous.

Reaction Rates

8. Chemical reaction rates depend on factors that influence the frequency of collision of reactant mole basis for understanding this concept:
   a. *Students know* the rate of reaction is the decrease in concentration of reactants or the incre concentration of products with time.
   b. *Students know* how reaction rates depend on such factors as concentration, temperature, a
   c. *Students know* the role a catalyst plays in increasing the reaction rate.
   d. * *Students know* the definition and role of activation energy in a chemical reaction.

Chemical Equilibrium

9. Chemical equilibrium is a dynamic process at the molecular level. As a basis for understanding this
   a. *Students know* how to use Le Chatelier's principle to predict the effect of changes in concer temperature, and pressure.
   b. *Students know* equilibrium is established when forward and reverse reaction rates are equa
   c. * *Students know* how to write and calculate an equilibrium constant expression for a reactioı

Organic Chemistry and Biochemistry

10. The bonding characteristics of carbon allow the formation of many different organic molecules of va shapes, and chemical properties and provide the biochemical basis of life. As a basis for understan concept:
    a. *Students know* large molecules (polymers), such as proteins, nucleic acids, and starch, are repetitive combinations of simple subunits.
    b. *Students know* the bonding characteristics of carbon that result in the formation of a large vε structures ranging from simple hydrocarbons to complex polymers and biological molecules
    c. *Students know* amino acids are the building blocks of proteins.

d. * *Students know* the system for naming the ten simplest linear hydrocarbons and isomers th single bonds, simple hydrocarbons with double and triple bonds, and simple molecules that benzene ring.

e. * *Students know* how to identify the functional groups that form the basis of alcohols, ketone amines, esters, aldehydes, and organic acids.

f. * *Students know* the R-group structure of amino acids and know how they combine to form t polypeptide backbone structure of proteins.

Nuclear Processes

11. Nuclear processes are those in which an atomic nucleus changes, including radioactive decay of na occurring and human-made isotopes, nuclear fission, and nuclear fusion. As a basis for understand concept:

a. *Students know* protons and neutrons in the nucleus are held together by nuclear forces that the electromagnetic repulsion between the protons.

b. *Students know* the energy release per gram of material is much larger in nuclear fusion or fi reactions than in chemical reactions. The change in mass (calculated by $E = mc^2$) is small l significant in nuclear reactions.

c. *Students know* some naturally occurring isotopes of elements are radioactive, as are isotop nuclear reactions.

d. *Students know* the three most common forms of radioactive decay (alpha, beta, and gamma how the nucleus changes in each type of decay.

e. *Students know* alpha, beta, and gamma radiation produce different amounts and kinds of da matter and have different penetrations.

f. * *Students know* how to calculate the amount of a radioactive substance remaining after an number of half-lives have passed.

g. * *Students know* protons and neutrons have substructures and consist of particles called qu

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Grades Nine Through Twelve - Physics

Science Content Standards.

Standards that all students are expected to achieve in the course of their studies are unmarked. Standards that all students should have the opportunity to learn are marked with an asterisk (*).

Motion and Forces

1. Newton's laws predict the motion of most objects. As a basis for understanding this concept:
   a. *Students know* how to solve problems that involve constant speed and average speed.
   b. *Students know* that when forces are balanced, no acceleration occurs; thus an object contin at a constant speed or stays at rest (Newton's first law).
   c. *Students know* how to apply the law F=ma to solve one-dimensional motion problems that ir constant forces (Newton's second law).
   d. *Students know* that when one object exerts a force on a second object, the second object al a force of equal magnitude and in the opposite direction (Newton's third law).
   e. *Students know* the relationship between the universal law of gravitation and the effect of gra object at the surface of Earth.
   f. *Students know* applying a force to an object perpendicular to the direction of its motion caus object to change direction but not speed (e.g., Earth's gravitational force causes a satellite ir orbit to change direction but not speed).
   g. *Students know* circular motion requires the application of a constant force directed toward th the circle.
   h. * *Students know* Newton's laws are not exact but provide very good approximations unless moving close to the speed of light or is small enough that quantum effects are important.
   i. * *Students know* how to solve two-dimensional trajectory problems.
   j. * *Students know* how to resolve two-dimensional vectors into their components and calculat magnitude and direction of a vector from its components.
   k. * *Students know* how to solve two-dimensional problems involving balanced forces (statics).
   l. * *Students know* how to solve problems in circular motion by using the formula for centripeta acceleration in the following form: $a=v^2/r$.
   m. * *Students know* how to solve problems involving the forces between two electric charges a (Coulomb's law) or the forces between two masses at a distance (universal gravitation).

Conservation of Energy and Momentum

2. The laws of conservation of energy and momentum provide a way to predict and describe the move objects. As a basis for understanding this concept:
   a. *Students know* how to calculate kinetic energy by using the formula $E=(1/2)mv^2$..
   b. *Students know* how to calculate changes in gravitational potential energy near Earth by usir formula (change in potential energy) =mgh (h is the change in the elevation).
   c. *Students know* how to solve problems involving conservation of energy in simple systems, s falling objects.
   d. *Students know* how to calculate momentum as the product mv.
   e. *Students know* momentum is a separately conserved quantity different from energy.

f. *Students know* an unbalanced force on an object produces a change in its momentum.

g. *Students know* how to solve problems involving elastic and inelastic collisions in one dimen: the principles of conservation of momentum and energy.

h. * *Students know* how to solve problems involving conservation of energy in simple systems sources of potential energy, such as capacitors and springs.

Heat and Thermodynamics

3. Energy cannot be created or destroyed, although in many processes energy is transferred to the er as heat. As a basis for understanding this concept:
   a. *Students know* heat flow and work are two forms of energy transfer between systems.
   b. *Students know* that the work done by a heat engine that is working in a cycle is the differenc the heat flow into the engine at high temperature and the heat flow out at a lower temperatu of thermodynamics) and that this is an example of the law of conservation of energy.
   c. *Students know* the internal energy of an object includes the energy of random motion of the atoms and molecules, often referred to as thermal energy. The greater the temperature of tl greater the energy of motion of the atoms and molecules that make up the object.
   d. *Students know* that most processes tend to decrease the order of a system over time and tl levels are eventually distributed uniformly.
   e. *Students know* that entropy is a quantity that measures the order or disorder of a system an quantity is larger for a more disordered system.
   f. * *Students know* the statement "Entropy tends to increase" is a law of statistical probability t all closed systems (second law of thermodynamics).
   g. * *Students know* how to solve problems involving heat flow, work, and efficiency in a heat er know that all real engines lose some heat to their surroundings.

Waves

4. Waves have characteristic properties that do not depend on the type of wave. As a basis for unders concept:
   a. *Students know* waves carry energy from one place to another.
   b. *Students know* how to identify transverse and longitudinal waves in mechanical media, such and ropes, and on the earth (seismic waves).
   c. *Students know* how to solve problems involving wavelength, frequency, and wave speed.
   d. *Students know* sound is a longitudinal wave whose speed depends on the properties of the which it propagates.
   e. *Students know* radio waves, light, and X-rays are different wavelength bands in the spectrur electromagnetic waves whose speed in a vacuum is approximately 3×10^8 m/s (186,000 mil
   f. *Students know* how to identify the characteristic properties of waves: interference (beats), d refraction, Doppler effect, and polarization.

Electric and Magnetic Phenomena

5. Electric and magnetic phenomena are related and have many practical applications. As a basis for understanding this concept:
   a. *Students know* how to predict the voltage or current in simple direct current (DC) electric cir constructed from batteries, wires, resistors, and capacitors.
   b. *Students know* how to solve problems involving Ohm's law.
   c. *Students know* any resistive element in a DC circuit dissipates energy, which heats the resis Students can calculate the power (rate of energy dissipation) in any resistive circuit element formula Power = IR (potential difference) × I (current) = I^2R.
   d. *Students know* the properties of transistors and the role of transistors in electric circuits.
   e. *Students know* charged particles are sources of electric fields and are subject to the forces electric fields from other charges.
   f. *Students know* magnetic materials and electric currents (moving electric charges) are sourc magnetic fields and are subject to forces arising from the magnetic fields of other sources.

g. *Students know* how to determine the direction of a magnetic field produced by a current flov straight wire or in a coil.

h. *Students know* changing magnetic fields produce electric fields, thereby inducing currents ir conductors.

i. *Students know* plasmas, the fourth state of matter, contain ions or free electrons or both anc electricity.

j. * *Students know* electric and magnetic fields contain energy and act as vector force fields.

k. * *Students know* the force on a charged particle in an electric field is qE, where E is the elec the position of the particle and q is the charge of the particle.

l. * *Students know* how to calculate the electric field resulting from a point charge.

m. * *Students know* static electric fields have as their source some arrangement of electric chai

n. * *Students know* the magnitude of the force on a moving particle (with charge q) in a magne qvB sin(a), where a is the angle between v and B (v and B are the magnitudes of vectors v a respectively), and students use the right-hand rule to find the direction of this force.

o. * *Students know* how to apply the concepts of electrical and gravitational potential energy tc problems involving conservation of energy.

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Earth Sciences - Grades Nine Through Twelve

Science Content Standards.

Standards that all students are expected to achieve in the course of their studies are unmarked.
Standards that all students should have the opportunity to learn are marked with an asterisk (*).

Earth's Place in the Universe

1. Astronomy and planetary exploration reveal the solar system's structure, scale, and change over tir basis for understanding this concept:
   a. *Students know* how the differences and similarities among the sun, the terrestrial planets, aı planets may have been established during the formation of the solar system.
   b. *Students know* the evidence from Earth and moon rocks indicates that the solar system wa from a nebular cloud of dust and gas approximately 4.6 billion years ago.
   c. *Students know* the evidence from geological studies of Earth and other planets suggest tha Earth was very different from Earth today.
   d. *Students know* the evidence indicating that the planets are much closer to Earth than the st
   e. *Students know* the Sun is a typical star and is powered by nuclear reactions, primarily the fu hydrogen to form helium.
   f. *Students know* the evidence for the dramatic effects that asteroid impacts have had in shap surface of planets and their moons and in mass extinctions of life on Earth.
   g. * *Students know* the evidence for the existence of planets orbiting other stars.

2. Earth-based and space-based astronomy reveal the structure, scale, and changes in stars, galaxie universe over time. As a basis for understanding this concept:
   a. *Students know* the solar system is located in an outer edge of the disc-shaped Milky Way g spans 100,000 light years.
   b. *Students know* galaxies are made of billions of stars and comprise most of the visible mass universe.
   c. *Students know* the evidence indicating that all elements with an atomic number greater thar lithium have been formed by nuclear fusion in stars.
   d. *Students know* that stars differ in their life cycles and that visual, radio, and X-ray telescope used to collect data that reveal those differences.
   e. * *Students know* accelerators boost subatomic particles to energy levels that simulate condi stars and in the early history of the universe before stars formed.
   f. * *Students know* the evidence indicating that the color, brightness, and evolution of a star ar determined by a balance between gravitational collapse and nuclear fusion.
   g. * *Students know* how the red-shift from distant galaxies and the cosmic background radiatio evidence for the "big bang" model that suggests that the universe has been expanding for 1 billion years.

Dynamic Earth Processes

3. Plate tectonics operating over geologic time has changed the patterns of land, sea, and mountains surface. As the basis for understanding this concept:
   a. *Students know* features of the ocean floor (magnetic patterns, age, and sea-floor topograph

evidence of plate tectonics.

b. *Students know* the principal structures that form at the three different kinds of plate boundar

c. *Students know* how to explain the properties of rocks based on the physical and chemical c which they formed, including plate tectonic processes.

d. *Students know* why and how earthquakes occur and the scales used to measure their inten magnitude.

e. *Students know* there are two kinds of volcanoes: one kind with violent eruptions producing s and the other kind with voluminous lava flows producing gentle slopes.

f. * *Students know* the explanation for the location and properties of volcanoes that are due to and the explanation for those that are due to subduction.

Energy in the Earth System

4. Energy enters the Earth system primarily as solar radiation and eventually escapes as heat. As a b understanding this concept:
   a. *Students know* the relative amount of incoming solar energy compared with Earth's internal the energy used by society.
   b. *Students know* the fate of incoming solar radiation in terms of reflection, absorption, and ph
   c. *Students know* the different atmospheric gases that absorb the Earth's thermal radiation an mechanism and significance of the greenhouse effect.
   d. * *Students know* the differing greenhouse conditions on Earth, Mars, and Venus; the origins conditions; and the climatic consequences of each.

5. Heating of Earth's surface and atmosphere by the sun drives convection within the atmosphere an producing winds and ocean currents. As a basis for understanding this concept:
   a. *Students know* how differential heating of Earth results in circulation patterns in the atmosp oceans that globally distribute the heat.
   b. *Students know* the relationship between the rotation of Earth and the circular motions of oce and air in pressure centers.
   c. *Students know* the origin and effects of temperature inversions.
   d. *Students know* properties of ocean water, such as temperature and salinity, can be used to layered structure of the oceans, the generation of horizontal and vertical ocean currents, an geographic distribution of marine organisms.
   e. *Students know* rain forests and deserts on Earth are distributed in bands at specific latitude
   f. * *Students know* the interaction of wind patterns, ocean currents, and mountain ranges resu global pattern of latitudinal bands of rain forests and deserts.
   g. * *Students know* features of the ENSO (El Niño southern oscillation) cycle in terms of sea-s air temperature variations across the Pacific and some climatic results of this cycle.

6. Climate is the long-term average of a region's weather and depends on many factors. As a basis fo understanding this concept:
   a. *Students know* weather (in the short run) and climate (in the long run) involve the transfer o and out of the atmosphere.
   b. *Students know* the effects on climate of latitude, elevation, topography, and proximity to larg water and cold or warm ocean currents.
   c. *Students know* how Earth's climate has changed over time, corresponding to changes in Ea geography, atmospheric composition, and other factors, such as solar radiation and plate m
   d. * *Students know* how computer models are used to predict the effects of the increase in gre gases on climate for the planet as a whole and for specific regions.

Biogeochemical Cycles

7. Each element on Earth moves among reservoirs, which exist in the solid earth, in oceans, in the atr and within and among organisms as part of biogeochemical cycles. As a basis for understanding th
   a. Students know the carbon cycle of photosynthesis and respiration and the nitrogen cycle.
   b. Students know the global carbon cycle: the different physical and chemical forms of carbon atmosphere, oceans, biomass, fossil fuels, and the movement of carbon among these reser
   c. Students know the movement of matter among reservoirs is driven by Earth's internal and e

sources of energy.

d. * Students know the relative residence times and flow characteristics of carbon in and out o reservoirs.

Structure and Composition of the Atmosphere

8. Life has changed Earth's atmosphere, and changes in the atmosphere affect conditions for life. As a understanding this concept:
   a. Students know the thermal structure and chemical composition of the atmosphere.
   b. Students know how the composition of Earth's atmosphere has evolved over geologic time a the effect of outgassing, the variations of carbon dioxide concentration, and the origin of atm oxygen.
   c. Students know the location of the ozone layer in the upper atmosphere, its role in absorbing radiation, and the way in which this layer varies both naturally and in response to human ac

California Geology

9. The geology of California underlies the state's wealth of natural resources as well as its natural haz basis for understanding this concept:
   a. Students know the resources of major economic importance in California and their relation t geology.
   b. Students know the principal natural hazards in different California regions and the geologic l those hazards.
   c. Students know the importance of water to society, the origins of California 's fresh water, an relationship between supply and need.
   d. * Students know how to analyze published geologic hazard maps of California and know ho map's information to identify evidence of geologic events of the past and predict geologic ch future.

MASSACHUSETTS

STRAND 3: PHYSICAL SCIENCES (CHEMISTRY AND PHYSICS)

The physical sciences (physics and chemistry) examine the physical world around us. Using the methods of the physical sciences, students learn about the composition, structure, properties, and reactions of matter and the relationships between matter and energy.

Students are best able to build understanding of the physical sciences through hands-on exploration of the physical world. This framework encourages repeated and increasingly sophisticated experiences that help students understand properties of matter, chemical reactions, forces and motion, and energy. The links between these concrete experiences and more abstract knowledge and representations are forged gradually. Over the course of their schooling, students develop more inclusive and generalizable explanations about physical and chemical interactions.

Tools play a key role in the study of the physical world, helping students to detect physical phenomena that are beyond the range of their senses. By using well-designed instruments and computer-based technologies, students can better explore physical phenomena in ways that support greater conceptual understanding.

The physical science learning standards for PreK–2 fall under the topics of *Observable Properties of Objects, States of Matter,* and *Position and Motion of Objects.* Young children's curiosity is engaged when they observe physical processes and sort objects by different criteria. During these activities, children learn basic concepts about how things are alike or different. As they push, pull, and transform objects by acting upon them, children see the results of their actions and begin to understand how part of their world works. They continue to build understanding by telling stories about what they did and what they found out.

The standards for grades 3–5 fall under the topics of *Properties of Objects and Materials, States of Matter,* and *Forms of Energy* (including electrical, magnetic, sound, and light). Students' growth in their understanding of ordinary things allows them to make the intellectual connections necessary for understanding how the physical world works. Students are able to design simple comparative tests, carry out the tests, collect and record data, analyze results, and communicate their findings to others.

The standards for grades 6–8 fall under the topics of *Properties of Matter, Elements, Compounds and Mixtures; Motion of Objects, Forms of Energy,* and *Heat Energy.* While students at the middle school level may be better able to manage and represent ideas through language and mathematics, they still need concrete, physical-world experiences to help them develop concepts associated with motion, mass, volume, and energy. As they learn to make accurate measurements using a variety of instruments, their experiments become more quantitative and their physical models more precise. Students are able to understand relationships and can graph one measurement in relation to another, such as temperature change over time. Students may collect data by using microcomputer- or calculator-based laboratories (MBL or CBL), and learn to make sense immediately of graphical and other abstract representations essential to scientific understanding.

The high school standards for physics include *Motion, Forces, Energy, Waves,* and *Electromagnetism.* At the end of their study based on these standards, students can understand the evidence that underlies more complex concepts of physics, including forces and vectors, and transformations of energy. Graphical representations and the gradual introduction of functions introduce students to well-defined laws and principles of physics.

The high school chemistry standards for a full-year study include *Properties of Matter, Atomic Structure and Bonding, Chemical Reactions and Stoichiometry, Solutions, Acids and Bases,* and *Equilibrium and Kinetics.* Because chemistry is central to our understanding of many other sciences, chemistry instruction should include links to actual applications to enable students to relate chemistry to their everyday lives and current engineering/technology. At the end of their study, students are capable of using sophisticated models and rigorous mathematical computations to make formal statements of principles of chemistry and understand their implications. They are able to apply their understanding in another science course, in a higher level of science or engineering/technology learning, or in the experiences they encounter.

Physical Sciences (Chemistry and Physics), Grades PreK–2

Please note: The technology/engineering standards for grades PreK–5 are on pages 75 and 76.

Learning Standard	Ideas for Developing Investigations and Learning Experiences	Suggested Extensions to Learning in Technology/Engineering
Observable Properties of Objects		
1. Sort objects by observable properties such as size, shape, color, weight, and texture.	• Manipulate, observe, compare, describe, and group objects found in the classroom, on the playground, and at home.	• *Predict from looking at the shape of a simple tool or object what things it might be used for, e.g., pliers, letter opener, paperweight. (T/E 1.2, 2.1)*
States of Matter		
2. 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.	• Using transparent containers of very different shapes (e.g., cylinder, cone, cube) pour water from one container into another. Observe and discuss the "changing shape" of the water.	• *Ask students to bring in different types of containers from home. Discuss and demonstrate whether the containers are appropriate to hold solids and liquids, e.g., an unwaxed cardboard box will absorb water and eventually disintegrate while a glass bottle will not. (T/E 1.1, 1.2)*
Position and Motion of Objects		
3. Describe the various ways that objects can move, such as in a straight line, zigzag, back-and-forth, round-and-round, fast, and slow.	• Use a spinning toy (e.g., a top) and a rocking toy (e.g., a rocking horse) to explore round-and-round motion and back-and-forth motion.	• *Using construction paper and glue, design a three-dimensional object that will roll in a straight line and a three-dimensional object that will roll around in a circle. (T/E 1.3, 2.1)*
4. 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.	• Observe objects as you push and pull them on a hard, smooth surface. Make predictions as to what direction they will move and how far they will go. Repeat using various surfaces, e.g., rough, soft.	

Physical Sciences (Chemistry and Physics), Grades PreK–2

Please note: The technology/engineering standards for grades PreK–5 are on pages 75 and 76.

LEARNING STANDARD	IDEAS FOR DEVELOPING INVESTIGATIONS AND LEARNING EXPERIENCES	SUGGESTED EXTENSIONS TO LEARNING IN TECHNOLOGY/ENGINEERING
	Position and Motion of Objects (cont.)	
5. Recognize that under some conditions, objects can be balanced.	• Try to make a long thin rectangular block of wood stand upright on each face. Note that it stands (balances) very easily on some faces, but not on all.	• *Design a lever, putting unequal weights on the ends of the balance board. Observe. Now find ways to restore the balance by moving the fulcrum, keeping each weight in the same place. Discuss what happens. (T/E 2.1)*

Physical Sciences (Chemistry and Physics), Grades 3–5

Please note: The technology/engineering standards for grades PreK–5 are on pages 75 and 76.

LEARNING STANDARD	IDEAS FOR DEVELOPING INVESTIGATIONS AND LEARNING EXPERIENCES	SUGGESTED EXTENSIONS TO LEARNING IN TECHNOLOGY/ENGINEERING
	Properties of Objects and Materials	
1. Differentiate between properties of objects (e.g., size, shape, weight) and properties of materials (e.g., color, texture, hardness).	• Gather a variety of solid objects. Collect data on properties of these objects such as origin (manmade or natural), weight (heavy, medium, light), length, odor, color, hardness, and flexibility.	• *Given a variety of objects made of different materials, ask questions and make predictions about their hardness, flexibility, and strength. Test to see if your predictions were correct. (T/E 1.1)*
	States of Matter	
2. Compare and contrast solids, liquids, and gases based on the basic properties of each of these states of matter.	• Design several stations, each of which demonstrates a state of matter, e.g., water table, balloon and fan table, sand and block table, etc.	• *Design one container for each of the states of matter, taking into account what material properties are important, e.g., size, shape, flexibility. (T/E 1.1, 2.3)*
3. Describe how water can be changed from one state to another by adding or taking away heat.	• Do simple investigations with evaporation, condensation, freezing, and melting. Confirm that water expands upon freezing.	• *Using given insulating materials, try to keep an ice cube from melting. (T/E 1.1)*
	Forms of Energy	
4. Identify the basic forms of energy (light, sound, heat, electrical, and magnetic). Recognize that energy is the ability to cause motion or create change.	• Play music through a speaker with and without a grill cover. Discuss the difference in sound.	• *Design and construct a candle wheel that demonstrates how heat can cause a propeller to spin (a very popular craft toy). (T/E 1.1, 1.2, 2.2, 2.3)*
5. Give examples of how energy can be transferred from one form to another.	• Rub two pieces of wood together (mechanical energy) and observe the change in temperature of the wood.	• *Design and build a simple roller coaster for a marble or toy car to demonstrate how energy changes from one form to another. (T/E 2.2, 2.3)*

Physical Sciences (Chemistry and Physics), Grades 3–5

Please note: The technology/engineering standards for grades PreK–5 are on pages 75 and 76.

LEARNING STANDARD	IDEAS FOR DEVELOPING INVESTIGATIONS AND LEARNING EXPERIENCES	SUGGESTED EXTENSIONS TO LEARNING IN TECHNOLOGY/ENGINEERING
	Electrical Energy	
6. Recognize that electricity in circuits requires a complete loop through which an electrical current can pass, and that electricity can produce light, heat, and sound.		• *Using graphic symbols, draw and label a simple electric circuit. (T/E 2.2)* • *Using batteries, bulbs, and wires, build a series circuit. (T/E 1.2, 2.2)*
7. Identify and classify objects and materials that conduct electricity and objects and materials that are insulators of electricity.	• Provide a collection of materials that are good conductors and good insulators. Have students determine each material's electrical conductivity by testing the materials with a simple battery/bulb circuit.	• *Select from a variety of materials (e.g., cloth, cardboard, Styrofoam, plastic, etc.) to design and construct a simple device (prototype) that could be used as an insulator. Do a simple test of its effectiveness. (T/E 1.1, 1.2, 2.2, 2.3)*
8. Explain how electromagnets can be made, and give examples of how they can be used.		• *Make an electromagnet with a six-volt battery, insulated wire, and a large nail. (T/E 1.2, 2.1, 2.2, 2.3)*
	Magnetic Energy	
9. Recognize that magnets have poles that repel and attract each other.	• Balance ring magnets on a pencil. Note: The shape of a ring magnet obscures the locations of its poles.	• *Design and build a magnetic device to sort steel from aluminum materials for recycling. (T/E 1.1)*
10. Identify and classify objects and materials that a magnet will attract and objects and materials that a magnet will not attract.	• Test a variety of materials with assorted magnets. Include samples of pure iron and magnetic steel. Include samples of non-magnetic metals. Mention the two other magnetic metals: pure cobalt and pure nickel. Test a U.S. five-cent coin. Is a U.S. nickel coin made of pure nickel?	

Physical Sciences (Chemistry and Physics), Grades 3–5

Please note: The technology/engineering standards for grades PreK–5 are on pages 75 and 76.

Learning Standard	Ideas for Developing Investigations and Learning Experiences	Suggested Extensions to Learning in Technology/Engineering
	Sound Energy	
11. Recognize that sound is produced by vibrating objects and requires a medium through which to travel. Relate the rate of vibration to the pitch of the sound.	• Use tuning forks to demonstrate the relationship between vibration and sound.	• *Design and construct a simple telephone (prototype) using a variety of materials, e.g., paper cups, string, tin cans, and wire. Determine which prototype works best and why. (T/E 1.1, 1.2, 2.2, 2.3)*
	Light Energy	
12. Recognize that light travels in a straight line until it strikes an object or travels from one medium to another, and that light can be reflected, refracted, and absorbed.	• Use a flashlight, mirrors, and water to demonstrate reflection and refraction.	• *Design and build a prototype to inhibit solar heating of a car, e.g., windshield reflector, window tinting. (T/E 1.2, 2.1, 2.3)*

Physical Sciences (Chemistry and Physics), Grades 6–8

Learning Standard	Ideas for Developing Investigations and Learning Experiences
Properties of Matter	
1. Differentiate between weight and mass, recognizing that weight is the amount of gravitational pull on an object.	• Explain how to determine the weight of a dense object in air and in water. Next carry out your plan. Explain how the results you obtain are related to the different definitions of mass and weight.
2. Differentiate between volume and mass. Define density.	
3. Recognize that the measurement of volume and mass requires understanding of the sensitivity of measurement tools (e.g., rulers, graduated cylinders, balances) and knowledge and appropriate use of significant digits.	• Calculate the volumes of regular objects from linear measurements. Measure the volumes of the same objects by displacement of water. Use the metric system. Discuss the accuracy limits of your procedures and how they explain any observed differences between your calculated volumes and your measured volumes.
4. Explain and give examples of how mass is conserved in a closed system.	• Melt, dissolve, and precipitate various substances to observe examples of the conservation of mass.
Elements, Compounds, and Mixtures	
5. Recognize that there are more than 100 elements that combine in a multitude of ways to produce compounds that make up all of the living and nonliving things that we encounter.	• Demonstrate with atomic models (e.g., ball and stick) how atoms can combine in a large number of ways. Explain why the number of combinations is large, but still limited. Also use the models to demonstrate the conservation of mass in the chemical reactions you are modeling.
6. Differentiate between an atom (the smallest unit of an element that maintains the characteristics of that element) and a molecule (the smallest unit of a compound that maintains the characteristics of that compound).	• Use atomic models (or Lego blocks, assigning colors to various atoms) to build molecules of water, sodium chloride, carbon dioxide, ammonia, etc.

Physical Sciences (Chemistry and Physics), Grades 6–8

Learning Standard	Ideas for Developing Investigations and Learning Experiences
Elements, Compounds, and Mixtures (cont.)	
7. Give basic examples of elements and compounds.	• Heat sugar in a crucible with an inverted funnel over it. Observe carbon residue and water vapor in the funnel as evidence of the breakdown of components. Continue heating the carbon residue to show that carbon residue does not decompose. Safety note: sugar melts at a very high temperature and can cause serious burns.
8. Differentiate between mixtures and pure substances.	
9. Recognize that a substance (element or compound) has a melting point and a boiling point, both of which are independent of the amount of the sample.	
10. Differentiate between physical changes and chemical changes.	• Demonstrate with molecular ball-and-stick models the physical change that converts liquid water into ice. Also demonstrate with molecular ball-and-stick models the chemical change that converts hydrogen peroxide into water and oxygen gas.
Motion of Objects	
11. Explain and give examples of how the motion of an object can be described by its position, direction of motion, and speed.	
12. Graph and interpret distance vs. time graphs for constant speed.	
Forms of Energy	
13. Differentiate between potential and kinetic energy. Identify situations where kinetic energy is transformed into potential energy and vice versa.	

Physical Sciences (Chemistry and Physics), Grades 6–8

LEARNING STANDARD	IDEAS FOR DEVELOPING INVESTIGATIONS AND LEARNING EXPERIENCES
Heat Energy	
14. Recognize that heat is a form of energy and that temperature change results from adding or taking away heat from a system.	
15. Explain the effect of heat on particle motion through a description of what happens to particles during a change in phase.	
16. Give examples of how heat moves in predictable ways, moving from warmer objects to cooler ones until they reach equilibrium.	• Place a thermometer in a ball of clay and place this in an insulated cup filled with hot water. Record the temperature every minute. Then remove the thermometer and ball of clay and place them in an insulated cup of cold water that contains a second thermometer. Observe and record the changes in temperature on both thermometers. Explain the observations in terms of heat flow. Include direction of heat flow and why it stops.

Chemistry, Grade 10 or 11

Learning Standards for a Full First-Year Course

1. Properties of Matter

Broad Concept: Physical and chemical properties can be used to classify and describe matter.

1.1 **Identify and explain some of the physical properties that are used to classify matter, e.g., density, melting point, and boiling point.***
1.2 **Explain the difference between mixtures and pure substances.***
1.3 **Describe the four states of matter (solid, liquid, gas, plasma) in terms of energy, particle motion, and phase transitions.***
1.4 **Distinguish between chemical and physical changes.**

2. Atomic Structure

Broad Concept: An atom is a discrete unit. The atomic model can help us to understand the interaction of elements and compounds observed on a macroscopic scale.

2.1 Trace the development of atomic theory and the structure of the atom from the ancient Greeks to the present (Dalton, Thompson, Rutherford, Bohr, and modern theory).
2.2 Interpret Dalton's atomic theory in terms of the Laws of Conservation of Mass, Constant Composition, and Multiple Proportions.
2.3 Identify the major components of the nuclear atom (protons, neutrons, and electrons) and explain how they interact.*
2.4 Understand that matter has properties of both particles and waves.
2.5 Using Bohr's model of the atom interpret changes (emission/absorption) in electron energies in the hydrogen atom corresponding to emission transitions between quantum levels.
2.6 Describe the electromagnetic spectrum in terms of wavelength and energy; identify regions of the electromagnetic spectrum.
2.7 Write the electron configurations for elements in the first three rows of the periodic table.
2.8 Describe alpha, beta, and gamma particles; discuss the properties of alpha, beta, and gamma radiation; and write balanced nuclear reactions.
2.9 Compare nuclear fission and nuclear fusion and mass defect.*
2.10 Describe the process of radioactive decay as the spontaneous breakdown of certain unstable elements (radioactive) into new elements (radioactive or not) through the spontaneous emission by the nucleus of alpha or beta particles. Explain the difference between stable and unstable isotopes.
2.11 Explain the concept of half-life of a radioactive element, e.g., explain why the half-life of C14 has made carbon dating a powerful tool in determining the age of very old objects.

Boldface type indicates core standards for full-year courses. An asterisk (*) indicates core standards for integrated courses.

Chemistry, Grade 10 or 11

Learning Standards for a Full First-Year Course

3. Periodicity

Broad Concept: Periodicity of physical and chemical properties relates to atomic structure and led to the development of the periodic table. The periodic table displays the elements in order of increasing atomic number.

3.1 **Explain the relationship of an element's position on the periodic table to its atomic number and mass. ***

3.2 **Use the periodic table to identify metals, nonmetals, metalloids, families (groups), periods, valence electrons, and reactivity with other elements in the table.**

3.3 **Relate the position of an element on the periodic table to its electron configuration.**

3.4 **Identify trends on the periodic table (ionization energy, electronegativity, electron affinity, and relative size of atoms and ions).**

4. Chemical Bonding

Broad Concept: Atoms form bonds by the interactions of their valence electrons.

4.1 **Explain how atoms combine to form compounds through both ionic and covalent bonding. ***

4.2 **Draw Lewis dot structures for simple molecules.**

4.3 Relate electronegativity and ionization energy to the type of bonding an element is likely to undergo.

4.4 Predict the geometry of simple molecules and their polarity (valence shell electron pair repulsion).

4.5 Identify the types of intermolecular forces present based on molecular geometry and polarity.

4.6 **Predict chemical formulas based on the number of valence electrons.**

4.7 **Name and write the chemical formulas for simple ionic and molecular compounds, including those that contain common polyatomic ions.**

5. Chemical Reactions and Stoichiometry

Broad Concept: The conservation of atoms in chemical reactions leads to the ability to calculate the mass of products and reactants.

5.1 **Balance chemical equations by applying the law of conservation of mass.***

5.2 **Recognize synthesis, decomposition, single displacement, double displacement, and neutralization reactions.**

5.3 **Understand the mole concept in terms of number of particles, mass, and gaseous volume.**

Boldface type indicates core standards for full-year courses. An asterisk (*) indicates core standards for integrated courses.

Learning Standards for a Full First-Year Course

5.4 Determine molar mass, percent compositions, empirical formulas, and molecular formulas.
5.5 Calculate mass-mass, mass-volume, volume-volume, and limiting reactant problems for chemical reactions.
5.6 Calculate percent yield in a chemical reaction.

6. Gases and Kinetic Molecular Theory

Broad Concept: The behavior of gases can be explained by the Kinetic Molecular Theory.

6.1 Using the kinetic molecular theory, explain the relationship between pressure and volume (Boyle's law), volume and temperature (Charles' law), and the number of particles in a gas sample (Avogadro's hypothesis).
6.2 Explain the relationship between temperature and average kinetic energy.
6.3 Perform calculations using the ideal gas law.
6.4 Describe the conditions under which a real gas deviates from ideal behavior.
6.5 Interpret Dalton's empirical Law of Partial Pressures and use it to calculate partial pressures and total pressures.
6.6 Use the combined gas law to determine changes in pressure, volume, or temperature.

7. Solutions

Broad Concept: Solids, liquids, and gases dissolve to form solutions.

7.1 Describe the process by which solutes dissolve in solvents.*
7.2 Identify and explain the factors that affect the rate of dissolving (i.e., temperature, concentration, and mixing).*
7.3 Describe the dynamic equilibrium that occurs in saturated solutions.
7.4 Calculate concentration in terms of molarity, molality, and percent by mass.
7.5 Use a solubility curve to determine saturation values at different temperatures.
7.6 Calculate the freezing point depression and boiling point elevation of a solution.
7.7 Write net ionic equations for precipitation reactions in aqueous solutions.

8. Acids and Bases

Broad Concept: Acids and bases are important in numerous chemical processes that occur around us, from industrial processes to biological ones, from the laboratory to the environment.

8.1 Define Arrhenius' theory of acids and bases in terms of the presence of hydronium and hydroxide ions, and Bronsted's theory of acids and bases in terms of proton donor and acceptor, and relate their concentrations to the pH scale. *

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Learning Standards for a Full First-Year Course

8.2 Compare and contrast the nature, behavior, concentration and strength of acids and bases.
  a. Acid-base neutralization
  b. Degree of dissociation or ionization
  c. Electrical conductivity

8.3 Identify a buffer and explain how it works.

8.4 Explain how indicators are used in titrations and how they are selected.

8.5 Describe an acid-base titration. Identify when the equivalence point is reached and its significance.

8.6 Calculate the pH or pOH of aqueous solutions using the hydronium or hydroxide ion concentration.

9. Equilibrium and Kinetics

Broad Concept: Chemical equilibrium is a dynamic process that is significant in many systems (biological, ecological and geological). Chemical reactions occur at different rates.

9.1 Write the equilibrium expression and calculate the equilibrium constant for a reaction.

9.2 Predict the shift in equilibrium when the system is subjected to a stress (LeChatelier's principle).

9.3 Identify the factors that affect the rate of a chemical reaction (temperature, concentration) and the factors that can cause a shift in equilibrium (concentration, pressure, volume, temperature).

9.4 Explain rates of reaction in terms of collision frequency, energy of collisions, and orientation of colliding molecules.

9.5 Define the role of activation energy in a chemical reaction.

10. Thermochemistry (Enthalpy)

Broad Concept: The driving forces of chemical reactions are energy and entropy. This has important implications for many applications (synthesis of new compounds, meteorology, and industrial engineering).

10.1 Interpret the law of conservation of energy.

10.2 Explain the relationship between energy transfer and disorder in the universe.

10.3 Analyze the energy changes involved in physical and chemical processes using calorimetry.

10.4 Apply Hess's law to determine the heat of reaction.

Boldface type indicates core standards for full-year courses. An asterisk (*) indicates core standards for integrated courses.

Learning Standards for a Full First-Year Course

11. Oxidation-Reduction and Electrochemistry

Broad Concept: Oxidation-reduction reactions occur by electron transfer and constitute a major class of chemical reactions. Examples of redox reactions occur everywhere; their consequences are experienced daily.

11.1 Describe the chemical processes known as oxidation and reduction.
11.2 Assign oxidation numbers.
11.3 Balance oxidation-reduction equations by using half-reactions.
11.4 Identify the components, and describe the processes that occur in an electrochemical cell.
11.5 Explain how a typical battery, such as a lead storage battery or a dry cell, works.
11.6 Compare and contrast voltaic and electrolytic cells and their uses.
11.7 Calculate the net voltage of a cell given a table of standard reduction potentials.

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Physics, Grade 9 or 10

Learning Standards for a Full First-Year Course

1. Motion and Forces

Broad Concept: Newton's laws of motion and gravitation describe and predict the motion of most objects.

1.1 **Distinguish between vector quantities (velocity, acceleration, and force) and scalar quantities (speed and mass).**
1.2 Illustrate how to represent vectors graphically and be able to add them graphically.
1.3 **Distinguish between, and solve problems involving, velocity, speed, and constant acceleration.**
1.4 **Create and interpret graphs of motion (position vs. time, speed vs. time, velocity vs. time, constant acceleration vs. time).**
1.5 **Explain the relationship between mass and inertia.***
1.6 **Interpret and apply Newton's first law of motion.***
1.7 **Interpret and apply Newton's second law of motion to show how an object's motion will change only when a net force is applied.***
1.8 **Use a free body force diagram with only co-linear forces to show forces acting on an object, and determine the net force on it.**
1.9 Qualitatively distinguish between static and kinetic friction, what they depend on and their effects on the motion of objects.
1.10 **Interpret and apply Newton's third law of motion.**
1.11 **Understand conceptually Newton's law of universal gravitation. ***
1.12 Identify appropriate standard international units of measurement for force, mass, distance, speed, acceleration, and time, and explain how they are measured.

2. Conservation of Energy and Momentum

Broad Concept: The laws of conservation of energy and momentum provide alternate approaches to predict and describe the movement of objects.

2.1 **Interpret and provide examples that illustrate the law of conservation of energy. ***
2.2 **Provide examples of how energy can be transformed from kinetic to potential and vice versa.**
2.3 Apply quantitatively the law of conservation of mechanical energy to simple systems.
2.4 **Describe the relationship among energy, work, and power both conceptually and quantitatively.**
2.5 **Interpret the law of conservation of momentum and provide examples that illustrate it. Calculate the momentum of an object.**
2.6 Identify appropriate standard international units of measurement for energy, work, power, and momentum.

Boldface type indicates core standards for full-year courses. An asterisk (*) indicates core standards for integrated courses.

Learning Standards for a Full First-Year Course

3. Heat and Heat Transfer

Broad Concept: Heat is energy that is transferred between bodies that are at different temperatures by the processes of convection, conduction, and/or radiation.

3.1 **Relate thermal energy to molecular motion.***
3.2 Differentiate between specific heat and heat capacity.
3.3 **Explain the relationship among temperature change in a substance for a given amount of heat transferred, the amount (mass) of the substance, and the specific heat of the substance.**
3.4 Recognize that matter exists in four phases, and explain what happens during a phase change.

4. Waves

Broad Concept: Waves carry energy from place to place without the transfer of matter.

4.1 **Differentiate between wave motion (simple harmonic nonlinear motion) and the motion of objects (nonharmonic).***
4.2 **Recognize the measurable properties of waves (e.g., velocity, frequency, wavelength) and explain the relationships among them. ***
4.3 **Distinguish between transverse and longitudinal waves.**
4.4 **Distinguish between mechanical and electromagnetic waves. ***
4.5 Interpret and be able to apply the laws of reflection and refraction (qualitatively) to all waves.
4.6 Recognize the effects of polarization, wave interaction, and the Doppler effect.
4.7 Explain, graph, and interpret graphs of constructive and destructive interference of waves.
4.8 Explain the relationship between the speed of a wave (e.g., sound) and the medium it travels through.
4.9 Recognize the characteristics of a standing wave and explain the conditions under which two waves on a string or in a pipe can interfere to produce a standing wave.

5. Electromagnetism

Broad Concept: Stationary and moving charge particles result in the phenomenon known as electricity and magnetism.

5.1 **Recognize the characteristics of static charge, and explain how a static charge is generated.**
5.2 Interpret and apply Coulomb's law.

Boldface type indicates core standards for full-year courses. An asterisk (*) indicates core standards for integrated courses.

Learning Standards for a Full First-Year Course

5.3 Explain the difference in concept between electric forces and electric fields.
5.4 Develop a qualitative and quantitative understanding of current, voltage, resistance, and the connection between them.
5.5 Identify appropriate units of measurement for current, voltage, and resistance, and explain how they are measured.
5.6 Analyze circuits (find the current at any point and the potential difference between any two points in the circuit) using Kirchoff's and Ohm's laws.

6. Electromagnetic Radiation

Broad Concept: Oscillating electric or magnetic fields can generate electromagnetic waves over a wide spectrum of energies.

6.1 Describe the electromagnetic spectrum in terms of wavelength and energy, and be able to identify specific regions such as visible light. *
6.2 Explain how the various wavelengths in the electromagnetic spectrum have many useful applications such as radio, television, microwave appliances, and cellular telephones.
6.3 Calculate the frequency and energy of an electromagnetic wave from the wavelength.
6.4 Recognize and explain the ways in which the direction of visible light can be changed.

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South Carolina

Chemistry Overview

The standards for chemistry establish scientific inquiry skills and core content for all chemistry courses in South Carolina schools. In chemistry, students acquire a fundamental knowledge of the substances in our world—their composition, properties, and interactions—that should not only serve them as a foundation for the more advanced science courses in secondary and postsecondary education but should also provide them with the science skills that are necessary in chemistry-oriented technical careers.

In order for students to achieve these goals, chemistry courses must include inquiry-based instruction, allowing students to engage in problem solving, decision making, critical thinking, and applied learning. Teachers, schools, and districts should therefore use these standards to make decisions concerning the structure and content of all their courses in chemistry and to make choices regarding additional content, activities, and learning strategies that will be determined by the objectives of the particular courses.

All chemistry courses are laboratory courses (minimum of 30 percent hands-on investigation). Chemistry laboratories will need to be stocked with all of the materials and apparatuses necessary to complete investigations.

The skills and tools listed in the scientific inquiry sections have been assessed on statewide tests independently from the content knowledge in the respective grade or high school core area under which they are listed. Moreover, scientific inquiry standards and indicators have been assessed *cumulatively*. Therefore, as students progress through this course, they are expected to know the content of the scientific inquiry indicators—including the use of tools—from all their previous grades and science courses. A table of the scientific inquiry standards and indicators for kindergarten through grade twelve is provided in appendix A, which teachers are urged to print out and keep as a ready reference.

CHEMISTRY

Scientific Inquiry

The skills of scientific inquiry, including a knowledge of the use of tools, will be assessed cumulatively on statewide tests. Students will therefore be responsible for the scientific inquiry indicators from all of their earlier grade levels. A table of the K–12 scientific inquiry standards and indicators is provided in appendix A.

Standard C-1: The student will demonstrate an understanding of how scientific inquiry and technological design, including mathematical analysis, can be used appropriately to pose questions, seek answers, and develop solutions.

Indicators

C-1.1 Apply established rules for significant digits, both in reading a scientific instrument and in calculating a derived quantity from measurement.

C-1.2 Use appropriate laboratory apparatuses, technology, and techniques safely and accurately when conducting a scientific investigation.

C-1.3 Use scientific instruments to record measurement data in appropriate metric units that reflect the precision and accuracy of each particular instrument.

C-1.4 Design a scientific investigation with appropriate methods of control to test a hypothesis (including independent and dependent variables), and evaluate the designs of sample investigations.

C-1.5 Organize and interpret the data from a controlled scientific investigation by using mathematics (including formulas, scientific notation, and dimensional analysis), graphs, models, and/or technology.

C-1.6 Evaluate the results of a scientific investigation in terms of whether they verify or refute the hypothesis and what the possible sources of error are.

C-1.7 Evaluate a technological design or product on the basis of designated criteria.

C-1.8 Use appropriate safety procedures when conducting investigations.

CHEMISTRY

Standard C-2: Students will demonstrate an understanding of atomic structure and nuclear processes.

Indicators

C-2.1 Illustrate electron configurations by using orbital notation for representative elements.
C-2.2 Summarize atomic properties (including electron configuration, ionization energy, electron affinity, atomic size, and ionic size).
C-2.3 Summarize the periodic table's property trends (including electron configuration, ionization energy, electron affinity, atomic size, ionic size, and reactivity).
C-2.4 Compare the nuclear reactions of fission and fusion to chemical reactions (including the parts of the atom involved and the relative amounts of energy released).
C-2.5 Compare alpha, beta, and gamma radiation in terms of mass, charge, penetrating power, and the release of these particles from the nucleus.
C-2.6 Explain the concept of half-life, its use in determining the age of materials, and its significance to nuclear waste disposal.

The following indicators should be selected as appropriate to a particular course for additional content and depth:

C-2.7 Apply the predictable rate of nuclear decay (half-life) to determine the age of materials.
C-2.8 Analyze a decay series chart to determine the products of successive nuclear reactions and write nuclear equations for disintegration of specified nuclides.
C-2.9 Use the equation $E = mc^2$ to determine the amount of energy released during nuclear reactions.

CHEMISTRY

Standard C-3: The student will demonstrate an understanding of the structures and classifications of chemical compounds.

Indicators

C-3.1 Predict the type of bonding (ionic or covalent) and the shape of simple compounds by using Lewis dot structures and oxidation numbers.
C-3.2 Interpret the names and formulas for ionic and covalent compounds.
C-3.3 Explain how the types of intermolecular forces present in a compound affect the physical properties of compounds (including polarity and molecular shape).
C-3.4 Explain the unique bonding characteristics of carbon that have resulted in the formation of a large variety of organic structures.
C-3.5 Illustrate the structural formulas and names of simple hydrocarbons (including alkanes and their isomers and benzene rings).

The following indicators should be selected as appropriate to a particular course for additional content and depth:

C-3.6 Identify the basic structure of common polymers (including proteins, nucleic acids, plastics, and starches).
C-3.7 Classify organic compounds in terms of their functional group.
C-3.8 Explain the effect of electronegativity and ionization energy on the type of bonding in a molecule.
C-3.9 Classify polymerization reactions as addition or condensation.
C-3.10 Classify organic reactions as addition, elimination, or condensation.

CHEMISTRY

Standard C-4: The student will demonstrate an understanding of the types, the causes, and the effects of chemical reactions.

Indicators

C-4.1 Analyze and balance equations for simple synthesis, decomposition, single replacement, double replacement, and combustion reactions.
C-4.2 Predict the products of acid-base neutralization and combustion reactions.
C-4.3 Analyze the energy changes (endothermic or exothermic) associated with chemical reactions.
C-4.4 Apply the concept of moles to determine the number of particles of a substance in a chemical reaction, the percent composition of a representative compound, the mass proportions, and the mole-mass relationships.
C-4.5 Predict the percent yield, the mass of excess, and the limiting reagent in chemical reactions.
C-4.6 Explain the role of activation energy and the effects of temperature, particle size, stirring, concentration, and catalysts in reaction rates.

The following indicators should be selected as appropriate to a particular course for additional content and depth:

C-4.7 Summarize the oxidation and reduction processes (including oxidizing and reducing agents).
C-4.8 Illustrate the uses of electrochemistry (including electrolytic cells, voltaic cells, and the production of metals from ore by electrolysis).
C-4.9 Summarize the concept of chemical equilibrium and Le Châtelier's principle.
C-4.10 Explain the role of collision frequency, the energy of collisions, and the orientation of molecules in reaction rates.

CHEMISTRY

Standard C-5: The student will demonstrate an understanding of the structure and behavior of the different phases of matter.

Indicators

C-5.1 Explain the effects of the intermolecular forces on the different phases of matter.
C-5.2 Explain the behaviors of gas; the relationship among pressure, volume, and temperature; and the significance of the Kelvin (absolute temperature) scale, using the kinetic-molecular theory as a model.
C-5.3 Apply the gas laws to problems concerning changes in pressure, volume, or temperature (including Charles's law, Boyle's law, and the combined gas law).
C-5.4 Illustrate and interpret heating and cooling curves (including how boiling and melting points can be identified and how boiling points vary with changes in pressure).

The following indicators should be selected as appropriate to a particular course for additional content and depth:

C-5.5 Analyze the energy changes involved in calorimetry by using the law of conservation of energy as it applies to temperature, heat, and phase changes (including the use of the formulas $q = mc\Delta T$ [temperature change] and $q = mLv$ and $q = mLf$ [phase change] to solve calorimetry problems).
C-5.6 Use density to determine the mass, volume, or number of particles of a gas in a chemical reaction.
C-5.7 Apply the ideal gas law ($pV = nRT$) to solve problems.
C-5.8 Analyze a product for purity by following the appropriate assay procedures.
C-5.9 Analyze a chemical process to account for the weight of all reagents and solvents by following the appropriate material balance procedures.

CHEMISTRY

Standard C-6: The student will demonstrate an understanding of the nature and properties of various types of chemical solutions.

Indicators

C-6.1 Summarize the process by which solutes dissolve in solvents, the dynamic equilibrium that occurs in saturated solutions, and the effects of varying pressure and temperature on solubility.
C-6.2 Compare solubility of various substances in different solvents (including polar and nonpolar solvents and organic and inorganic substances).
C-6.3 Illustrate the colligative properties of solutions (including freezing point depression and boiling point elevation and their practical uses).
C-6.4 Carry out calculations to find the concentration of solutions in terms of molarity and percent weight (mass).
C-6.5 Summarize the properties of salts, acids, and bases.
C-6.6 Distinguish between strong and weak common acids and bases.
C-6.7 Represent common acids and bases by their names and formulas.

The following indicators should be selected as appropriate to a particular course for additional content and depth:

C-6.8 Use the hydronium or hydroxide ion concentration to determine the pH and pOH of aqueous solutions.
C-6.9 Explain how the use of a titration can determine the concentration of acid and base solutions
C-6.10 Interpret solubility curves to determine saturation at different temperatures.
C-6.11 Use a variety of procedures for separating mixtures (including distillation, crystallization filtration, paper chromatography, and centrifuge).
C-6.12 Use solubility rules to write net ionic equations for precipitation reactions in aqueous solution.
C-6.13 Use the calculated molality of a solution to calculate the freezing point depression and the boiling point elevation of a solution.
C-6.14 Represent neutralization reactions and reactions between common acids and metals by using chemical equations.
C-6.15 Analyze the composition of a chemical sample by using gas chromatography.

APPENDIX B

Revised Bloom's Taxonomy

In 1956, Benjamin Bloom and his colleagues published the *Taxonomy of Educational Objectives: The Classification of Educational Goals*, a groundbreaking book that classified educational goals according to the cognitive processes that learners must use in order to attain those goals. The work, which was enthusiastically received, was utilized by teachers to analyze learning in the classroom for nearly fifty years.

However, research during that time span generated new ideas and information about how learners learn and how teachers teach. Education practice is very different today. Even the measurement of achievement has changed; teachers now live in a standards-based world defined by state accountability systems.

In order to reflect the new data and insights about teaching and learning that the past forty-five years of research have yielded—and to refocus educators' attention on the value of the original Bloom's taxonomy—Lorin Anderson and David Krathwohl led a team of colleagues in revising and enhancing that system to make it more usable for aligning standards, instruction, and assessment in today's schools. The results of their work were published in 2001 as *A Taxonomy for Learning, Teaching, and Assessing: A Revision of Bloom's Taxonomy of Educational Objectives* (New York: Allyn and Bacon)—a book that is important to educators because it provides the common understanding of expectations that is critical for improving student achievement in all subjects.

The revised taxonomy is two-dimensional, identifying both the kind of knowledge to be learned (knowledge dimension) and the kind of learning expected from students (cognitive processes) to help teachers and administrators improve alignment and rigor in the classroom. This taxonomy will assist educators to improve instruction, to ensure that their lessons and assessments are aligned with one another and with the state standards, that their lessons are cognitively rich, and that instructional opportunities are not missed.

Science goes well beyond simple recognition and the memorization of facts that many people mistake for scientific literacy. Therefore, many of the main verbs in the indicators of the South Carolina science standards reflect the cognitive processes described in the revised Bloom's taxonomy under the category *understand*. This category requires *interpreting, exemplifying, classifying, summarizing, inferring, comparing*, and *explaining* from students—understanding rather than rote memorization of materials. Students might have to *compare* two organisms or *explain* how variations in habitats affect the survival of an organism. Several indicators require students to demonstrate two even higher categories of cognitive processes—*analyze* and *evaluate*—by *organizing* and *critiquing* data and/or the results of scientific investigation, for example.

Tables 1 and 2 on the following pages are reproduced from Anderson and Krathwohl's *Taxonomy for Learning, Teaching, and Assessing,* pages 46 and 67, respectively. Table 3, "A Taxonomy for Teaching, Learning, and Assessing," describes both dimensions of the taxonomy: types and subtypes of knowledge described in table 1 and the cognitive categories and processes described in table 2. This matrix is provided as a template for teachers to use in analyzing their instruction as they seek to align standards, units/lessons/activities, and assessments. Examples and more information about specific uses of the matrix can be found in the *Taxonomy for Learning.*

Table 1: The Knowledge Dimension		
MAJOR TYPES AND SUBTYPES		**EXAMPLES**
A. FACTUAL KNOWLEDGE—The basic elements students must know to be acquainted with a discipline or solve problems in it		
AA.	Knowledge of terminology	Technical vocabulary, musical symbols
AB.	Knowledge of specific details and elements	Major natural resources, reliable sources of information
B. CONCEPTUAL KNOWLEDGE—The interrelationships among the basic elements within a larger structure that enable them to function together		
BA.	Knowledge of classifications and categories	Periods of geological time, forms of business ownership
BB.	Knowledge of principles and generalizations	Pythagorean theorem, law of supply and demand
BC.	Knowledge of theories, models, and structures	Theory of evolution, structure of Congress
C. PROCEDURAL KNOWLEDGE—How to do something, methods and inquiry, and criteria for using skills, algorithms, techniques, and methods		
CA.	Knowledge of subject-specific skills and algorithms	Skills used in painting with watercolors, whole-number division algorithm
CB.	Knowledge of subject-specific techniques and methods	Interviewing techniques, scientific method
CC.	Knowledge of criteria for determining when to use appropriate procedures	Criteria used to determine when to apply a procedure involving Newton's second law, criteria used to judge the feasibility of using a particular method to estimate business costs
D. METACOGNITIVE KNOWLEDGE—Knowledge of cognition in general as well as awareness and knowledge of one's own cognition		
DA.	Strategic knowledge	Knowledge of outlining as a means of capturing the structure of a unit of subject matter in a textbook, knowledge of the use of heuristics
DB.	Knowledge about cognitive tasks including appropriate contextual and conditional knowledge	Knowledge of the types of tests particular teachers administer, knowledge of the cognitive demands of different tasks
DC.	Self-knowledge	Knowledge that critiquing essays is a personal strength, whereas writing essays is a personal weakness; awareness of one's own knowledge level

From Lorin W. Anderson and David R. Krathwohl, *A Taxonomy for Learning, Teaching, and Assessing: A Revision of Bloom's Educational Objectives,*

Table 2: The Cognitive Process Dimension

CATEGORIES & COGNITIVE PROCESSES	ALTERNATIVE NAMES	DEFINITIONS AND EXAMPLES
1. REMEMBER—Retrieve relevant knowledge from long-term memory		
1.1 RECOGNIZING	Identifying	Locating knowledge in long-term memory that is consistent with presented material (e.g., Recognize the dates of important events in United States history)
1.2 RECALLING	Retrieving	Retrieving relevant knowledge from long-term memory (e.g., Recall the dates of important events in United States history)
2. UNDERSTAND—Construct meaning from instructional messages including oral, written, and graphic communication		
2.1 INTERPRETING	Clarifying, paraphrasing, representing, translating	Changing from one form of representation (e.g., numerical) to another (e.g., verbal) (e.g., Paraphrase important speeches and documents)
2.2 EXEMPLIFYING	Illustrating, instantiating	Finding a specific example or illustration of a concept or principle (e.g., Give examples of various artistic painting styles)
2.3 CLASSIFYING	Categorizing, subsuming	Determining that something belongs to a category (e.g., Classify observed or described cases of mental disorders)
2.4 SUMMARIZING	Abstracting, generalizing	Abstracting a general theme or major point(s) (e.g., Write a short summary of events portrayed on a videotape)
2.5 INFERRING	Concluding, extrapolating, interpolating, predicting	Drawing a logical conclusion from presented information (e.g., In learning a foreign language, infer grammatical principles from examples)
2.6 COMPARING	Contrasting, mapping, matching	Detecting correspondences between two ideas, objects, and the like (e.g., Compare historical events to contemporary situations)
2.7 EXPLAINING	Constructing models	Constructing a cause-and-effect model of a system (e.g., Explain the causes of important 18th Century events in France)
3. APPLY—Carry out or use a procedure in a given situation		
3.1 EXECUTING	Carrying out	Applying a procedure to a familiar task (e.g., Divide one whole number by another whole number, both with multiple digits)
3.2 IMPLEMENTING	Using	Applying a procedure to an unfamiliar task (e.g., Use Newton's Second Law in situations in which it is appropriate)

Table 2: The Cognitive Process Dimension

CATEGORIES & COGNITIVE PROCESSES	ALTERNATIVE NAMES	DEFINITIONS AND EXAMPLES
4. ANALYZE—Break material into its constituent parts and determine how the parts relate to one another and to an overall structure or purpose		
4.1 DIFFERENTIATING	Discriminating, distinguishing, focusing, selecting	Distinguishing relevant from irrelevant parts or important from unimportant parts of presented material (e.g., Distinguish between relevant and irrelevant numbers in a mathematical word problem)
4.2 ORGANIZING	Finding coherence, integrating, outlining, parsing, structuring	Determining how elements fit or function within a structure (e.g., Structure evidence in a historical description into evidence for and against a particular historical explanation)
4.3 ATTRIBUTING	Deconstructing	Determine a point of view, bias, values, or intent underlying presented material (e.g., Determine the point of view of the author of an essay in terms of his or her political perspective)
5. EVALUATE—Make judgments based on criteria and standards		
5.1 CHECKING	Coordinating, detecting, monitoring, testing	Detecting inconsistencies or fallacies within a process or product; determining whether a process or product has internal consistency; detecting the effectiveness of a procedure as it is being implemented (e.g., Determine if a scientist's conclusions follow from observed data)
5.2 CRITIQUING	Judging	Detecting inconsistencies between a product and external criteria, determining whether a product has external consistency; detecting the appropriateness of a procedure for a given problem (e.g., Judge which of two methods is the best way to solve a given problem)
6. CREATE—Put elements together to form a coherent or functional whole; reorganize elements into a new pattern or structure		
6.1 GENERATING	Hypothesizing	Coming up with alternative hypotheses based on criteria (e.g., Generate hypotheses to account for an observed phenomenon)
6.2 PLANNING	Designing	Devising a procedure for accomplishing some task (e.g., Plan a research paper on a given historical topic)
6.3 PRODUCING	Constructing	Inventing a product (e.g., Build habitats for a specific purpose)

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	✓	✓	✓
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)

Country	TIMSS 4th grade	TIMSS 8th grade	PISA 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.

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[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.