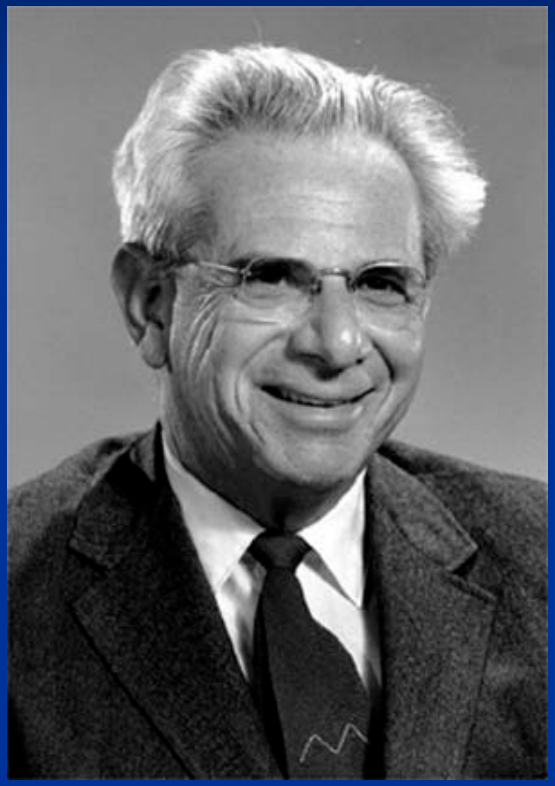
Guiding the Future: Developing Research-based Physics Standards

Patricia Heller
University of Minnesota

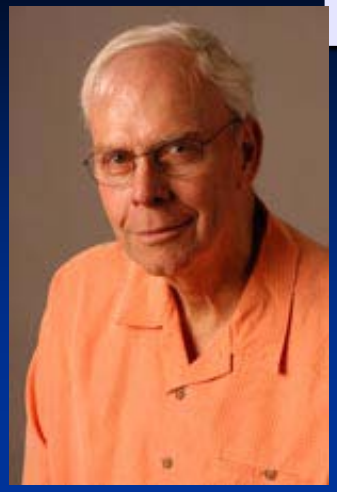
Mentor



Arnold Arons
1916 - 2001

- 1969 - 1972: TA & Instructor in physics course for elementary teachers
  - physics
  - teaching

Major Project Collaborators



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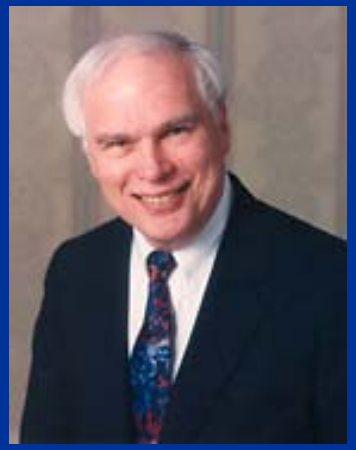

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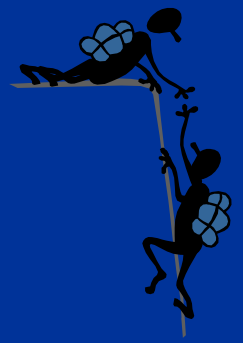
Jennifer Blue

Laura McCullough

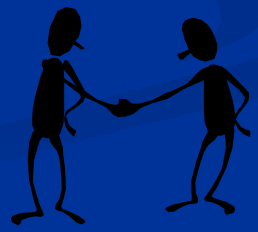
Charles Henderson

Hsia-Po (Vince) Kuo

Many colleagues in PER, teachers, educators, and students who have influenced my work and are too numerous to name.



You know who you are.

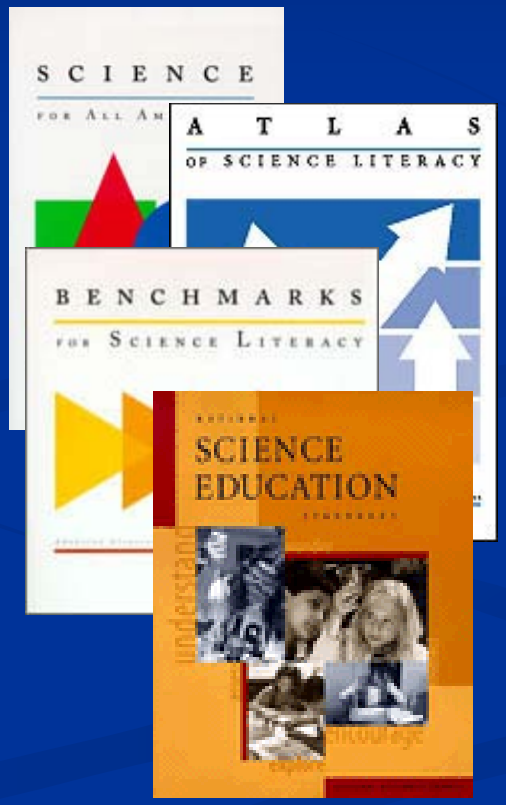


Agenda

- Why does The AAPT need K-12 college-ready physics standards?
- What conceptual framework should be used for organizing physics standards?
- How can research about student learning of physics be built into physics standards?

K-12 National Science Standards

- AAAS Project 2061: *Benchmarks for Science Literacy* (1994)
- National Research Council: *National Science Education Standards* (1996)



Evaluation of State Standards

- Content standards are embedded with many other standards.

  ⇒ Often unfocused and incoherent --
  a list of topics from textbooks.

- Middle school physical science standards usually do not provide the background of knowledge and skills for the high school physics standards.

- High school standards often mirror introductory college physics -- unrealistic.

Pacific Research Institute (1999). *Developing and Implementing Standards*
Thomas B. Fordham Institute (2005). *The State of State Science Standards*
American Federation of Teachers (2001). *Making Standards Matter*

Criteria for Exemplary Standards

1. Standards have a Clear Conceptual Framework
2. Standards Reflect What is Known about Student Learning
3. Standards Balance Breadth and Depth
4. Standards Balance Knowledge and Skills
5. Standards are Specific and Measurable
6. Standards are Scientifically Correct and Rigorous
7. Standards are Written Clearly and Intelligibly

Pacific Research Institute (1999). *Developing and Implementing Standards*
Thomas B. Fordham Institute (2005). *The State of State Science Standards*
American Federation of Teachers (2001). *Making Standards Matter*

College Board Science Standards for College Success™ (2009)

- Science standards for:
  - Earth Science (6-8 & 9-12)
  - Life Science (6-8 & 9-12)
  - Physical Science (6 - 8)
    - Chemistry
    - Physics
  - Chemistry (9-12)
  - Physics (9-12)

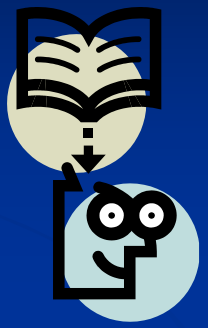
Middle-school physical science standards are unfocused and do not prepare students for high school physics.

NAS Board on Science Education Draft Framework for Science Education

- Framework for ALL students:
  - Earth and Space Science (K-12)
  - Life Science (K-12)
  - Physical Science (K-12)
  - Engineering and Technology (K-12)

In September, Achieve Inc. will use this framework to produce national science standards.

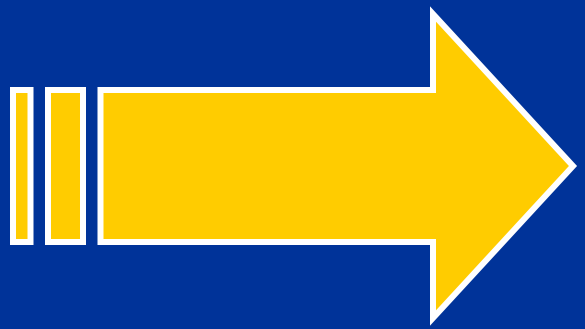
Why does the AAPT need K-12 physics standards?



- Standards are here to stay. (e.g., new NAS Standards).
- The physics knowledge and skills taught in K-12 schools are driven more and more by standards.
- NSF and DOE research agendas will be determined, in part, by standards.
- Standards will determine the knowledge and skills students have entering high school physics and college introductory physics courses.

Why does the AAPT need prototype physics standards?

- Colleges and universities will need to prepare teachers to teach to the physics standards.



It is important for people who understand physics and physics teaching (AAPT) to take an active part in the creation of standards before other organizations create flawed physics standards.

Agenda

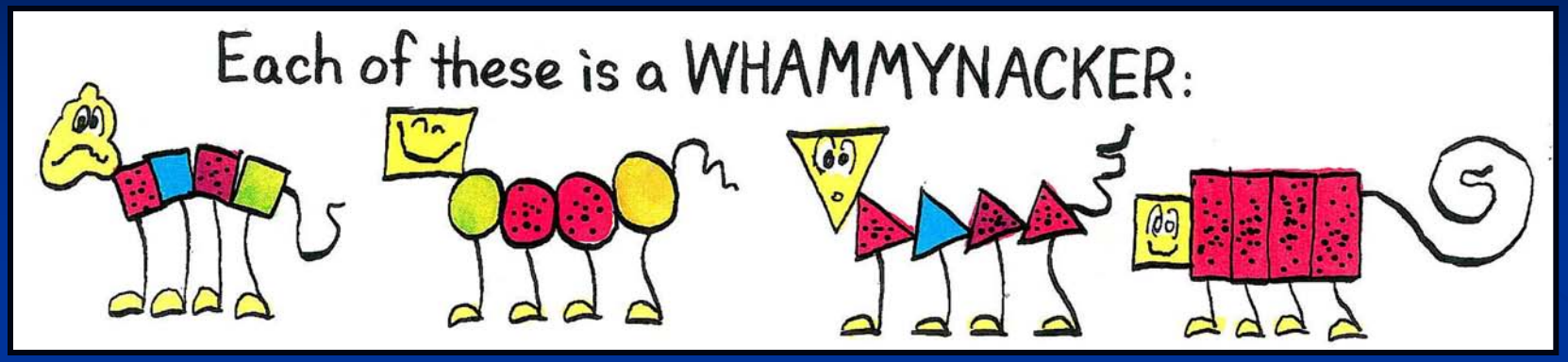
- ☑ Why does The AAPT need K-12 college-ready physics standards?
- What conceptual framework should be used for organizing college-ready physics standards?

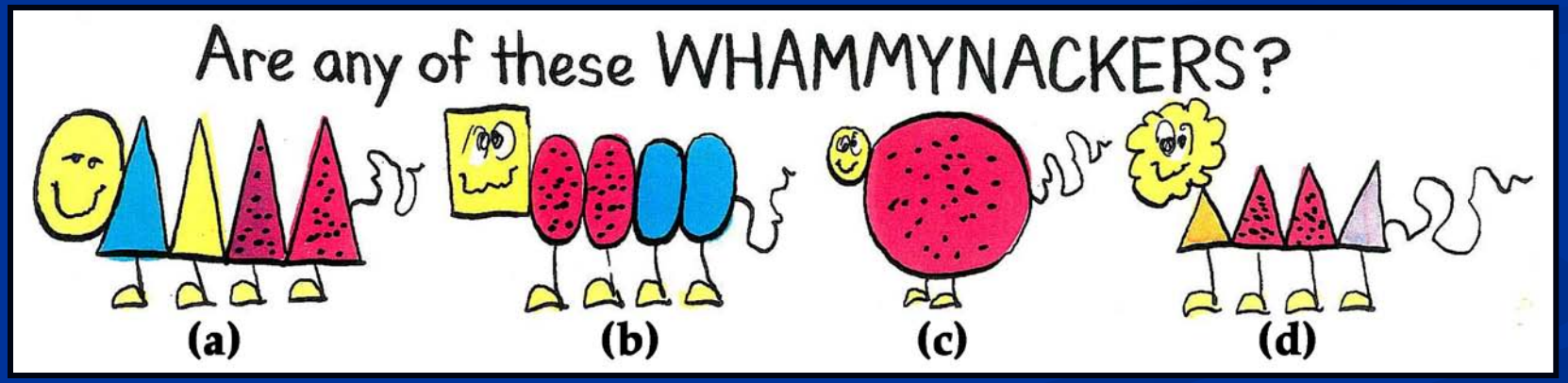
- How can research about learning physics be built into physics standards?

“Aronism” for Learning

Students cannot understand what something is until they know what it isn’t.

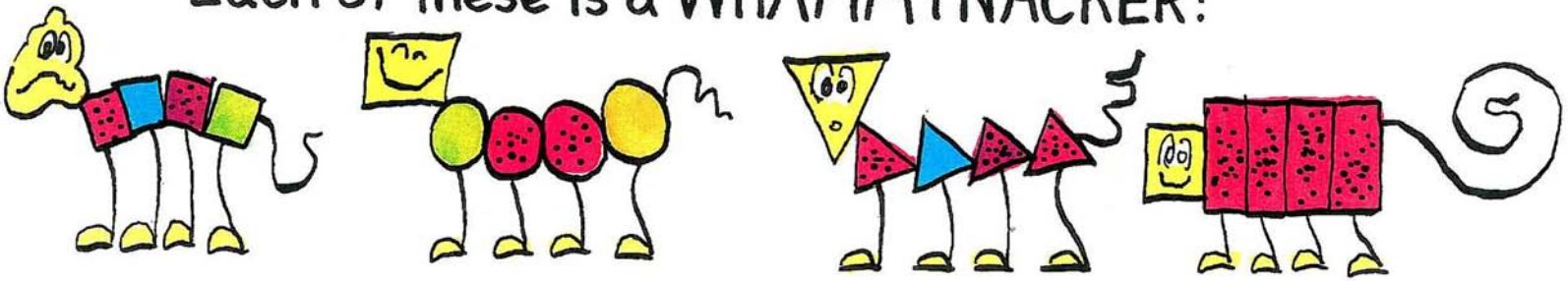
Students cannot understand what something is until they know what it isn't.



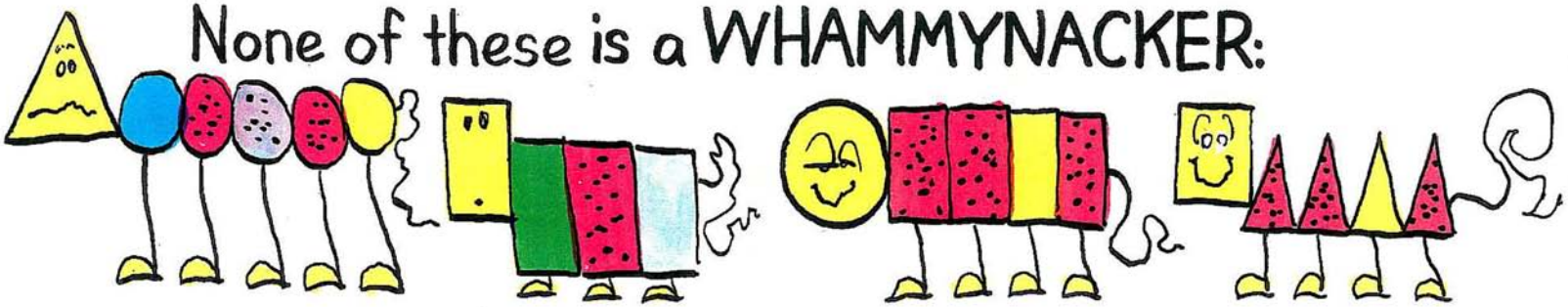


Gillespie, D.C. (1972). Weeple Peeple: A Sciencing Unit, McGraw Hill. 1972. Similar to Creature Cards in earlier *Elementary Science Study* unit (1960's).

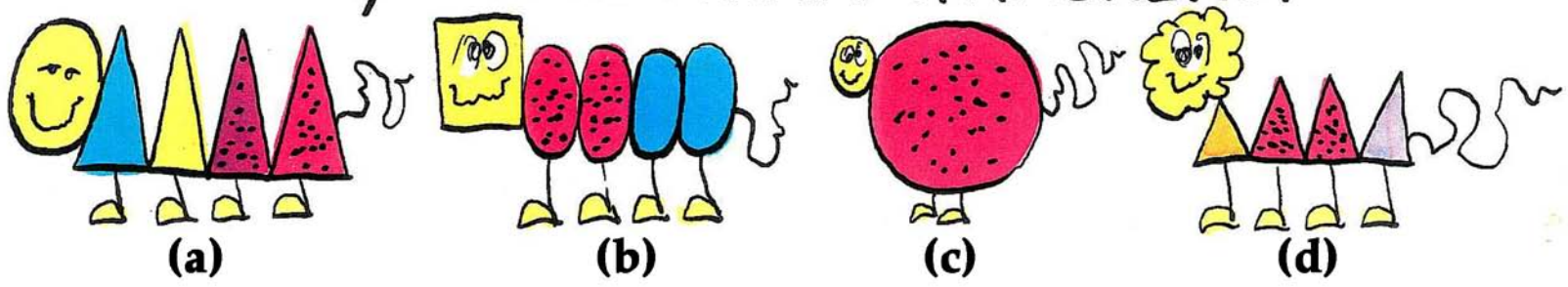
Each of these is a WHAMMYNACKER:



None of these is a WHAMMYNACKER:



Are any of these WHAMMYNACKERS?



Students cannot understand what something is until they know what it isn't.

Essential Knowledge Statement (5-8). *Most quantities, like surface area, volume and density are not conserved for all types of interactions.* Mass is always conserved for physical and chemical interactions (excluding nuclear) and for both closed and open systems.

Learning Outcomes (5-8). Ways in which students engage with and apply the essential knowledge:

- Provide evidence which supports the idea that a gravitational interaction is *not* caused by the Earth's magnetism, the Earth's rotation, or air pressure.
- Compare and contrast the magnetic and electrical interactions, based on the defining characteristics of each interaction.

P.H. & Gay Stewart, Prototypical College Ready Physics Standards

Criterion for Exemplary Standards

1. **Standards Have a Clear Conceptual Framework**
   - Organize principles and subsidiary concepts in a coherent way.
   - Structured in a logical order.
   - Are consistent with the theoretical framework of the science discipline (physics).

Pacific Research Institute (1999), *Developing and Implementing Standards*
Thomas B. Fordham Institute (2005). *The State of State Science Standards*
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"Big Ideas" from AP Physics Redesign

- Objects and systems have properties such as mass, charge and internal structure.
- The interactions of an object with other objects can be described by forces, which can cause a change of motion.
- The interaction of one object or system with another is governed by conservation laws.
- Fields existing in space can be used to explain interactions.

Science
College Board Standards for College Success

Interaction Conceptual Framework

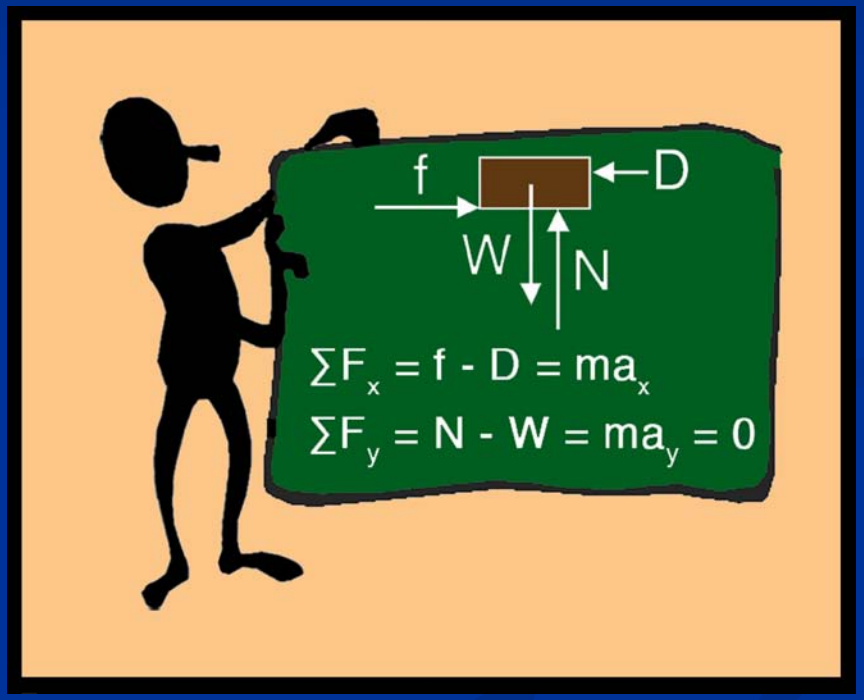
- Interaction is a causality statement in physics.
- Two objects interact when they act on or influence each other to *cause* an effect (s).
- The effect is usually an observed change, which is the evidence of the interaction (e.g., change in motion, shape, temperature).
- The exception of the above is an equilibrium situation.

Robert Karplus
1927 - 1990

Interaction Conceptual Framework

- The history of physics has been to find different ways to describe and explain interactions.

- Two objects/systems can interact by exerting forces on each other.

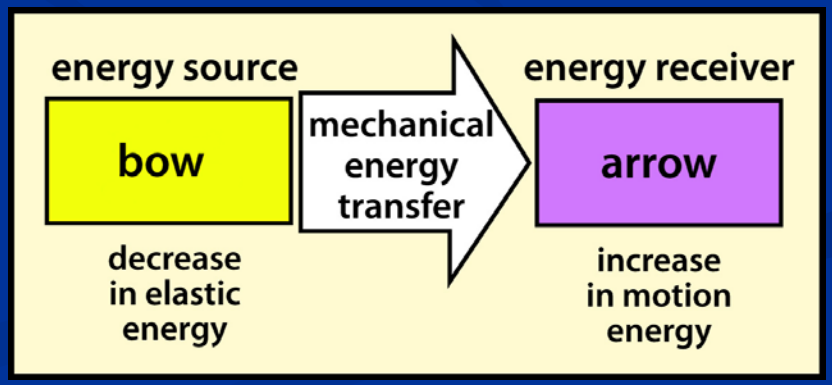


Karplus (2003), *Introductory Physics: A Model Approach*, F. Braunshwig (Ed.), Buzzards Bay, MA: Captain's Engineering Services. Originally published in 1969.

Interaction Conceptual Framework

- The history of physics has been to find different ways to describe and explain interactions.

- Two objects/systems can interact by a transfer of energy from the “source” system to the “receiver” system.

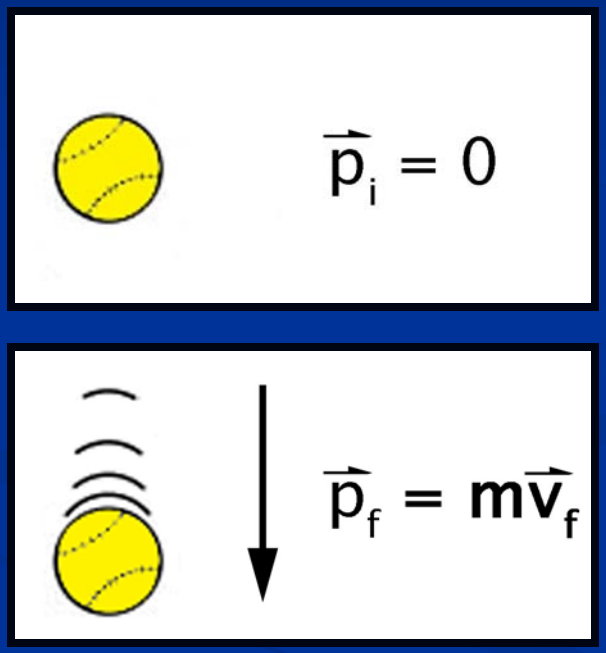


Interaction Conceptual Framework

- The history of physics has been to find different ways to describe and explain interactions.

- Two objects/systems can interact by a transfer of momentum from one system to the other system.

System = falling object



$p_i = 0$

$p_f = mv_f$

$p_{in} = F_{ave}\Delta t = mg\Delta t$

Interaction Conceptual Framework

- The history of physics has been to find different ways to describe and explain interactions.

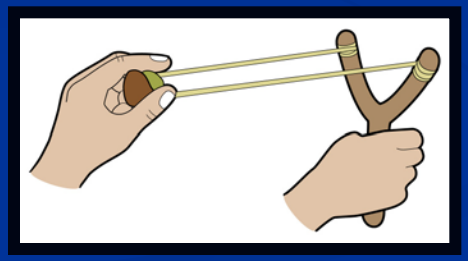
- Two mutually attracting or repelling objects can interact at a distance through the intermediary of fields.

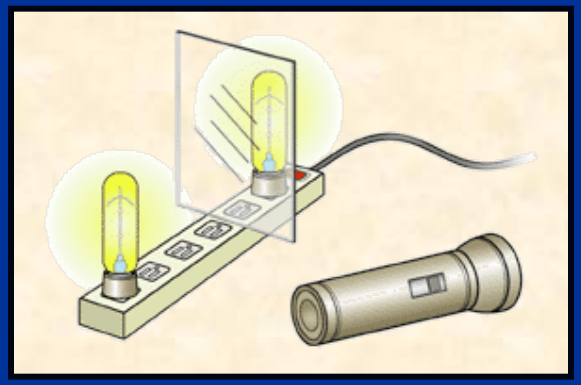
Ruth Chabay. Electric and Magnetic Interactions: The Movies, http://www4.ncsu.edu/~rwchabay/emimovies/

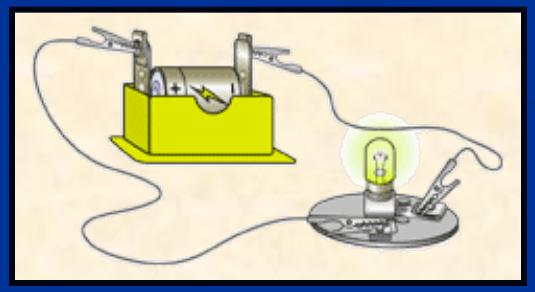
- Modern Physics: Two subatomic particles can interact by exchanging virtual particles.

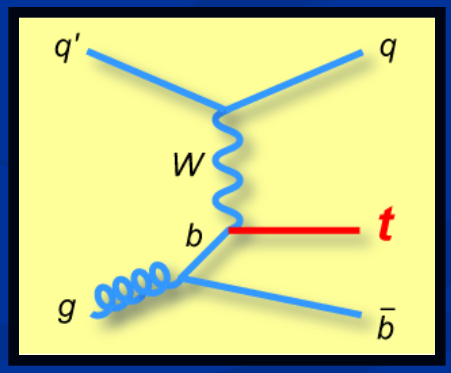
Defining Characteristics

To search for consistent patterns in the multitude of interactions and changes we observe, physicists classify different types of interactions.









Goldberg, F., Bendall, S., Heller, P., & Poel, R. (2006). *InterActions in Physical Science*. Armonk, NY: It's About Time, Herff Jones Education Division.

Criterion for Exemplary Standards

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Thomas B. Fordham Institute (2005). *The State of State Science Standards*
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Titles Are Not Enough

1. Interactions, Models, and Scales
2. Conservation Principles
3. Newton's Laws of Motion
4. Energy Transfer and Storage
5. Forces, Energy, and Fields

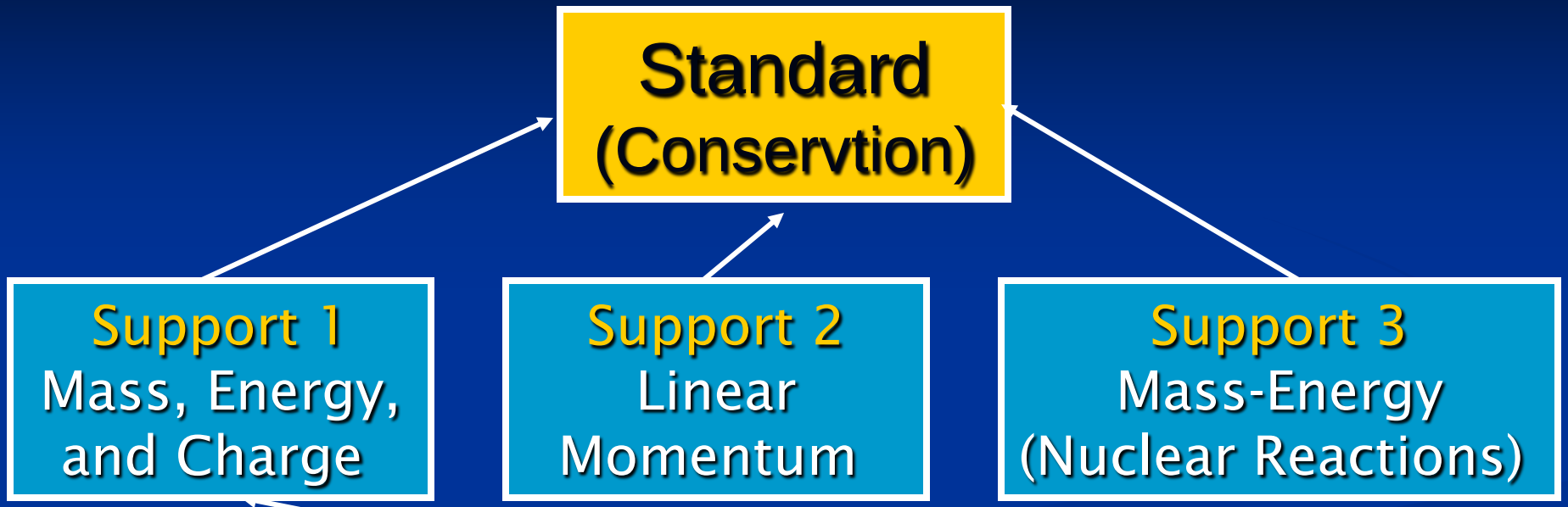
One Sentence is Not Enough

Interactions, Models and Scale: Changes in the natural world are the result of interactions. The description, explanation, and prediction of interactions depend on the distance and time scale and our models of the structure of matter. For objects moving very fast, the macro (human) scale ideas of absolute space and time must be revised.

Conservation Principles: The interaction of one object with another object is governed by a few conservation principles, such as the conservation of mass, energy, mass-energy (nuclear interactions), charge, and linear momentum. These principles are considered fundamental because they apply to interactions at all time and size scales and cannot be derived from other theories.

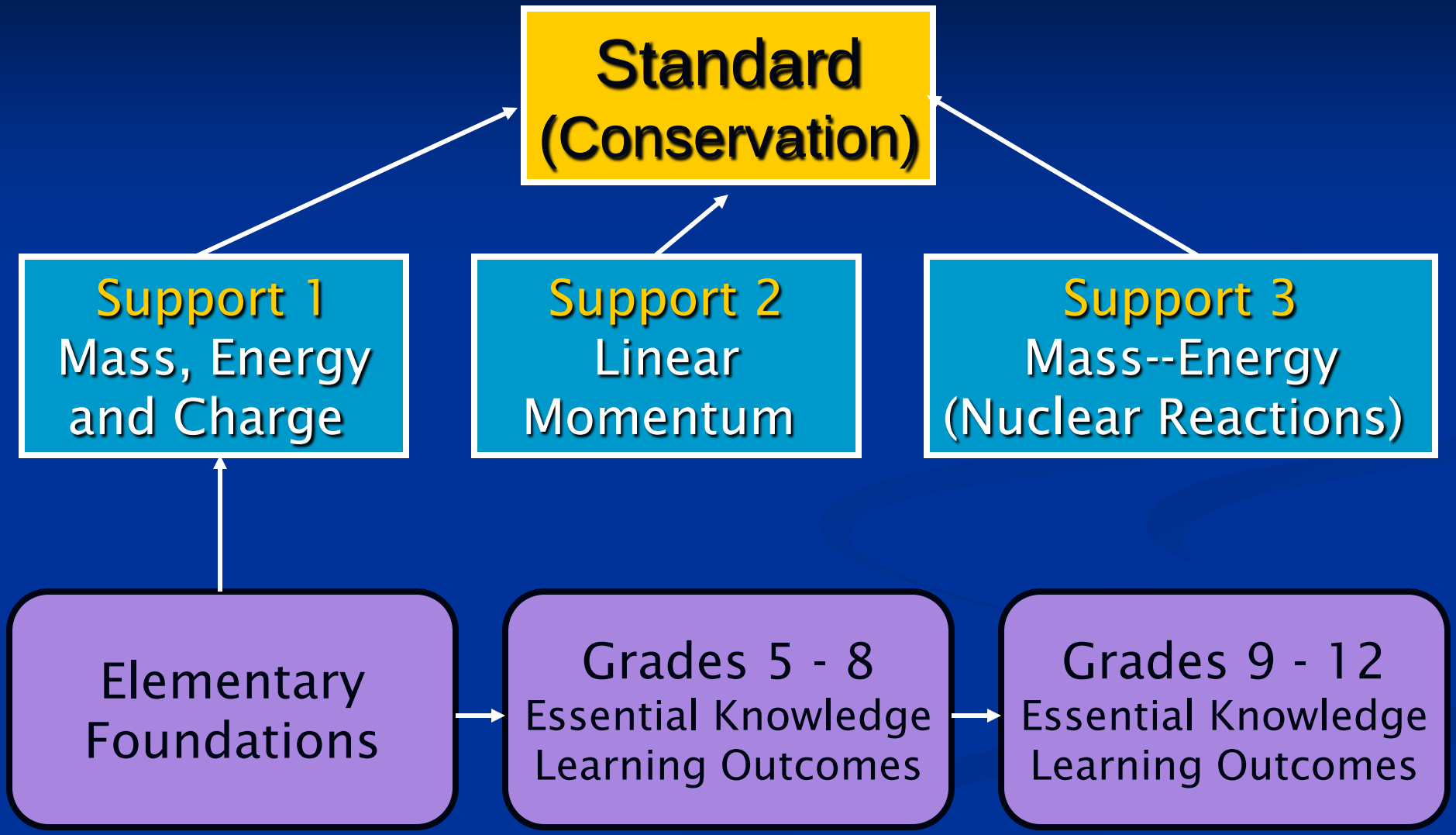
P.H. & Gay Stewart (2010), College Ready Physics Standards: A Look to the Future

Structure of Standards



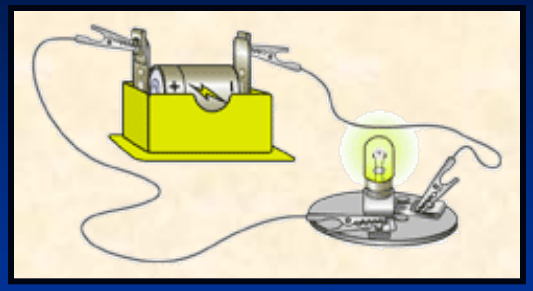
At the macro (human) and atomic scales, mass and energy are conserved separately for all types of chemical and physical interactions and defined systems (open or closed). Charge is always conserved at all scales.

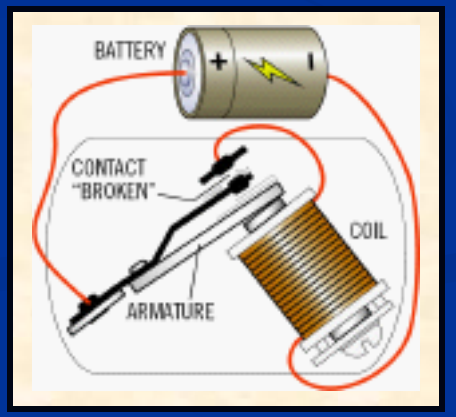
Structure of Standards

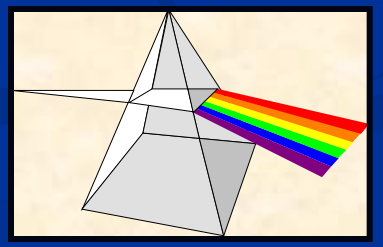


“Aronism” for Learning

Students must encounter a principle in at least 4 - 6 different contexts before it can be generalized and applied to new or unfamiliar contexts. [Called “far transfer”].







Standard 3: Newton's Laws of Motion

Interactions of an object with other objects can be described, explained, and predicted using the concept of forces, which can cause a change in motion of one or both interacting objects. Different types of interactions are identified by their defining characteristics. At the macro (human) scale, interactions are governed by Newton's second and third laws of motion.

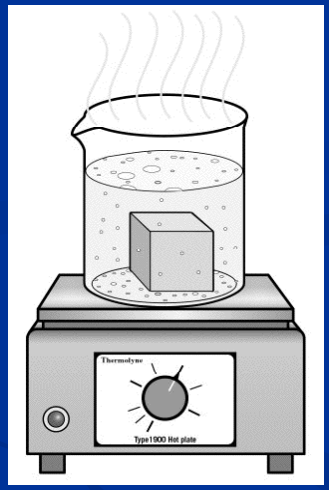
- Constant and Changing Linear Motion (5-8 and 9-12)
- Forces and Changes in Motion (5-8 and 9-12)
- Contact Interactions and Forces (5-8 and 9-12)
- Gravitational Interactions and Forces (5-8 and 9-12)
- Magnetic and Electrical Interactions and Forces (5-8 and 9-12)

P.H. & Gay Stewart (2010), College Ready Physics Standards: A Look to the Future

Standard 4: Energy Transfer and Storage

Interactions of an object with other objects can be described and explained by using the concept of the transfer of energy from one object to another, both within a defined system and across the boundary of the system. . . .

- Contact Interactions and Energy (5-8 and 9-12)
- Electric Circuit Interactions and Energy (5-8 and 9-12)
- Mechanical Wave Interactions and Energy (5-8 and 9-12)
- Radiant Energy Interactions (5-8 and 9-12)
- Heating and Cooling Interactions and Energy (5-8 and 9-12)



P.H. & Gay Stewart (2010), College Ready Physics Standards: A Look to the Future

Standard 5: Forces, Energy, and Fields

Attractive and repulsive interactions at a distance (e.g., magnetic, gravitational, electrical and electromagnetic) can be described and explained using a field model. The field model explains how objects exert forces on each other at a distance, and where energy is stored in the system.

- Forces and Fields (5-8 and 9-12)
- Energy and Fields (5-8 and 9-12)
- Electromagnetic Interactions and Fields (5-8 and 9-12)

P.H. & Gay Stewart (2010), College Ready Physics Standards: A Look to the Future

Learning Progressions

- **Learning Progressions** in standards "require increasing intellectual sophistication and higher levels of abstraction as grade levels progress."
  - Closest in Physics: Start with anchoring intuitions -- bridging analogies to correct physics idea (or to more abstract idea).

Smith, C. L., Wiser, M., Anderson, C. W., and Krajcik, J. (2004), *Measurement*, **14**(1&2), 1-98.

Clement, J. (1993)., J. *Res. Sci Teach*, **30**(10), 1241-1257

Student Learning Research

- Elementary and middle school students are *both:*
  - more capable of learning physics concepts and skills than we think, and
  - less capable than we think.

National Research Council (2007), *Taking Science to School: Learning and Teaching Science in Grades K-8*, Washington DC: National Academies Press.

Middle School Students are Smarter Than We Think

"The law of conservation of mass is that the mass of a closed system (in the sense of a completely isolated system) will remain constant over time. . . . A similar statement is that mass cannot be created/destroyed, although it may be rearranged in space, and changed into different types of particles." (http://en.wikipedia.org/)

- In an open system, mass is not conserved -- mass can disappear (cease to exist, as in evaporation).

Middle School Students are Smarter Than We Think

"The law of conservation of mass is that the mass of a closed system (in the sense of a completely isolated system) will remain constant over time. . . . A similar statement is that mass cannot be created/destroyed, although it may be rearranged in space, and changed into different types of particles." (http://en.wikipedia.org/)

- Scientists (and my teacher) know how to pick the right system, but they are not telling me.

Middle School Students are Smarter Than We Think

"The law of conservation of mass is that the mass of a closed system (in the sense of a completely isolated system) will remain constant over time. . . . A similar statement is that mass cannot be created/destroyed, although it may be rearranged in space, and changed into different types of particles." (http://en.wikipedia.org/)

- The conservation of mass is not special because all quantities are conserved in a closed system

Students try to make sense of what they are learning, and often end up with misconceptions.

Students are capable of learning concepts and skills we think are too difficult for them.

Conservation Principle. A quantity is conserved when the total change of the quantity within a defined system and time interval is equal to the total transfer of the quantity into or out of the system during the defined time interval.

total quantity change within system
= total quantity transferred into or out of system

a. change of quantity within system
= End Quantity – Start Quantity.

b. total transfer of quantity
= Quantity In – Quantity Out.

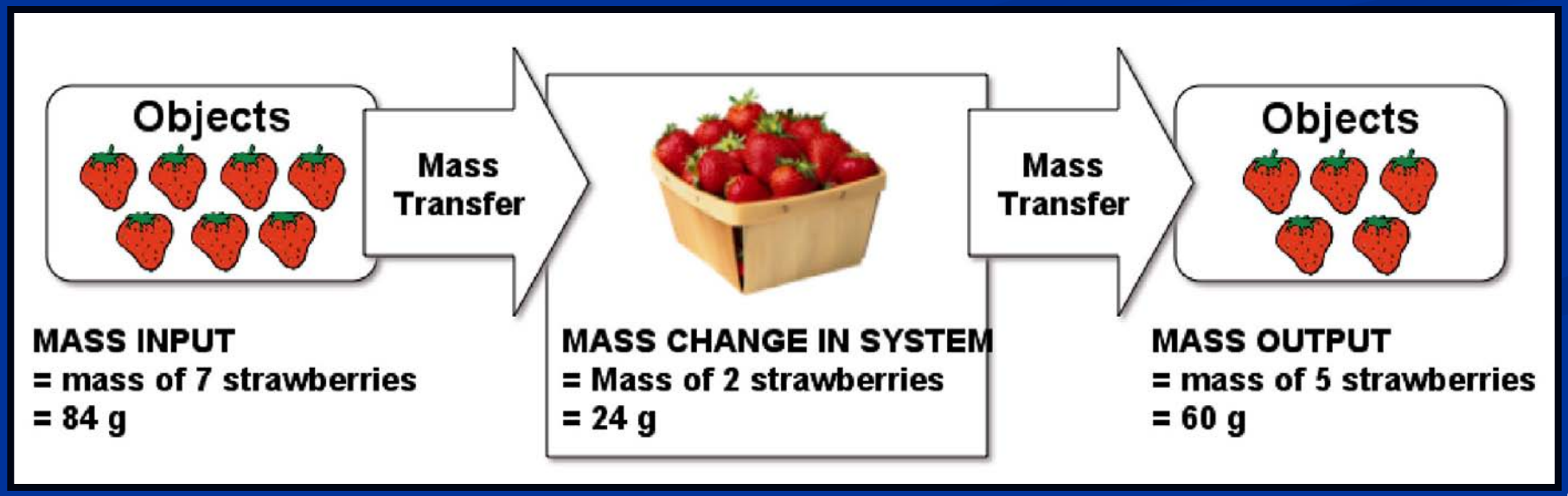
Start With Anchoring Intuitions

- Children in grades 3 - 5 have few prior experiences with closed systems.
- They have a great deal of prior experiences with gaining and losing objects and using the conservation principle.
  - You started with 10 quarters. You went to the grocery store and spent 5 quarters. When you got back home, you had 3 quarters.

- Children have no difficulty figuring out that they must have mislaid two quarters.

Progression of Learning

- Start by applying conservation principle to identical objects (grades 3-5) .
- Gradually try applying conservation principles to continuous quantities, such as surface area, mass, volume, and speed (grades 6-8).



Progression of Learning:

Conservation of Mass (Grades 5-8)	End Mass - Start Mass = Mass In - Mass Out
Energy and Charge (Grades 9-12)	$\Delta E_{system} = E_{in} - E_{out}$ $\Delta q_{system} = q_{in} - q_{out}$
Conservation of Linear Momentum (Grades 9-12)	$\Delta \vec{p}_{system} = \vec{p}_{in} - \vec{p}_{out}$
Conservation of Mass-Energy (nuclear reactions) (Grades 9-12)	$\Delta E_{out} = (\Delta m)c^2$

Jewett Jr., J. W. (2008). Energy and the confused student IV: A global approach to energy, *The Phys. Teach*, 46: 210

What Can We Do?

- We need to be vigilant and proactive. Standards are established by each state. Get involved. AAPT through its sections can disseminate information about the process in your state.

- Fill out the survey from the NAS Board on Science Standards about the draft conceptual framework for science education, particularly the physical science core ideas. They obviously need help.

http://www7.nationalacademies.org/bose/Standards_Framework_Public_Draft_Cover_Letter.html

What Can We Do?

- AAPT can make available prototypical standards that are organized around the core ideas of physics, conform to the findings of physics & science education research, are practical to teach, and allow students to be college ready. These, and other documents, can be used to give feedback to emerging national standards from the College Board, Achieve Inc., and others.

- AAPT can emphasize that fundamental physics ideas should not be buried and compromised by homogenizing them into physical science standards.

The End

http://www.physics.umn.edu/groups/physed