Some Results Regarding 21st Century Content Standards in Physics, Chemistry, and Engineering as Developed by Three Panels of Practicing Scientists and Engineers

Jim Batterson
Special Assistant on Loan from NASA to the Secretary of Education

September 2007
Richmond, VA

Jim.Batterson@governor.virginia.gov
James.G.Batterson@nasa.gov
804.692.2547 757.864.4059

Preview of Major Points

- Panels of broadly selected practicing engineers and scientists
- Addressed the question of what science the “average” (or 90% of) Virginian needs to know for the 21^{st} Century
- Called for major changes to current content philosophy in chemistry & physics
  - 20% laboratory integrated and assessed
  - Contemporary & emerging applications must be taught & integrated
  - Move to a core/elective approach
  - DOE support open-source wiki for timely content
- Engineering design process *learned* by all students and pre-engineering high school program *available* to all students in VA

Basis for Activity and Objective of Panels

- Activity sponsored through Intergovernmental Personnel Act (IPA) as a partnership for ensuring quality of NASA's next-generation workforce capabilities, and…

- Provide "gap analysis" of SOL in physics & chemistry and of Virginia's K-12 program in engineering from the viewpoint of practicing engineers and scientists

Panel Philosophy & Composition

- Practicing engineers and scientists drawn from
  - University content-area departments
  - University engineering schools
  - Government research labs
  - Industry
- Additional members from K-12
- Complementary to usual K-12 panels
- Covered “A to W” (Astronaut to Weed Science!)
- Covered full range of technology readiness levels from
  - Basic & applied research
  - Technology & development
  - Operations & manufacturing

Logistics

- Nine (9) members on *each* of physics & chemistry panels
- Fourteen (14) members on engineering panel
- Extensive pre-meeting reading sent out 4 weeks prior to meeting
  - VA SOL and Curriculum Frameworks
  - SOL from other leading states (Fordham reviewed)
  - IB, AP, National Science Education Standards, and AAAS Project 2061 (“Science for All Americans” & “Benchmarks”)
  - NRC (National Research Council) and AIP (American Institute of Physics) studies on content of advanced high school chemistry and physics courses
  - Kentucky “Emerging Technology Awareness”
- Each panel met face-to-face for two days at National Institute of Aerospace in Hampton

Big Question for Panels

- What (physics/chemistry/engineering) content do 80% - 90% of Virginia's high school graduates need to know to participate in political, social, economic, and technological business of the 21st century?
  - Not about advanced science
  - 10% of 9-12 students are in one or more AP course
  - 1% of 9-12 students are in a Governor's School
  - 0.25% of 9-12 students are in IB programs

- (Also asked Engineering Panel what would be appropriate high school preparation for an engineering major)

But before looking at results, some definitions…

STEM Components & Innovation Defined

- **Science** – the ***study*** of the physical world and its manifestations, especially through systematic observation and experiments.

- **Technology** – the application of scientific and engineering knowledge to achieve a ***practical result***.

- **Engineering** – the creation or development of new devices and objects that are of ***importance or value*** to humans and society.

- **Mathematics** – a branch of pure science or philosophy (logic) that in its ***applied*** state can be used to help make quantitative analysis and predictions for science, technology, and engineering.

Innovation – Creation of new ***value***

Example 1:

Humans to the Moon and Safely Home

Need for National Response to Sputnik/Cold War/Missile Gap

Carried out by:

Carried out by	
Engineers & many other professions & skills	**Innovation** – Humans to the Moon and Safely Return
Engineers, Technicians & Scientists	**Technology** – Rockets, Protective Clothing, Computers
Scientists & Engineers	**Science** – Newton's Laws of Motion/Gravitation, Chemistry
Mathematicians	**Mathematics** – Algebra, Geometry, Trigonometry, Calculus

Some Selected Results – Chemistry & Physics

- Laboratories and demonstrations must be integrated into Physics and Chemistry courses and be assessed
  - Written lab reports required

- In Physics and Chemistry, teams created “Core” or “Essential” knowledge and “Elective” knowledge with the teacher to choose from among “Elective” subjects
  - Physics SOL way too broad and miss some more important things
  - Some existing Physics and Chemistry modules can be eliminated or made elective
  - Organic chemistry is essential

- Contemporary applications & emerging technologies of Physics and Chemistry must be taught
  - Electives: choose from nano, bio, particle physics, superconductors,….
  - DOE should develop and support an open-source wiki for contemporary applications, emerging technologies, and laboratories

- Consider Leon Lederman’s “ARISE” or “Physics First” science curriculum from Fermilab as a total restructuring

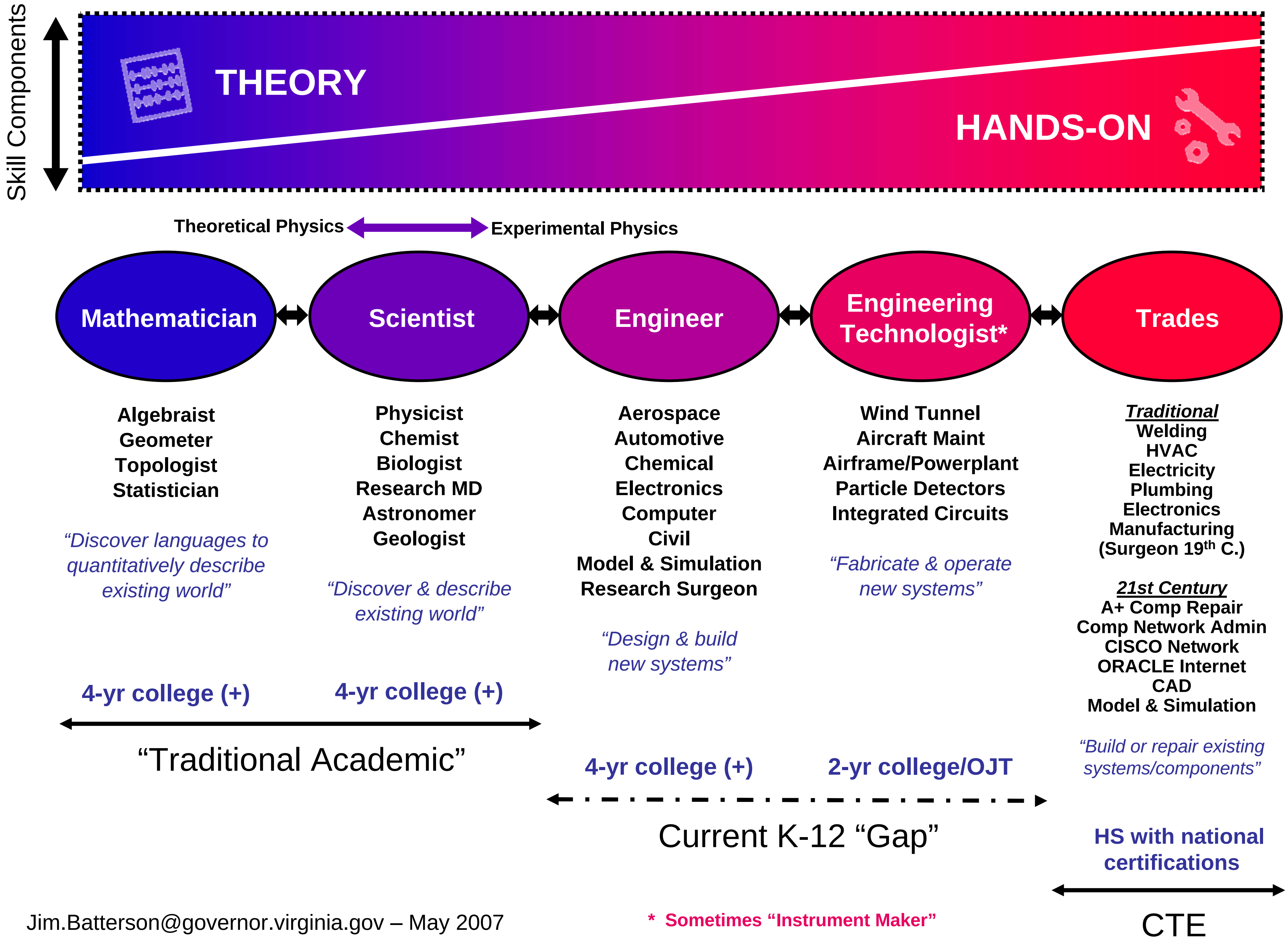
Some Selected Results – Engineering

- There is no “STEM” program in VA
  - There is Math (Theory) and Science (Theory) and some Technology (St_M)
  - Engineering is not required for students in VA nor is it generally available to all students.
  - Engineering is book-kept in CTE

- Engineering Design Process differs from Scientific Method and should be required content in VA

- Women and minorities continue to be under-represented in engineering profession

- Project Lead The Way (PLTW) is a turn-key national engineering program being taught in 14/134 school divisions in VA and covers almost all that would be needed to learn the engineering design process – ODU is “lead” or “affiliate” university in VA
  - Ford Motor Company’s PAS and TI’s Infinity Project also turn-key
  - FIRST (LEGO, VEX, Robotics) available
  - Children’s Engineering Guide is available (K-5) – used in 12/134 VA school divisions



Skill Components
THEORY
HANDS-ON
Theoretical Physics
Experimental Physics
Mathematician
Scientist
Engineer
Engineering Technologist*
Trades
Algebraist
Geometer
Topologist
Statistician
"Discover languages to quantitatively describe existing world"
Physicist
Chemist
Biologist
Research MD
Astronomer
Geologist
"Discover & describe existing world"
Aerospace
Automotive
Chemical
Electronics
Computer
Civil
Model & Simulation
Research Surgeon
"Design & build new systems"
Wind Tunnel
Aircraft Maint
Airframe/Powerplant
Particle Detectors
Integrated Circuits
"Fabricate & operate new systems"
Traditional
Welding
HVAC
Electricity
Plumbing
Electronics
Manufacturing
(Surgeon 19th C.)
21st Century
A+ Comp Repair
Comp Network Admin
CISCO Network
ORACLE Internet
CAD
Model & Simulation
"Build or repair existing systems/components"
4-yr college (+)
4-yr college (+)
"Traditional Academic"
4-yr college (+)
2-yr college/OJT
Current K-12 "Gap"
HS with national certifications
CTE
Jim.Batterson@governor.virginia.gov – May 2007
* Sometimes "Instrument Maker"

Summary

- Panels of broadly selected practicing engineers and scientists
- Addressed the question of what science the “average” (or 90% of) Virginian needs to know for the 21st Century
- Called for major changes to current content philosophy in chemistry & physics
  - 20% laboratory integrated and assessed
  - Contemporary & emerging applications must be taught & integrated
  - Move to a core/elective approach
  - DOE support open-source wiki for timely content
- Engineering design process *learned* by all students and pre-engineering high school program *available* to all students in VA

Backup Slides

Example 2:
Economic Development and Demographic Expansion

Need for safe and rapid mobility for people & goods (19th C.)

Carried out by:

Carried out by	
Engineers & many other professions & skills	**Innovation** – Bridges across great rivers (*Architecture*, *Urban Design*)
Engineers, Technicians & Scientists	**Technology** – Iron, Steel
Scientists & Engineers	**Science** – Physics Forces, Chemistry
Mathematicians	**Mathematics** – Algebra, Geometry, Trigonometry

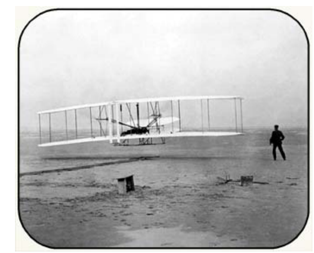
Example 3a:

Air Transportation <u>Vehicle</u> (Practical Airplane)

<u>Carried out by:</u>

Military needs for WW I

Carried out by	
Engineers & many other professions & skills	**<u>Innovation</u>** – Curtis Jenny and other practical airplanes
Engineers, Technicians	**<u>Technology</u>** – Wright Flyer (Prototype for a *practical* airplane)
Engineers, Technicians & Scientists	**<u>Technology</u>** – Internal combustion engine, Wind tunnel, Wing warping
Scientists & Engineers	**<u>Science</u>** – Newton's Laws of Motion, Fluids, Chemistry
Mathematicians	**<u>Mathematics</u>** – Algebra, Trigonometry, Geometry

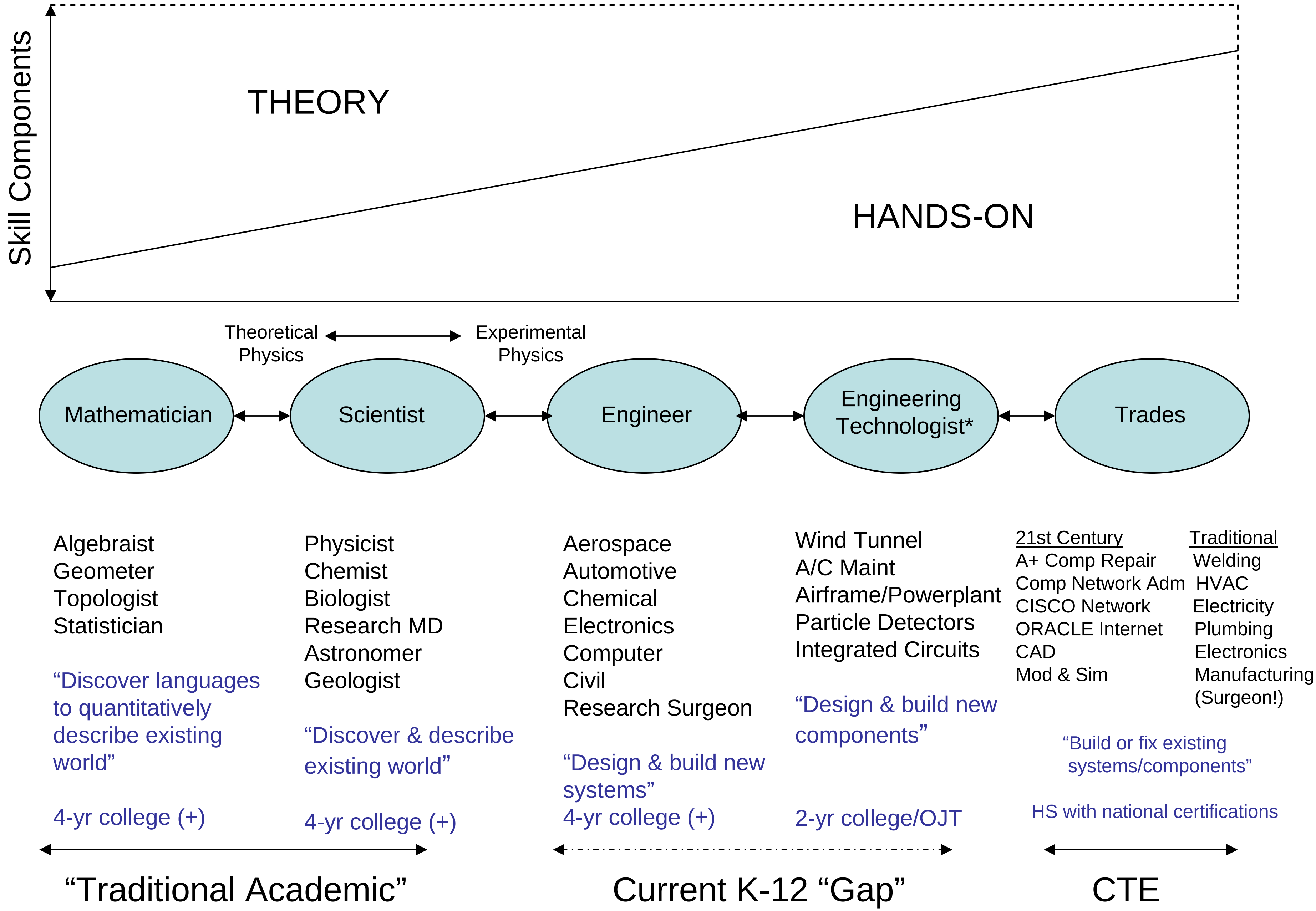


Science & Engineering Processes*

A Side-by-Side Comparison

SCIENTIFIC METHOD	ENGINEERING DESIGN ALGORITHM
1. Observe some aspect of the universe	1. Identify the problem or design objective
2. Invent a tentative description (hypothesis) consistent with what you have observed	2. Define the goals and identify the **constraints**
3. Use the hypothesis to make predictions	3. Research & gather information
4. Test the predictions by experiments or further observations, and modify your hypothesis in light of your results	4. Create potential design solutions
5. Repeat steps 3 & 4 until there are (no) discrepancies between theory and/or observation	5. Analyze the viability of solutions
	6. Choose the most appropriate solution
	7. Build or implement the design
	8. Test and evaluate the design
	9. Repeat ALL steps as necessary

* From: “The Infinity Project: Engineering Our Digital Future”



* Sometimes "Instrument Maker"

Jim.Batterson@governor.virginia.gov – May 2007

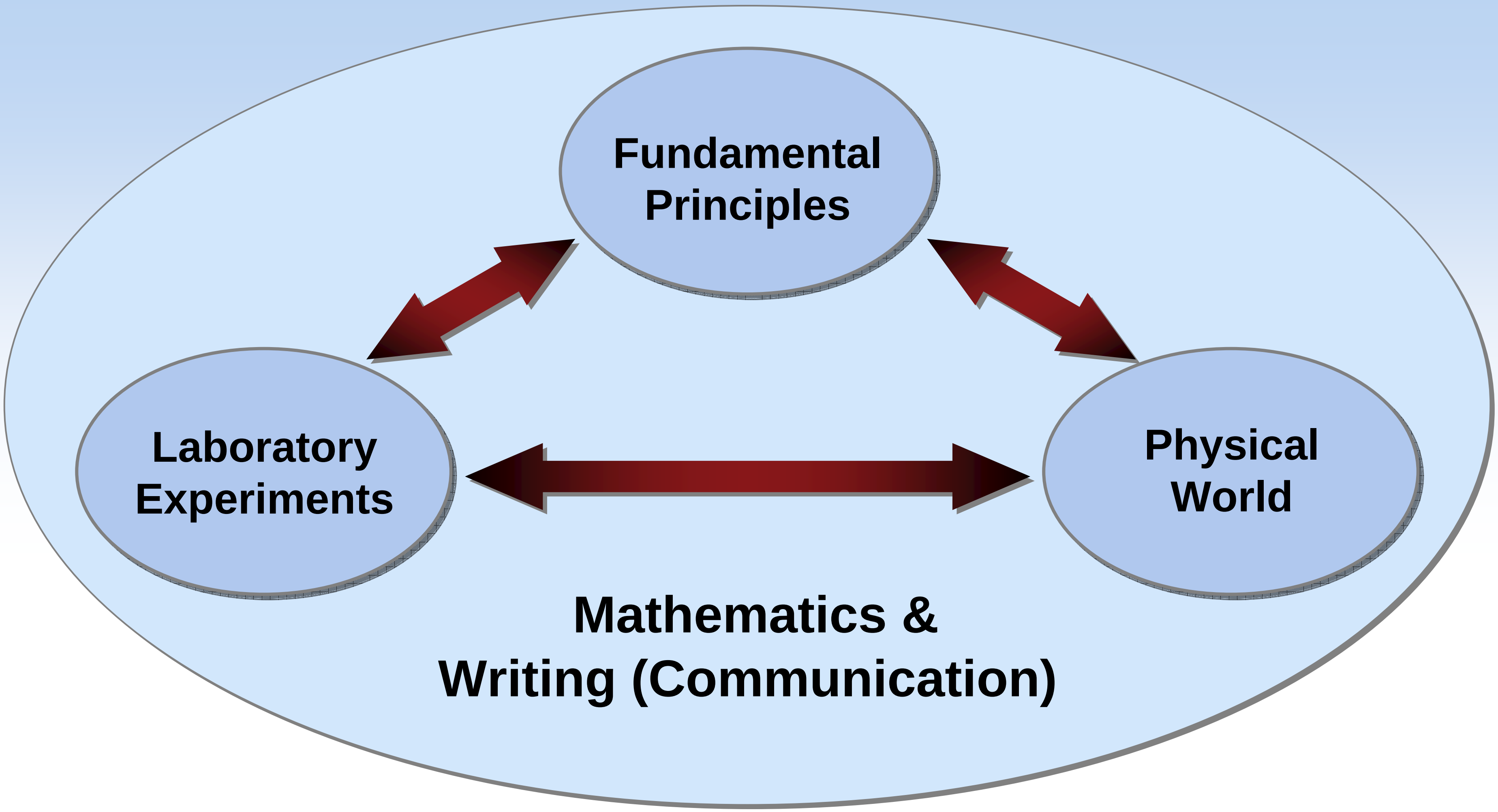
Distribution of Panel Members' Affiliations

- University
  - UVA
  - VA Tech
  - W&M
  - HU
  - CNU
  - JMU
  - VCU/J. Sargent Reynolds CC
  - University of Southern California
  - ODU
- Industry
  - Northrop-Grumman
  - Micron Technology
  - LUNA Innovations
  - National Institute of Aerospace
  - Lockheed Martin
- Research Labs
  - Jefferson Lab (DOE)
  - NSWC – Dahlgren (DOD)
  - NSWC – Indian Head (DOD)
  - NASA – Langley (Exec Agency)
  - NASA – Johnson (Exec Agency)
  - Naval Research Lab (DOD)
- K-12
  - Chantilly Academy Fairfax
  - Jamestown High School
  - Appomattox Gov School
  - Newport News Public Schools
  - Piedmont Governor's School

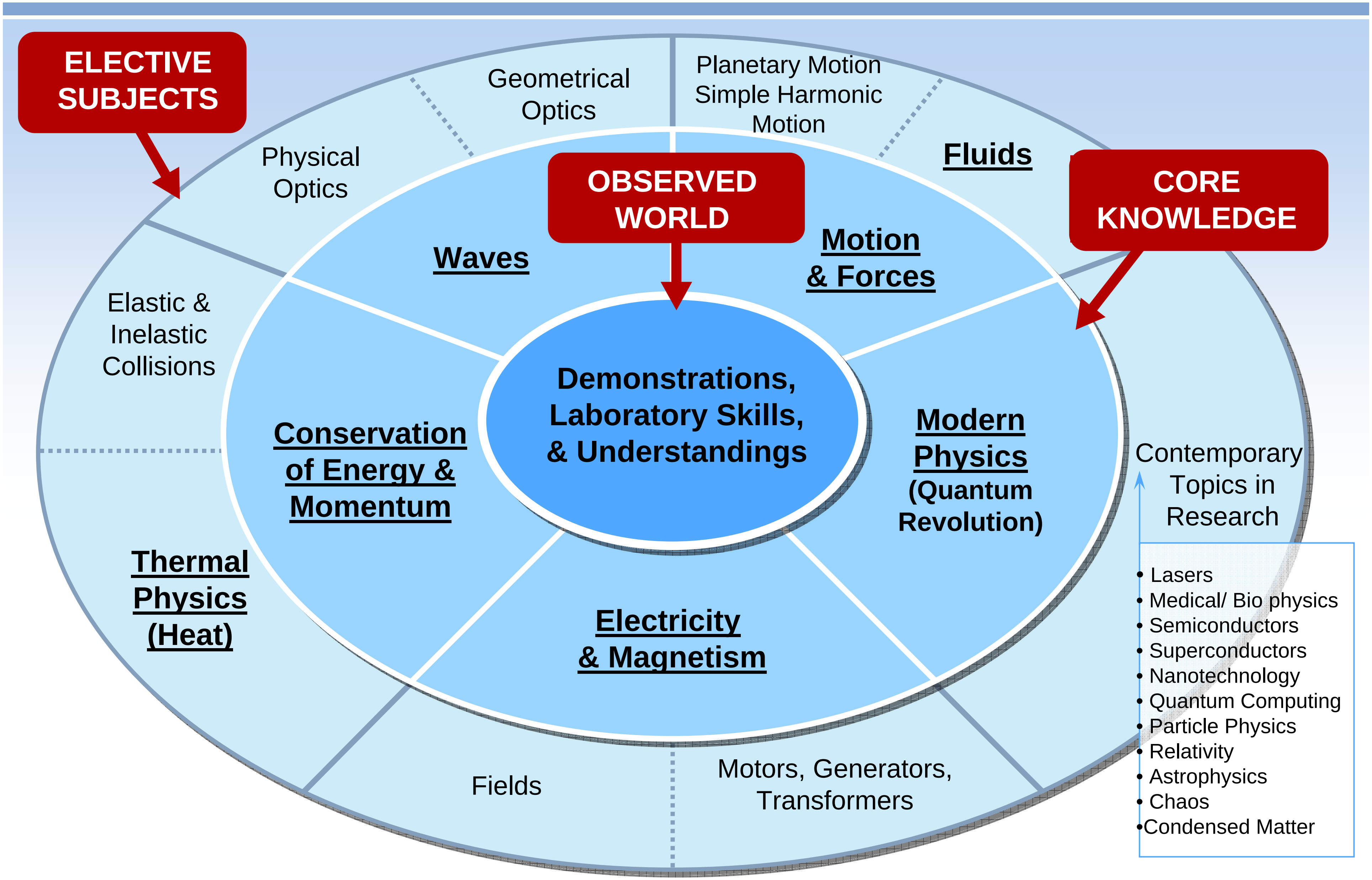
A Fundamental Guiding Principle from Physics & Chemistry Panels

Physics and chemistry relate real-world phenomena to fundamental abstract principles that are discovered using <u>laboratory methodology</u> and observational skills to then express the relationships quantitatively with the language of mathematics and qualitatively through the written word.

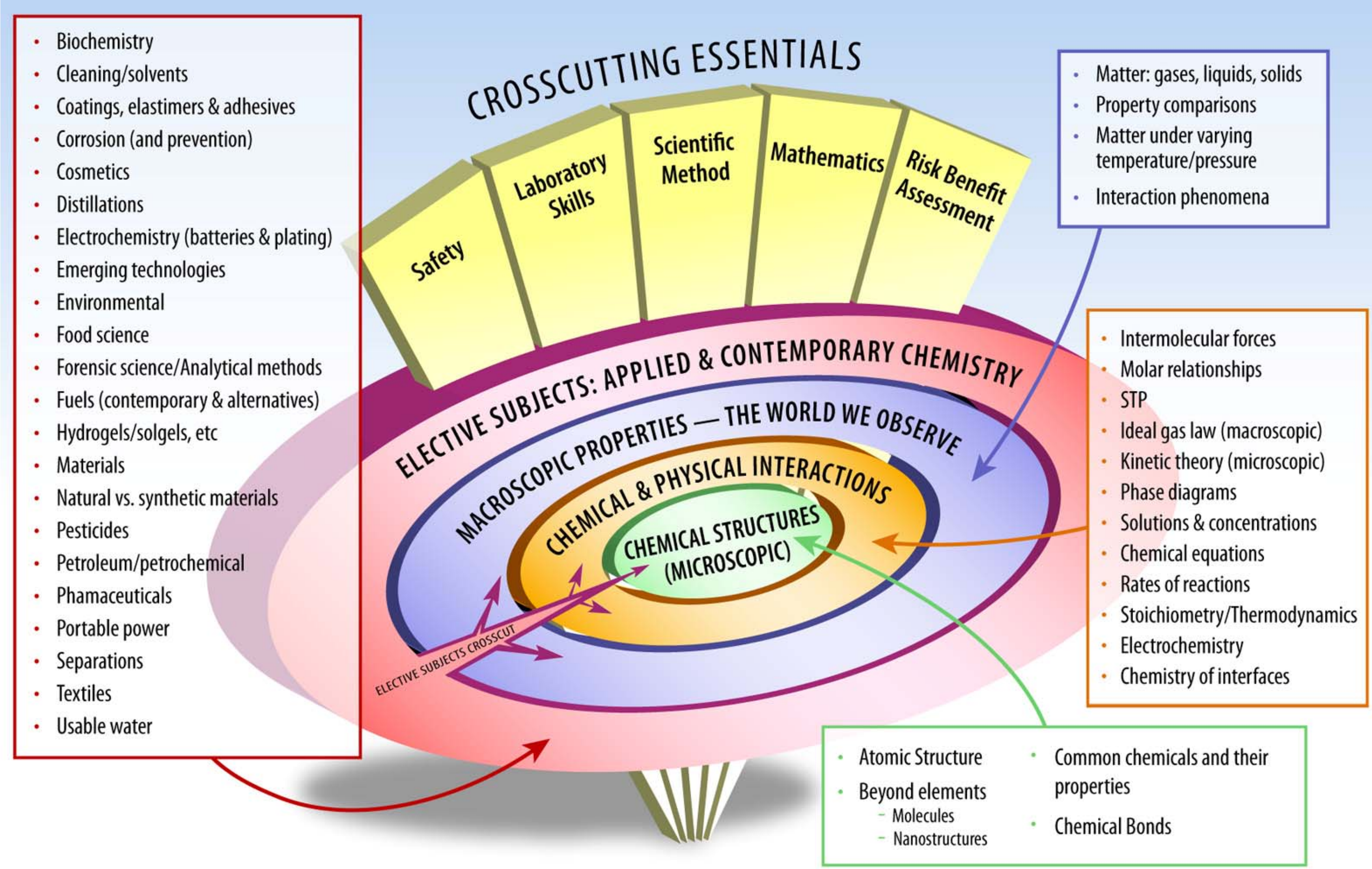
Physics & Chemistry Describe the Physical World Quantitatively in the Language of Mathematics and Qualitatively in Words



A Hierarchy of Physics Content



A Hierarchy of Chemistry Content



Summary of Selected Physics & Chemistry Findings/Recommendations

- 20% of course content in integrated laboratories that are assessed on SOL
- Contemporary and emerging applications integrated
- Core content + electives (selected by teacher & assessed)
- Open source wiki supported by DOE for timely availability of contemporary and emerging applications and laboratories.
- Consider Leon Lederman's "ARISE" or integrated science approach
  - Organic chemistry is critical to understanding molecular biology

Some Selected Results - Engineering

- **There is no “STEM” program in VA**
  - There is Math (Theory) and Science (Theory) and some Technology (St_M)
  - Engineering is not required for students in VA nor is it generally available to all students.
  - Engineering is book-kept in CTE
- **Two major Project 2061 strands, “The Designed World” and “The Nature of Technology” are not adequately addressed in VA required K-12 curriculum**
- ***Engineering Design Process* differs from *Scientific Method* and should be required & assessed (not just multiple choice) content for all students in VA**
- **Women and minorities continue to be underrepresented in engineering profession and must be reached to assure an adequate 21st Century workforce talent pool**
- **Project Lead The Way (PLTW) is a turn-key national engineering program being taught in 14/134 school divisions in VA and covers almost all that would be needed to learn the engineering design process – ODU is “lead” or “affiliate” university in VA**
  - Ford Motor Company’s PAS and TI’s Infinity Project also turn-key
  - FIRST (LEGO, VEX, Robotics) design projects available (K-12)
  - Children’s Engineering Guide is available (K-5) – used in 12/134 VA school divisions

Student Success: Engineering Fills a K-12 Curriculum "Gap"

- Offers additional opportunities to students whose learning modalities are more hands-on than abstract
- Aimed at the top 80% of students
- Completes a continuum out of the current dichotomy of Math/Science theory and traditional hands-on vocational or career education
- Inherently interdisciplinary
- Supports technological innovation processes

Some Selected Results – Chemistry & Physics

- **Laboratories and demonstrations must be integrated into Physics and Chemistry courses and be assessed**
  - Current SOL fail to stress integrated labs
  - Recommend 20% of course time with subjects chosen by teachers from open-source labs on DOE-supported wiki
  - Written lab reports required
  - Employ state-of-the-practice methods (modeling & sim; lab on a chip, probeware, etc)

- **In Physics and Chemistry, panels created “Core” knowledge and “Elective” knowledge with the teacher to choose from among “Elective” subjects**
  - Physics SOL way too broad and miss some more important things
  - Some existing Physics and Chemistry modules can be eliminated or made elective
  - The order of teaching chemistry should be from physical world observed phenomena (macroscopic) to fundamental building blocks (microscopic)
  - Understanding organic chemistry is essential to life in the 21st century (Molecular Bio)

- **Contemporary applications & emerging technologies of Physics and Chemistry must be taught**
  - Electives: choose from nano, bio, particle physics, superconductors, astrophysics,….
  - DOE should develop and support an **open-source wiki** for contemporary applications, emerging technologies, and laboratories provided by teachers & practitioners world-wide

- **Consider Leon Lederman’s “ARISE” or “Physics First” science curriculum from Fermilab as a total restructuring**

A 2nd Fundamental Guiding Principle from Physics & Chemistry Panels

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 a knowledge of chemistry. Learning occurs best when reiterated with increasing levels of sophistication – rather than 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 SOL in an integrated mode such as that advocated by Lederman.

A Chronology of “Nanotechnology”

First Use of Term Japan (1974)

Scanning Tunneling Microscope (1982)

Carbon nanotubes/fullerenes (1986)

Atomic Force Microscope (1987)

Science Magazine Special Issue (29Nov 1991)

Should be read by
HS science teachers

Scientific American Magazine (1996)

Should be read by
lay citizens

Nobel Prize to R. Smalley et al (1996)

National Nanotechnology Initiative – U.S. (2001)

Congress figures it out

60% science teachers aware of nano;
33% familiar with nano;
18% understand; 7% teach nano (2003 KY survey)

VA Science SOL review – no nano (2003)

Nanotechnology Day at
VA General Assembly (2007)

Panel of experts recommends
inclusion in VA chemistry SOL (2007)

VA Board of Education
SOL Review? (2010)