American Association of Physics Teachers

August 22, 2011

Dr. Helen Quinn, Chair
Conceptual Framework for New Science Education Standards
Board on Science Education
The National Academies
500 Fifth Street, NW – 11th Floor
Washington, D.C. 20001

Dear Dr. Quinn,

The American Association of Physics Teachers (AAPT) commends the NRC for its work on developing the conceptual framework for new science education standards. The end result is a document that incorporates some of the educational research in teaching and learning over the last 15 years. This document will provide the foundation for engaging students more deeply into understanding, performing, and appreciating science.

We are particularly pleased to see that much of the feedback that AAPT, the American Physical Society and the American Institute of Physics provided on the first draft was incorporated into the version that was released in mid-July. A select group of K12 science education experts and AAPT members[1] has reviewed the newly released version. Attached is a list of errors in the current version of the framework that the group generated. We felt that the NRC would appreciate receiving this list as it prepares a final, edited version of the framework document for public dissemination. This group of experts is also in the process of preparing a list of inconsistencies that may result in misunderstanding of some of the concepts, particularly in the physical science section. The list of inconsistencies will be sent to Achieve in early September.

AAPT appreciates the opportunity to provide feedback on the framework throughout the process of developing it. We look forward to working with the NRC on future science education issues. We realize that much hard work has occurred in preparing the framework but additional work is needed to transform the framework into standards. We look forward to working with Achieve as the new science standards are developed.

Sincerely yours,

Beth A. Cunningham, Ph.D.
Executive Officer

[1] Gary Baier, Green Bay East High School; Beverly T. Cannon, Highland Park High School; Dewey Dykstra, Boise State University; Patricia Heller, University of Minnesota; and Drew Isola, Allegan High School

LIST OF OUTRIGHT ERRORS IN CHAPTER 5
AMERICAN ASSOCIATION OF PHYSICS TEACHERS
8/22/2011

Errors Related to Forces and Momentum

1. Pages 5-7 to 5-8. "Within an isolated system of interacting objects, Newton's laws result in the fact that any change in momentum of one object is balanced by an equal and oppositely directed change in the total momentum of the other objects. Thus total momentum is a conserved quantity.

This is misleading because it implies that Newton's second law is more fundamental than the conservation of momentum. The conservation of momentum holds even when Newton's second law does not.

There is also an inconsistency in the definition of conservation of momentum compared to the conservation of energy. Like energy, momentum is always conserved, even when momentum is transferred into or out of a system. ***Conservation should be defined the same way for both momentum and energy.***

Suggested change: "For any system of interacting objects, the total change of momentum within the system is equal to the total transfer of momentum (impulse) into or out of the system. This is the conservation of momentum. In a closed system of interacting objects (no transfer of momentum into or out of the system), the change in momentum of one object is equal to but in an opposite direction to the total change in momentum of the other objects."

2. Page 5-8, 4th paragraph, 3rd sentence. "The heavier the object, the greater the force needed to achieve the same change in motion."

This needlessly confuses mass, weighing, and weight. By the end of 8th grade, students should know how to measure mass, and that mass is not the same as weight (weight is the everyday term we use for the gravitational pull of the Earth on an object).

Suggested change: "The *greater the mass of the object*, the greater the force needed to achieve the same change in motion."

3. Page 5-8, 5th paragraph, 2nd sentence. "Momentum **is a property of objects**, defined for a particular frame of reference, that depends on their mass and **speed.**"

Speed is wrong -- should be velocity (momentum is a vector quantity). Whether momentum is the property of an object depends on the definition of property. Since the momentum of an object can change depending on its interactions, most people would not call it a property of an object. For example, if a person were walking west, most people would not think that walking west is a property of the person.

Suggested change: "*The momentum of an object*, defined for a particular frame of reference, *is the mass times the velocity of the object*."

4. Page 5-9, 7th paragraph, 1st sentence. "Objects in contact exert forces on each other (friction, **pressure**, pushes and pulls)."

Pressure is not a force – it is a scalar quantity. In addition, students need more than one type of contact force to describe everyday situations in terms of forces.

Suggested change: "Objects in contact exert forces on each other (*e.g., applied, friction, drag, elastic pushes and pulls)*."

5. Page 5-16, 4th paragraph. "A bigger push or pull makes things go faster, and faster motion can cause a bigger change in shape when things collide."

Forces do not cause motion; they cause a change in motion. It's better not to start misconceptions early.

Suggested change: "Pushing or pulling on an object can change its speed or direction of motion. Faster speeds during a collision can cause a bigger change in shape."

Errors Related to Heat

6. Page 5-13, 6th paragraph. The term "heat" as used in everyday language refers both to thermal motion (the motion of atoms or molecules within a substance) and radiation (particularly infrared and light). Temperature is not a measure of energy; the relationship between the temperature and the total energy of a system depends on the types, states, and amounts of matter present.

This paragraph does not address the scientific meaning of the term heat (e.g., consequence of the zeroth law of thermodynamics). ***Students should learn the scientific meaning for the term heat (even if it is often misused in our everyday language and in textbooks).*** Moreover, to say that temperature is not a measure of energy is misleading, because temperature is a measure of the average kinetic energy of the particles of matter.

Suggested change: "In our everyday language, heat refers to both thermal energy (related to the motion of atoms or molecules within a substance) and to heat energy transfers. In science, heat is the energy transferred when two objects or systems are at different temperatures (which includes radiant energy transfers, particularly light and infrared). Temperature is a measure of the average kinetic energy of the particles of matter. But temperature is not a measure of the total energy (internal energy) of a system; the relationship between the temperature and the total energy of a system depends on the types, states, and amounts of matter present."

7. Page 5-14, 5th paragraph, 1st and 2nd sentences. "Heating is another process for transferring energy. **Energy moves out of hotter objects and into colder ones, cooling the former and heating the latter**.

The error here is that the most important aspect of heat energy transfer is left out – a heat energy transfer occurs when two objects are at different temperatures (consequence of the zeroth law of thermodynamics). In addition, students often believe that both "heat" and "cold" are transferred.

Suggested Change: "Heating is another process for transferring energy. *Heat energy transfer occurs when two objects (a defined quantity of a gas, liquid, or solid) are at different temperatures. Energy moves out of higher temperature objects and into lower temperature objects*, cooling the former and heating the latter."

8. Page 5-17, 5th paragraph, 1st sentence. "When two objects are rubbed together **heat is produced; this is called friction.**"

Heat is not "produced" in this process, and the production of heat is not called friction.

Suggested change: "When the surfaces of two objects rub against each other, *this interaction is called friction. Friction between two surfaces can increase the temperature of the surfaces (e.g., rubbing hands together)."*

Incorrect Use of Heat

9. Page 5-14, 3rd paragraph, 1st sentence. "When objects collide or otherwise come in contact, the motion energy of one object can be transferred to the motion of the other objects (or to energy stored within them as they are deformed or heated)."

No heat energy transfer occurs within the system. In addition, forms of energy are not transferred. (See error #25 below)

Suggested change: "When objects collide or otherwise come in contact, some of the energy of one object can be transferred to the other objects resulting in a change their kinetic energy and the energy stored within them. This stored energy might be observed as deformation or a temperature increase.

10. Page 5-14, 3rd paragraph, 2nd sentence. "For macroscopic objects, any such process (e.g., collisions, sliding contact) also transfers some of the energy to the surrounding air as sound, *radiation, or thermal motion*."

Thermal motion is not a transfer of energy, and only applies at the atomic scale. Heat energy transfer includes thermal radiation.

Suggested change: "For macroscopic objects, any such process (e.g., collisions, sliding contact) also transfers some of the energy to the surrounding air by sound or heat."

11. Page 5-15, 5th paragraph, 3rd sentence. "**For example, the friction that causes a moving object to stop also heats the object and the surrounding environment.**

Friction is the most complex interaction to select for this example. There is no heat in this situation except the transfer of energy from the object and the surface to the air. If the system includes both surfaces, then friction is not an external force. So the motion energy of the sliding object decreases and the thermal energy of the two surfaces increases. If the system is the sliding object, then friction is an external force. The frictional force causes an internal energy transfer to the surface of the sliding object and the transformation of the object's kinetic energy into the object's internal energy.

Suggested change: "For example, the friction that causes a moving object to stop also results in an increase in the thermal energy of both surfaces. Eventually heat energy is transferred to the surrounding environment as the surfaces cool down."

12. Page 5-17, 4th paragraph, 2nd sentence. "In designing a system for energy storage, energy distribution, or to perform some practical task (e.g., to power an airplane), it is important to design for maximum efficiency—thereby ensuring that the largest possible fraction of the energy is used for the desired purposes rather than being transferred out of the system in unwanted ways (e.g., through friction, **which heats** the surrounding environment).

Friction itself does not include heat production.

Suggested change: "… (e.g., through friction, which *eventually results in heat energy transfer to* the surrounding environment).

13. Page 5-18, 7th paragraph, 1st sentence. ***Although energy cannot be destroyed, it can be converted to less useful forms—for example, to heat in the surrounding environment.***

This is an incorrect use of the term heat in this context.

Suggested change: "Although energy cannot be destroyed, it can be converted to less useful forms—for example, to *thermal energy* in the surrounding environment."

ERRORS RELATED TO OBSERVATIONS, MODELS, AND EXPLANATIONS

14. Page 5-2, 2nd paragraph, 1st sentence: "The existence of atoms, now verified by observation with modern instruments…"

This kind of claim is problematic because it implies that we verify theories, which is not true. We build up a long chain of experimental evidence that *supports* a theory, always looking for experiments that would disprove the theory. After a long time, we accept the theory, knowing that future experiments will modify parts of the theory (e.g., The Standard Model of Subatomic Particles and Interactions).

Suggested change: "The existence of atoms, now supported by evidence with modern instruments, …"

15. Page 5-3, 5th paragraph, 2nd sentence: "For example, a model showing that gases are made from matter particles that are too small to see and are moving freely around in space can explain many observations including: the impacts of gas particles on surfaces (e.g., of a balloon) and on larger particles or objects (e.g., wind, dust suspended in air), and the appearance of visible scale water droplets in condensation, fog, and, by extension, also in clouds or the contrails of a jet."

The problem is that we do not ***observe*** "the impacts of gas particles on surfaces." We may observe balloons, but the pressure inside the balloons we ***explain*** with a kinetic-molecular theory of "gas particles" impacting on the inner (and outer) surface of balloons.

Suggested change: ""For example, a model showing that gases are made from matter particles that are too small to see and are moving freely around in space can explain many observations, including: the inflation and shape of a balloon; observations about larger particles or objects (e.g., wind, dust suspended in air); and the appearance of visible-scale water droplets in condensation, fog, and, by extension, also in clouds or the contrails of a jet." [Left out the problematic phrase and adjusted wording to fit existing sentence.]

16. Page 5-9, 2nd paragraph, 2nd sentence: "These forces are **mediated** by fields that transfer energy through space and that can be mapped by their effect on a test object (mass, charge, or magnet, respectively)."

Page 5-10, 2nd paragraph: "Forces that act at a distance (gravitational, electric, and magnetic) **involve** fields that can be mapped by their effect on a test object (mass, charge, or magnet, respectively)."

Page 5-10, 4th paragraph, 1st sentence: "Forces at a distance are **mediated** by fields that can transfer energy through space."

These three sentences shift back and forth between the word "mediated" and the word "involve." All three leave out the explanatory nature of the idea (model) of a field in physics. The problem of action-at-a-distance was such a problem and unsolved; Newton himself wrote that he "framed no hypotheses" concerning the matter in the Principia. Later, the idea of a field was introduced as a possible way of resolving the dilemma. The idea worked so well that we still use it. The sentences are misleading on the issue of the status of fields as explanatory concepts.

Suggested changes:

Page 5-9 and page 5-10: "These forces are *explained* by fields that transfer energy through space and that can be mapped by their effect on *an object* (*e.g., a ball, a charged particle, or a* magnet, respectively)." [Replaced "mediated" with "explained." In addition, "test object" leads to the idea that a special object is needed to map fields. Moreover, mass and charge are not objects. This language leads to much confusion among students. Replaced "test object" with "an object," and replaced mass and charge with real objects.]

Page 5-10, 2nd paragraph: "Forces that act at a distance (gravitational, electric, and magnetic) are *explained* by fields and that can be mapped by their effect on *an object* (*e.g., a ball, a charged particle, or a* magnet, respectively)." [Replaced "involve" with "explained by". Also dealt with conceptual difficulty with "test object."]

Page 5-10, 4th paragraph: "Forces at a distance are explained by fields…" (Replaced mediated with explained.)

17. Page 5-16: "Forces between two objects at a distance **indicate that there are** force fields (gravitational, electric, or magnetic) between them."

As before a misleading statement about fields is being made. Force fields are used to explain action-at-a-distance. The statement as it is confuses an important distinction between experience and explanation.

Suggested change: "Forces between two objects at a distance are *explained by the idea of* force fields (gravitational, electric, or magnetic) between them." [Removing "indicate that there are" and inserting "are explained by the idea of."]

Errors Due to Not Explicitly Stating Assumptions or Scale

18. Page 5-13, 2nd paragraph, last sentence and page 5-15, 8th paragraph, 1st sentence. "Mathematical expressions, **which quantify how the stored energy in a system depends on relative particle positions and how kinetic energy depends on mass and speed**, allow the concept of conservation of energy to be used to predict and describe the behavior of a system."

This sentence is only true for specific closed systems at the macroscopic scale. You cannot predict the behavior of a system unless you know the energy transfers into or out of the system. The sentence also contributes to the misconception that the conservation of energy is not useful except when kinetic and potential energies can be defined. In fact, the conservation of energy is useful at different scales and for different kinds of systems. An example is the first law of thermodynamics ($\Delta U = W + Q$), which has no potential or kinetic energies, but has remarkable predictive power. Minimal editing would be to leave out the parenthetical statement.

Suggested change: "Mathematical expressions *which quantify changes in the forms of energy within a system and transfers of energy into and out of a system at different scales (e.g., cosmic, everyday, atomic, subatomic)* allow the concept of conservation of energy to be used to predict and describe the behavior of a system."

19. Page 5-12, 2nd paragraph, and page 5-13, last paragraph,: **"Energy is a quantitative property of a system that depends on the motion and interactions of matter and radiation within the system. That there is a single quantity called energy is due to the remarkable fact that a system's *total* energy is conserved as smaller quantities of energy are transferred between subsystems—or into and out of the system through diverse mechanisms and stored in various ways."**

The 1st sentence only applies at the atomic level, which should be *explicitly stated*. Most people would not call energy a property of a system. For example, a person is the same whether he is running fast or not. Running is not a property of the person. Moreover, energy transfer terms are also energies in the conservation or energy equation, which are not properties of a system.

The 2nd sentence does not follow the first, since it applies at all scales. There is no "single" quantity called energy – transfer terms in the conservation of energy equation are energies. Moreover, it would be easy for a reader to conclude that the total energy of the system is constant (i.e., that conservation means constant).

Suggested change: "That there is a quantity called energy is due to the remarkable fact that the total energy of a system is always conserved in all experiments conducted to date. That is, regardless of the quantities of energy transferred between subsystems, or in and out of the system through diverse mechanisms and stored in various ways, *the change in a system's total energy is always equal to the total energy transferred into or out of the system. At the microscopic scale, all forms energy are some mixture of kinetic energy, potential (field) energies (which mediate interactions between particles), and radiant energy transfers within the system.*

20. **Page 5-12, 4th paragraph, 4th and 5th sentences. "Stored energy is also called potential energy. Changes in stored energy occur when the relative positions of any two interacting objects are changed."**

Not all stored energy is potential energy – in certain circumstances thermal energy, chemical energy and even motion energy can be considered stored energy, but not potential energy. For example, energy can be stored in a rotating flywheel. Moreover, changes in stored (potential) energy do not occur when the relative positions *any two interacting objects* change – only for objects interacting at a distance. Finally, stored is not used consistently in Chapter 5 to mean potential energy (e.g., see Error #9).

Suggested change: "Objects or systems have potential energy when their energy is the same when returned to their original configuration or starting condition, regardless of the path taken. For example, elastic potential energy is associated with objects (e.g., springs, bungee cords) that return to their original shape when they are stretched or compressed. -Systems of two objects that interact at a distance also have potential energy. Changes in stored (potential) energy occur when the relative positions of two objects interacting at a distance are changed."

21. **Page 5-12, 4th paragraph, 6th sentence. "Any such change in stored energy is inevitably compensated for by changes in motion energy or radiation."**

This sentence only applies at the atomic scale, which should be *explicitly* stated**.** Moreover, the examples in the next sentences are macroscopic examples, for which this statement *does not apply*.

For consistency, a *suggested change* is: "Any such changes in stored (potential) energy is inevitably compensated for by changes in motion energy *or energy transfers into or out of the system*.

22. **Page 5-12, 4th paragraph, 7th and 8th sentences. "For example, lifting an object increases the stored energy in the gravitational field between that object and Earth (gravitational potential energy); when the object falls, the stored energy decreases and the object's kinetic energy increases *correspondingly*. When a pendulum swings, some stored energy is transferred into kinetic energy and back again into stored energy during each swing.**

The last part of the 7th sentence is only true when air resistance is negligible (i.e., no transfers of energy into or out of the system) – this assumption should be explicitly stated. In addition, most students have difficulty with idealized systems, especially when they contradict their direct experience.

Suggested change: "When energy is transferred into an Earth-object system by lifting an object to a certain height, the energy stored in the gravitational field between that object and Earth (gravitational potential energy) increases; when the object is released and falls, the gravitational field energy decreases and the object's kinetic energy increases. Energy is also transferred out of the system as the falling object pushes aside and moves the air. When a pendulum swings, some stored (potential) energy is transformed into kinetic energy and back again into stored energy during each swing. The pendulum stops swinging because energy is transferred out of the pendulum system during each swing.

Incorrect Use of Energy Transfer

23. Page 5-16, 5th paragraph, 2nd sentence. Magnets can exert forces on other magnets or on magnetizable materials, thereby transferring energy **(e.g., in the form of motion)** even when the objects are not touching.

Forms of energy, like motion energy, are not transferred (see #25 below).

Suggested change: "Even when they are not touching, magnets can exert forces on other magnets or magnetiizable materials, *causing a transfer of energy to the objects which changes their motion*."

24. Page 5-16, 6th paragraph. "When two objects interact, each one exerts a force on the other, and **these forces can transfer energy between them**. For example, **gravitational interactions between an object and Earth store energy as the object is raised** and release energy as the object falls; magnetic and electric **forces between two objects at a distance can transfer energy between** the interacting objects."

Forces do not transfer energy – forces have to act over a distance (work) to transfer energy. In addition, the gravitational interaction between an object and the earth does not store energy when the object is raised – energy must be transferred into the system.

Suggested change: "When two objects interact, they can exert forces on each other t*hat can cause energy to be transferred to or from each object*. For example, when energy is transferred into an Earth-object system by lifting the object to a certain height, the gravitational field energy of the system increases. This energy is released as the object falls and the mechanism of that release is the gravitational force. Two magnetic or electric objects interacting at a distance can exert forces on each other that can cause a transfer energy between the interacting objects."

25. **Page 5-12, 4th paragraph, 8th sentence. "When a pendulum swings, some stored energy is *transferred* into kinetic energy and back again into stored energy during each swing."**

Page 5- 12, last paragraph, 2nd sentence. "**When a particle in a molecule of solid matter vibrates, energy is continually being *transferred* back and forth between the energy of motion and the energy stored in the electric and magnetic fields within the matter.**

Page 5-14, 6th paragraph. "When matter absorbs light or infrared radiation, the energy of that radiation is ***transferred*** to thermal motion of particles in the matter, … ."

Page 5-16, 3rd paragraph, 2nd sentence. "Patterns of motion, such as a weight bobbing on a spring or a swinging pendulum, can be understood in terms of forces at each instant or in terms of ***transfer of energy between*** the motion and one or more forms of stored energy."

The word *transferred* cannot be substituted for *transformed* (or *converted*). Forms of energy are not transferred into other forms of energy. There are several specific methods by which energy is transferred [e.g., when a force parallel to the direction of motion acts over a distance (work); when two objects/systems are at different temperatures (heat)], and the word *transfer* only refers to these methods.

Sometimes transformed is the right word. You could introduce the circumstances when the word transformation is appropriate – when we do not care or know about the energy transfer mechanisms occurring *within a system*, we say that the form of energy within a system that is decreasing is "transformed" or "converted" into the form of energy that is increasing.

Page 5-12, 4th paragraph. *Suggested change*: " … some stored energy is *transformed* into kinetic energy and back again into stored energy during each swing."

Page 5- 12, last paragraph. *Suggested change*: "When a particle in a molecule of solid matter vibrates, energy is continually being *transformed* back and forth between the energy of motion and the energy stored in the electric and magnetic fields within the matter."

Page 5-14, 6th paragraph. *Suggested change*: "When matter absorbs light or infrared radiation, the energy of that radiation is *transformed* into the thermal motion of particles in the matter, … ."

Page 5-16, 2nd sentence. *Suggested change*: "… . in terms of forces at each instant or in terms of the *transformation of energy between* the motion and one or more forms of stored energy.

LIST OF OUTRIGHT ERRORS IN CHAPTER 4

1. Page 4-7, 3rd paragraph, 3rd sentence. "They then examine the system in detail while treating the effects of things outside the boundary only in terms of what flows across it, such as forces, matter, and energy—the gravitational effect of Earth on a book lying on a table, for example, or the carbon dioxide expelled by an organism."

> Forces do not flow across a boundary – forces are not transferred from one object to another. Forces can act across an imaginary boundary, but do not "flow" into the object/subsystem across a boundary in the same way that matter and energy can be transferred or said to "flow" across a boundary.

2. Page 4-12, 6th paragraph, 1st sentence: "For example, the stability of the book lying on the table depends on the fact that minute distortions of the table caused by the book's weight in turn cause changes in the positions of the table's atoms."

> The weight of the book is the gravitational pull of the Earth on the book. Weight does not push down on the table -- the book pushes down on the table. Thus, "book's weight" should be replaced by "book's downward push on the table."