


Physics and 21st Century Science Standards: The Role of Physics in the NGSS*

A publication of the American Association of Physics Teachers



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Editor's Introduction

In 2012, Achieve, Inc. and the Lead States released the first draft of the Next Generation Science Standards (NGSS Lead States, 2013), commonly known as the NGSS, for public comment. These standards were meant to provide a coherent set of internationally-benchmarked guidelines for K-12 science teachers across the nation. In response, the American Association of Physics Teachers (AAPT), the American Physical Society, the American Chemical Society, the American Institute of Physics, the American Society for Engineering Education, and the Department of Energy compiled feedback on the first draft of the standards. A summary of the group's May 29, 2012, response can be found in the 1st Draft Summary Response: http://goo.gl/nJlFSk. Upon release of a revised version of the NGSS, the AAPT created an additional focus group comprised of persons involved in high school physics education. The AAPT responded again in their 2nd Draft Summary Response: http://goo.gl/qrxldf. This response, from February 1, 2013, described both their support for standards based upon the National Research Council and National Academy of Science's *Framework for K-12 Science Education: Practices, Crosscutting Concepts, and Core Ideas,* while also identifying some weaknesses and omissions in the standards with recommendations for improvement.

The AAPT supports the spirit and purpose of NGSS as implemented in the context of the Framework, but does not endorse any set of standards. Please refer to the AAPT's physics focus group's final response to Achieve about the NGSS for details: http://goo.gl/tlvdVW.

It is my hope that this document will help K-12 teachers of physics to better understand how their classroom practice is aligned with the NGSS or how it can be effectively aligned if your state or your school adopt the NGSS.

~ Rebecca E. Vieyra, K-12 Program Manager, AAPT

Approved by the AAPT Board of Directors, 9 January 2016

Acknowledgement

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AAPT
PHYSICS EDUCATION

Table of Contents

Quick FAQ's about the NGSS for Physics Teachers

- The NGSS are best understood in the context of the National Academy's Framework for K-12 Science Education. **It is highly suggested that teachers and administrators read the Framework** first before attempting to implement the standards.
- **What are the Next Generation Science Standards (NGSS)?** The NGSS are a set of performance expectations that describe what students should know and be able to do at various stages in their K-12 development, and were written with wide-scale student assessment in mind. The NGSS are not written as curriculum: they do not provide details about what students need in order to master a big idea. The NGSS do not provide explicit guidelines to teachers about instructional approaches; educators are expected to use their discretion when making decisions about pacing, order, and teaching method.
- **Why should I care about the NGSS?** The NGSS is a result of a nationwide attempt to increase science literacy for all. Physics is fundamental to this effort. The writing of the NGSS was based upon work by the National Academies and the American Association for the Advancement of Science. It was written by 41 science educators and leaders from 26 Lead States. Even if your school district or state has not adopted the NGSS, understanding them is key to engaging in the national discussion about science education.
- **What do the NGSS look like?** Below is a sample standard related to physics. The NGSS are performance objectives (defining a student action for assessment) that include both depth of content (Disciplinary Core Ideas), skills (Science and Engineering Practices), and interconnections with other science disciplines (Crosscutting Concepts). The NGSS are also aligned with Common Core State Standards for English Language Arts / Literacy and Mathematics. See "Reading the NGSS" in this guide for a much more detailed explanation of how these facets of each standard are related to one another.
  - Ex.: HS-PS3-5. Develop and use a model of two objects interacting through electrical or magnetic fields to illustrate the forces between objects and the changes in energy of the objects due to the interaction. [Clarification Statement: Examples of models could include drawings, diagrams, and texts, such as drawings of what happens when two charges of opposite polarity are near each other.] [Assessment Boundary: Assessment is limited to systems containing two objects.]
- **Where do I find physics content in the NGSS?** Because the NGSS place heavy emphasis on the interdisciplinary nature of science and engineering, the standards are not explicitly organized by subject. Although physics can be found (alongside chemistry) in the Physical Science grouping of standards, physics concepts can also be found in the study of Earth and Space Science (i.e. gravity), Life Sciences (i.e. energy flow), and Engineering standards.
- **How would adoption of the NGSS affect the physics courses that I teach?** The answer to this is dependent upon both your existing teaching style and course content. While most standard high school physics courses will include the "big topics" addressed by the NGSS (Motion, Forces, Energy, and Waves), the NGSS also place a heavy emphasis on interdisciplinary understandings and engineering. Teachers might find that they need to make more room for teaching these additional skills, shift their instructional approach, and/or to take more professional development themselves in order to help students address these standards.
- **What is the AAPT's position on the NGSS?** The AAPT supports the spirit and purpose of NGSS as implemented in the context of the Framework, but does not endorse any set of standards.
- **Where can I learn more about the NGSS?** Get new resources that align with and support the use of the NGSS at http://aapt.org/k12. Visit http://www.nextgenscience.org to read and learn more about each of the NGSS performance expectations. See "Resources for Implementing the NGSS" near the end of this booklet for more information.

Overview and History of the NGSS

The Next Generation Science Standards (NGSS) were written as a response to the growing need for a STEM-ready U.S. workforce with critical thinking and inquiry-based problem solving skills. The NGSS addresses science understanding and skills at the K-12 level and includes performance expectations for students to have accomplished by the end of Kindergarten, grades 1, 2, 3, 4, and 5, and at the end of Middle School (MS) and High School (HS).

Many physics teachers across the country have found themselves impacted by statewide, local, or even personal adoption of the NGSS. As a result, physics teachers might find that they need to make shifts in the type of content that they teach and the instructional practices that they use. To fully understand the NGSS, it is important to understand the origin of the NGSS, as well as the full K-12 spectrum that it spans.

The NGSS were based on A Framework for K-12 Science Education (2012), produced by the National Research Council. In order to understand the content and organization of the NGSS, this document is a "must read" for educators.

What sets the NGSS apart from previous standards are the three dimensions of the Framework that are interwoven into each standard:

- **Disciplinary Core Ideas**
- **Science and Engineering Practices**
- **Crosscutting Concepts**

In addition to these three dimensions, standards are also connected to:

- **Understanding the Scientific Enterprise: The Nature of Science**
- **Engineering Design**
- **Science, Technology, Society, and the Environment**
- **Common Core State Standards for Mathematics**
- **Common Core State Standards for Literacy in Science and Technical Subjects**

The NGSS were released for adoption by states in April 2013. Reviewing the nationwide progression of the NGSS can be very helpful to comprehending the fairly complex nature of the document. Refer to **Resources for Implementing the NGSS** near the back of this document for more information. All of the listed documents are available for free download and serve as an introduction to the evolution of STEM education in the United States over the past 20 years.

Using the Framework and its three dimensions (Disciplinary Core Ideas, Science and Engineering Practices, and Crosscutting Concepts), the Next Generation Science Standards were developed by a coalition of 26 lead states under the guidance of Achieve, Inc., and published by the National Academies Press.

As of early 2016, nearly a third of U.S. states and the District of Columbia have adopted the NGSS (Figure 1). Many states already had their own standards in advance of the development of the NGSS, and did not opt to adopt the new standards. Some states feel that the NGSS are insufficient to provide curricular or instructional guidance to teachers, and that their standards are superior to the NGSS. However, many school districts are adopting the standards in advance of their states – in some cases, with the NGSS being adopted in tandem with different state standards.

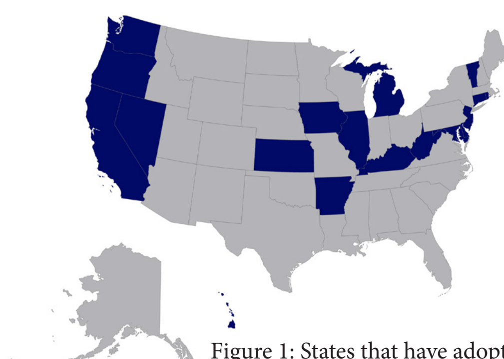


Figure 1: States that have adopted the NGSS are shown in blue.

Adoption of the standards is slow, but progressing. There are a number of speculations about the factors that have influenced the slow adoption of the NGSS in comparison to the relatively quick adoption of the Common Core State Standards (CCSS). Because the CCSS were used by many states as "college and career-ready" standards to comply with incentives for the Race to the Top program, it is possible that many states are waiting before adopting yet another set of new standards. Additionally, states have put significant efforts into improving student achievement in mathematics and English/language arts (the content associated with the CCSS) through the development of assessments following the implementation of No Child Left Behind. No nationwide assessment has yet been developed for science education aligned with the NGSS, and the results of student achievement in science have significantly less political clout than mathematics or English/language arts. In some cases, states have opposed any national standards.

Even so, teachers who work in districts or states where the NGSS have not been adopted should still be aware of the standards both because many professional organizations have endorsed them and so that they can effectively engage in national discussions about science education.

Reading the NGSS

Attempting to read and understand the layout of the NGSS can seem overwhelming, given the number and depth of interdisciplinary connections. This challenge can be compounded for teachers who look at the NGSS with a desire to see only what standards apply to them and their students. Because the NGSS were written to highlight only the "big ideas" as they fit into the larger context of science, but not the minutiae, it is important to get a K-12 overview across all of the sciences in order to understand how physics fits into the equation.

The Standards

Keep the following items in mind as you read through the standards:

1. **The NGSS are written as performance expectations for wide-scale testing.** Performance expectations clearly identify what a student should know and be able to do with their knowledge. Although teachers should use their discretion when selecting assessments for students to demonstrate their abilities at the classroom level, the language of the standards was written with the expectation that they would be used to measure school, state, and/or national performance. Although physics teachers should not limit themselves to assessing students on the NGSS performance expectations, teachers are likely to find that they need to modify their existing assessments in order to determine if students have met the NGSS.
2. The **NGSS are not a curriculum.** The standards are not written in such a level of detail that students can transition directly from one standard to the next, nor are the standards written in a developmentally-appropriate order for instruction. The standards only highlight the most important points of emphasis during the learning process. Teachers working in their educational setting should use their professional discretion in regard to their own teaching style, pacing, instructional approaches, curricular resources, and course sequencing. Additionally, physics teachers are likely to find that not all of the topics that they typically teach are explicitly included in the NGSS (notably, many aspects of circuitry, geometric optics, and color are not mentioned in the high school grade band), or that they might need to remove some content in order to increase emphasis on the three dimensions of the NGSS.
3. **The NGSS provide guidance for the minimal expectations of all students at the end of their grade band.** Further considerations need to be made for students and their diverse needs (remediation, accelerated or advanced work, or other considerations). For example, these standards might comprise most of the expectations for a conceptual physics or physical science course, but would be insufficient for an honors-level physics or AP physics course.
4. **The NGSS performance expectations are intended to be read by science-literate adults and pedagogically-prepared science educators.** The spirit and language of the NGSS make the most sense in the context of the Framework in which they were written. The performance objectives are not necessarily appropriate for use as guidelines for student consumption. Additionally, physics teachers need to have both a depth of understanding of their content area, as well as a breadth of familiarity with other science disciplines and engineering practices in order to understand and implement the standards.

Those reading the NGSS performance expectations for the first time – especially novice physics teachers – should be wary of misinterpreting the standards.

The first clearly identifiable high school physics standard, HS-PS2-1, for example, focuses on Newton's 2nd Law. This performance expectation does not suggest that Newton's 2nd Law be the first topic addressed in an introductory physics class!

Read the section "Depth of the Standards" in this document to learn more about what is embedded in each standard.

The NGSS can be read and have been organized in two different ways (Table 1) to meet the preferences of the readers and the interdisciplinary nature of some of the core ideas.

- **Organized by Disciplinary Core Ideas (DCIs)** – This is the arrangement that is reflective of the big ideas and content storylines identified in the Framework. Regardless of a standard's topical categories, the standards are coded to be organized by DCIs. To learn more about this organizational structure and its rationale, read the Framework Dimension 3: Disciplinary Core Ideas-Physical Sciences.
- **Organized by topic** – This is the more traditional arrangement similar to the "chapter headers" that one would find in a textbook.

Performance expectations for high school science are structured by **DCI** as follows. Although the chemistry and physics can become fairly intermixed, the majority, but by no means all, of traditional physics content falls into the DCIs and topics below in bold blue typeface. Standards designated with a "◊" have additional strong connections to physics content.

Table 1: NGSS organized by DCI and Topic

	Organized by **DCI**	Organized by **Topic**
Physical Sciences	• **Matter and Its Interactions** • **Motion and Stability: Force & Motion** • **Energy** • **Waves and Their Applications in Technologies for Information Transfer**	• **Structure and Properties of Matter** • **Chemical Reactions** ◊ • **Forces and Interactions** • **Energy** • **Waves and Electromagnetic Radiation**
Life Sciences	• From Molecules to Organisms: Structures and Processes ◊ • Ecosystems: Interactions, Energy, and Dynamics ◊ • Heredity: Inheritance and Variation of Traits • Biological Evolution: Unity and Diversity ◊	• Structure and Function • Matter and Energy in Organisms and Ecosystems ◊ • Interdependent Relationships in Ecosystems • Inheritance and Variation of Traits • Natural Selection and Evolution
Earth and Space Sciences	• Earth's Place in the Universe ◊ • Earth's Systems ◊ • Earth and Human Activity ◊	• Space Systems ◊ • History of Earth • Earth's Systems ◊ • Weather and Climate ◊ • Human Sustainability ◊
Engineering Design	• Engineering Design	• Engineering Design

The Dimensions

The key elements of the NGSS are the three dimensions that are interwoven into each standard.

- **Disciplinary Core Ideas** (DCIs)

  These are the key pieces of discipline-focused knowledge (i.e. content) that students should know.
  - Earth and Space Sciences
  - Life Sciences
  - Physical Sciences
  - Engineering

- **Science and Engineering Practices** (SEPs)

  These practices describe specific skills and actions that can be performed by students that parallel the activities of scientists to build models and theories and by engineers to design and build systems.
  - Asking questions (for science) and defining problems (for engineering)
  - Developing and using models
  - Planning and carrying out investigations
  - Analyzing and interpreting data
  - Using mathematics and computational thinking
  - Constructing explanations (for science) and designing solutions (for engineering)
  - Engaging in argument from evidence
  - Obtaining, evaluating, and communicating information.

- **Crosscutting Concepts** (CCs)

  These are the unifying ideas that span all science disciplines that students with a broad science literacy should understand.
  - Patterns
  - Cause and effect: Mechanism and explanation
  - Scale, proportion, and quantity
  - Systems and system models
  - Energy and matter: Flows, cycles, and conservation
  - Structure and function
  - Stability and change

Other NGSS Connections

In addition to these three dimensions, standards are also connected to:

- **Understanding the Scientific Enterprise: The Nature of Science** Surrounding the context of the NGSS is the expectation that students will learn about the development of scientific knowledge with its many historical and social implications. The nature of science is not an additional dimension to the three dimensions above, but is interwoven with the SEPs and CCs. The first four are closely related to the SEPs (◆), and the last four are closely related to CCs (►).
    - Scientific investigations use a variety of methods.◆
    - Scientific knowledge is based on empirical evidence. ◆
    - Scientific knowledge is open to revision in light of new evidence.◆
    - Scientific models, laws, mechanisms, and theories explain natural phenomena.◆
    - Science is a way of knowing.►
    - Science knowledge assumes an order and consistency in natural systems.►
    - Science is a human endeavor.►
    - Science addresses questions about the natural and material world.►
- **Engineering Design**

In the NGSS documents, engineering is defined as "any engagement in a systematic practice of design to achieve solutions to particular human problems." Although many models of engineering design exist, the NGSS focus on a three-part approach that includes the following components, with modified descriptors for each component dependent upon the grade band.

- Defining and delimiting engineering problems
- Designing solutions to engineering problems
- Optimizing the design solution

- **Science, Technology, Society, and the Environment**

Science, technology, society, and environment are interdependent upon one another. Likewise, teachers must encourage their students to make connections between the classroom, their home lives, and their community.

- **Common Core State Standards for Mathematics and Literacy in Science and Technical Subjects**

Where appropriate, the NGSS connect to Common Core State Standards (CCSS). However, adoption of the NGSS does not mandate adoption of the CCSS or have any impact on the incorporation of the NGSS alone. The appendixes to the NGSS provide examples of how teachers can incorporate the CCSS with specific scenarios, including the use of qualitative skills (ex: proportional reasoning) and quantitative skills (ex: mathematical modeling with algebra).

NGSS Format

The NGSS are presented in a table in the Achieve, Inc. documentation. Within a single table, all of the standards will be listed for a given DCI or topic area, with associated Science and Engineering Practices, Disciplinary Core Ideas, and Crosscutting Concepts, as well as connections within the NGSS and across grade bands, and Common Core State Standards.

It is important to note that because the NGSS are written as performance expectations, each standard is closely linked to one or more DCIs, SEPs, and/or CCs. These standards are written with an assessment in mind, and therefore have a very narrow focus. In contrast, teachers can and should use instructional practices and curriculum designs that help students to see that a single DCI can have connections to many or even all of the SEPs and CCs, not only those that are explicitly linked to the performance expectation.

The structure of a table entry is shown on the following page in Table 2.

Table 2: Achieve, Inc. table cell format

DCI or Topic		
Performance expectations - Identifiable by HS-letter,letter,number-NUMBER (ex: HS-PS3-1)		
Science and Engineering Practices	Disciplinary Core Ideas	Crosscutting Concepts
List of **SEPs** identifiable in blue headings with connections to each of the specific performance expectations above. ************************ List of any aspects of the **Nature of Science** with connections to each of the specific performance expectations above.	List of **DCIs** identifiable by HS-letter,letter,number-LETTER (ex: HS-PS3-A) with connections to each of the specific performance expectations above.	List of **CCs** identifiable in green headings with connections to each of the specific performance expectations above.
Connections to other DCIs in the grade band.		
Articulation of DCIs across grade-levels.		
Common Core State Standards Connections: ELA/Literacy – Mathematics –		

Physics in the NGSS

Physics is not explicitly differentiated from chemistry within physical science topics or DCIs. As a result, there is some overlap. Schools and teachers are expected to use their professional discretion to determine who teaches these concepts and in what order, although Achieve has released a set of suggested course maps for middle and high school. In some cases, fundamental physics concepts are not mentioned at all, and teachers are expected to use good judgment when making decisions about detailed curriculum, using the NGSS only as guideposts for student achievement along the way. Table 3 shows high school physics-related NGSS, organized by topic.

Table 3: High school physics-related standards

TOPIC	KEY PHYSICS
Structure and Properties of Matter	
HS-PS1-3: Plan and conduct an investigation to gather evidence to compare the structure of substances at the bulk scale to infer the strength of electrical forces between particles.	Coulomb's Law
HS-PS1-8: Develop models to illustrate the changes in the composition of the nucleus of the atom and the energy released during the processes of fission, fusion, and radioactive decay.	Nuclear Physics
HS-PS2-6: Communicate scientific and technical information about why the molecular-level structure is important in the functioning of designed materials. ***ENGINEERING DESIGN***	Materials Science
Forces and Interactions	
HS-PS2-1: Analyze data to support the claim that Newton's second law of motion describes the mathematical relationship among the net force on a macroscopic object, its mass, and its acceleration.	Newton's Laws Kinematics
HS-PS2-2: Use mathematical representations to support the claim that the total momentum of a system of objects is conserved when there is no net force on the system.	Impulse = ΔMomentum
HS-PS2-3: Apply scientific and engineering ideas to design, evaluate, and refine a device that minimizes the force on a macroscopic object during a collision. ***ENGINEERING DESIGN***	Conservation of Energy
HS-PS2-4: Use mathematical representations of Newton's Law of Gravitation and Coulomb's Law to describe and predict the gravitational and electrostatic forces between objects.	Uni. Gravitation Coulomb's Law
HS-PS2-5: Plan and conduct an investigation to provide evidence that an electric current can produce a magnetic field and that a changing magnetic field can produce an electric current.	Current Magnetism Induction
Energy	
HS-PS3-1: Create a computational model to calculate the change in the energy of one component in a system when the change in energy of the other component(s) and every flow in and out of the system are known.	Forms of Energy
HS-PS3-2: Develop and use models to illustrate that energy at the macroscopic scale can be accounted for as a combination of energy associated with the motions of particles (objects) and energy associated with the relative positions of particles (objects).	Conservation of Energy
HS-PS3-3: Design, build, and refine a device that works within given constraints to convert one form of energy into another form of energy. ***ENGINEERING DESIGN***	
HS-PS3-4: Plan and conduct an investigation to provide evidence that the transfer of thermal energy when two components of different temperature are combined within a closed system results in a more uniform energy distribution among the components in the system	Thermodynamics
HS-PS3-5: Develop and use a model of two objects interacting through electric or magnetic fields to illustrate the forces between objects and the changes in energy of the objects due to the interaction.	Electromagnetic Fields

Waves and Electromagnetic Radiation	
HS-PS4-1: Use mathematical representations to support a claim regarding relationships among the frequency, wavelength, and speed of waves traveling in various media.	Waves Refraction
HS-PS4-2: Evaluate questions about the advantages of using a digital transmission and storage of information.	Information Technology
HS-PS4-3: Evaluate the claims, evidence, and reasoning behind the idea that electromagnetic radiation can be described either by a wave model or a particle model, and that for some situations one model is more useful than the other.	Wave-Particle Duality Photoelectric Eff.
HS-PS4-4: Evaluate the validity and reliability of claims in published materials of the effects that different frequencies of electromagnetic radiation have when absorbed by matter.	Absorption
HS-PS4-5: Communicate technical information about how some technological devices use the principles of wave behavior and wave interactions with matter to transmit and capture information and energy. ***ENGINEERING DESIGN***	E&M Waves
Engineering	
HS-ETS1-1: Analyze a major global challenge to specify qualitative and quantitative criteria and constraints for solutions that account for societal need and wants.	No specific physics concepts listed.
HS-ETS1-2: Design a solution to a complex real-world problem by breaking it down into smaller, more manageable problems that can be solved through engineering.	
HS-ETS1-3: Evaluate a solution to a complex real-world problem based on prioritized criteria and tradeoffs that account for a range of constraints, including cost, safety, reliability, and aesthetics, as well as possible social, cultural, and environmental impacts.	
HS-ETS1-4: Use a computer simulation to model the impact of proposed solutions to a complex real-world problem with numerous criteria and constraints on interactions within and between systems relevant to the problem.	
Additional Standards with Connections to Physics	
HS-PS1-4: Develop a model to illustrate that the release or absorption of energy from a chemical reaction system depends on the changes in total bond energy.	Energy
HS-LS1-5: Use a model to illustrate how photosynthesis transforms light energy into stored chemical energy.	Energy
HS-LS2-3: Construct and revise an explanation based on evidence for the cycling of matter and flow of energy in aerobic and anaerobic conditions.	Energy
HS-LS2-4: Use mathematical representations to support claims for the cycling of matter and flow of energy among organisms in an ecosystem.	Energy
HS-ESS1-1: Develop a model based on evidence to illustrate the life span of the sun and the role of nuclear fusion in the sun's core to release energy that eventually reaches Earth in the form of radiation.	Nuclear Physics E&M Waves
HS-ESS1-2: Construct an explanation of the Big Bang theory based on astronomical evidence of light spectra, motion of distant galaxies, and composition of matter in the universe.	Light Doppler Effect
HS-ESS1-3: Communicate scientific ideas about the way stars over their life cycle, produce elements.	Nuclear Physics
HS-ESS1-4: Use mathematical or computational representations to predict the motion of orbiting objects in the solar system.	Uni. Gravitation
HS-ESS2-3: Develop a model based on evidence of Earth's interior to describe the cycling of matter by thermal convection.	Thermal, Waves
HS-ESS2-4: Use a model to describe how variations in the flow of energy into and out of Earth's systems result in changes in climate.	Energy

From the above discussion alone, it might seem to teachers that achieving all of the physics-related high school standards during one or two physics courses might be impossible. However, it is important to keep in mind that all of the standards are embedded within a K-12 framework that anticipates that students will progress toward these ideas from their earliest years in school.

Although each of the grade-level standards merit reading individually, Table 4 below gives a very brief overview of the concepts addressed in each grade band to lead up to high school physics.

Table 4: Physics-related standards across the grade bands

Grade Band	
K	Forces (pushes/pulls), collisions, gravity
1	Sound, EM spectrum, light, color, reflection, refraction, lenses
2	Physical properties
3	Balanced/unbalanced forces, inertia, momentum, harmonic motion, E&M forces
4	Forms of energy (kinetic/motion, sound, light, heat, electric), conservation of energy
	Geometric optics
5	Nuclear, chemical, and physical properties
MS	Atomic and molecular models, heat
	Newton's Laws, E&M fields and forces, universal gravitation
	Kinetic and potential energy (inc. proportionalities/equations), conservation of energy
	Wave speed (inc. proportionalities/ equations), reflection, absorption, transmission
HS	Atomic particles, fission/fusion
	Newton's Laws, force diagrams, impulse and momentum, conservation of energy, Law of Gravitation, Coulomb's Law, induction, EM interactions
	Forms of energy, conservation of energy, Laws of Thermodynamics
	Wave propagation (sound, light), wave-particle duality, absorption, communication

What Physics is not in the NGSS?

Because the standards are highly interconnected and emphasize SEPs and CCs just as much as DCIs, it is possible to teach nearly any physics concept in such a way that it helps to address the goals of the NGSS. Although no content is explicitly excluded, certain physics concepts are explicitly included. The language, vocabulary, and structure of the NGSS will certainly affect those who are charged with evaluation the NGSS teaching practices of a teacher. When appropriate, physics teachers should be prepared to explain how the content and skills that they teach relate to the NGSS.

Table 5, on the next page, identifies topics that are typically included in an introductory high school physics course. The columns demonstrate what language is explicitly included and what is omitted from the NGSS. Language included in the performance expectations is listed in bold. Language included in the associated DCIs, clarifying statements, or assessment boundaries is shown in plain font. The last column in the table shows language that is omitted from any elements of the NGSS. Although a physics teacher might understand that a lesson on Hooke's Law is important and worthwhile (but not explicitly mentioned in the NGSS), it is important for the teacher to recognize and communicate to evaluators that it has strong connections to topics explicitly listed in the NGSS, such as energy transformations, conservation of energy, and a variety of SEPs and CCs.

Table 5: Physics language in High School NGSS

	Explicitly Included in the NGSS	Language Omitted in the NGSS
Mechanics (Motion, Force, Energy, Momentum)	• **Motion** (1-dimensional) • x-t and v-t graphs • **Newton's Second Law of Motion** • **Force, net force** • **Balanced, unbalanced systems** • **Mass** • **Acceleration** • **Energy** (kinetic/motion, chemical, sound, light, thermal, position, electrical, spring, radiation, renewable energy, etc.) • **Closed systems** • **Conservation of mass/matter** • **Conservation of energy** • **Energy transfer/transformations**/efficiency • **Conservation of momentum** • **Newton's Law of Gravitation** • **Gravitational Field** • Orbital motion (2 bodies), Kepler's Laws	• Vectors / scalars • Displacement, distance • 2-dimensional motion • Projectile motion • Newton's First Law / Inertia • Periodic Motion • Torque • Work, power • Hooke's Law • Potential energy
Waves, Sound, and Optics	• **Frequency** • **Wavelength** • **Speed** • **Media** • Electromagnetic radiation, sound, and seismic waves • **Wave behavior and interaction, absorption**, reflection, resonance, interference (relative phase, peaks, troughs), diffraction, and photoelectric effect/ materials. • Wave and particle model of electromagnetic radiation. • **Light spectra,** radio, microwaves, light, heat, ultraviolet, X-rays, gamma rays, cosmic microwave background radiation • Brightness	• Optics (mirrors, lenses, vision, color) • Snell's Law, refraction, • Polarization • Inverse-Square Law (for light) • Standing waves (on strings or air columns) • Hearing (pitch, loudness, timbre) • Beats • Doppler Effect
Heat and Thermodynamics	• **Temperature** • **Second Law of Thermodynamics**	• Zeroth, First, and Third Laws of Thermodynamics • Kinetic Theory • Gas Laws
Electricity and Magnetism	• **Charges** • **Coulomb's Law** • **Electrical Field** • **Electrical Current** • Electrically conductive materials • Batteries • **Magnets** • **Magnetic Field** • Polarity	• Circuits (simple, series, parallel) • Circuit concepts (resistance, voltage, AC/DC, Ohm's Law) • Circuit components (resistor, capacitor, inductor).

	Explicitly Included in the NGSS	Language Omitted in the NGSS
Modern Physics (Nuclear, Quantum, Relativity, Astrophysics)	• **Fission, fusion, radioactive decay,** nucleosynthesis, alpha, beta, and gamma radioactive decay • **Atoms, protons, neutrons, electrons** • **Big Bang Theory** • **Photoelectric effect** • **Materials**	• Blackbody Radiation • Plank's Constant • Uncertainty Principle
Mathematical Methods	• 1-dimensional • Basic algebraic expressions or computations	• Trigonometry • Calculus

Depth of the Standards

Each of the standards in the NGSS have a significant depth that must not be overlooked by teachers. Take, for example, the first standard for high school students associated with mechanics. Experienced teachers recognize that this standard requires multiple layers of student understanding before it can be achieved.

HS-PS2-1: Analyze data to support the claim that Newton's second law of motion describes the mathematical relationship among the net force on a macroscopic object, its mass, and its acceleration.

Taking the Core Disciplinary Idea alone, students need to have an understanding of fundamental kinematics, which might take weeks or months to develop in an introductory physics setting. Indeed, many teachers report spending upwards of a half of a semester to develop models (verbal, graphical, mathematical, physical, etc.) for conceptual and quantitative understanding of the following:

- Vectors
- Constant velocity
- Uniform acceleration
- Forces (tension, weight, normal force, friction)
- Force diagrams in balanced and unbalanced systems
- Newton's laws
- Conservation of mass

The standard's associated Science and Engineering Practice, Analyzing and Interpreting Data, closely associated with the Common Core State Standards for literacy, require students to: "Analyze data using tools, technologies, and/or models (e.g., computational, mathematical) in order to make valid and reliable scientific claims or determine an optical design solution." Logistically, one might interpret this standard by having students perform an inquiry lab to determine the relationship between net force, mass, and acceleration using probeware (i.e. sonic motion detector, force meter) and data analysis tools (i.e. graphical analysis software, graphing calculator) to make meaning of the data as displayed on a graph. Graphical analysis also entails students understanding mathematical models, such as linear algebraic relationships and the calculation and meaning of slope and intercept. Asking students to support the claim also requires students to engage in communication with their peers or with the teacher in order to share data, come to a conclusion, and defend their results, all of which can happen in some way through whiteboarding sessions, lab reports, and/or whole class discussion carefully guided by the teacher and through the development of a respectful environment.

The Crosscutting Concept associated with the standard, Cause and Effect, requires that students demonstrate an understanding that "Empirical evidence is required to differentiate between cause and correlation and make claims about specific causes and effects." Looking more deeply at this concept, students need to understand how to perform a controlled experiment in which causal relationships are determined. Because experiments associated with Newton's second law require students to understand the relationship among three potential variables (net force, mass, and acceleration), students need to understand how to perform two controlled experiments, and then merge the relationships together to make a claim about their interrelationship.

The above is just one of the many standards associated with physics. Each standard needs to be read not only for its physics content, but for the associated performance objective, skills, and understandings about science as well.

Evidence Statements

Authored after the standards, evidence statements were developed to further break down the observable features of student performance. For example, standard HS-PS2-1 includes the following evidence statements:

Observable features of student performance by the end of the course:		
1	**Organizing Data**	
	a	Students organize data that represent the net force on a macroscopic object, its mass (which is held constant), and its acceleration (e.g., via tables, graphs, charts, vector drawings).
2	**Identifying relationships**	
	a	Students use tools, technologies, and/or models to analyze the data and identify relationships within the datasets, including:
		i. A more massive object experiencing the same net force as a less massive object has a smaller acceleration and a larger net force on a given object produces a correspondingly larger acceleration; and
		ii. The result of gravitation is a constant acceleration on a macroscopic object as evidenced by the fact that the ratio of net force to mass remains constant.
3	**Interpreting data**	
	a	Students use the analyzed data as evidence to describe that the relationship between the observed quantities is accurately modeled across the range of data by the formula $a = F_{net}/m$ (e.g., double force yields double acceleration, etc.)
	b	Students use the data as empirical evidence to distinguish between causal and correlational relationships linking force, mass, and acceleration.
	c	Students express the relationship $a = F_{net}/m$ in terms of causality, namely that a net force on an object causes the object to accelerate.

Although these evidence statements provide additional details about the performance expectation, they do not fully describe all the elements necessary to understand the physics concepts to be assessed. As with the performance expectations, evidence statements are meant only for clarification, and not to be used as curriculum or to place boundaries on instruction.

Engineering and HS Physics-Related Standards

Perhaps one of the biggest shifts that physics teachers, in particular, will notice upon adoption of the NGSS is the heavy emphasis on engineering. Although engineering is interwoven into specific standards, the NGSS also do have a set of stand-alone engineering standards for each grade band.

In Figure 2 and Figure 3 on the following pages, the physics-related standards are shown in concept webs. Although the NGSS only explicitly describe the relationships between topics, not between specific standards, an attempt has been made here to show example learning pathways, and how physics concepts (DCIs) from each grade band support other physics concepts in later grade bands. However, the nuances of each standard could result in a myriad of interconnections, especially if one is instead looking at the complexity or depth of the SEPs or CCs within each standard.

Figure 2 displays the most relevant physics standards across the grade bands. Please note that this is not a complete listing of the standards. For simplicity, it does not include most physics-related standards that fall outside of the largest groupings of physics standards (Structures and Properties of Matter, Forces and Interactions, Energy, and Waves). It also does not directly incorporate the engineering standards, although the standards with ties to engineering are denoted by the **gold** outline.

Figure 3 displays an example pathway of a single DCI that begins at the Kindergarten grade band and supports additional standards all the way through to the high school grade band.

It should be evident that all of the standards are highly interrelated, with forces and energy being the dominant underlying themes.

Assessing Implementation of the NGSS in Physics

Although no discipline-specific teacher evaluation system exists for NGSS-aligned instructional practice, Achieve has produced an **Educators Evaluating the Quality of Instructional Products (EQuIP) Rubric for Lessons and Units** (http://goo.gl/fYwr0b). This rubric employs a "check list" system of characteristics of a lesson or unit that incorporate considerations for:

- Alignment to the NGSS

- Instructional Supports
- Monitoring Student Progress

Reading, integrating, and assessing the use of the NGSS in teaching requires both scientific literacy as well as an understanding of effective teaching practice. Achieve has produced a set of ten lessons and handouts to help teachers and leaders in education to effectively use the EQuiP rubric: **EQuiP Professional Learning Facilitator's Guide** (http://goo.gl/wjZsws).

Figure 2 : Physics Standards Across the Grade Bands

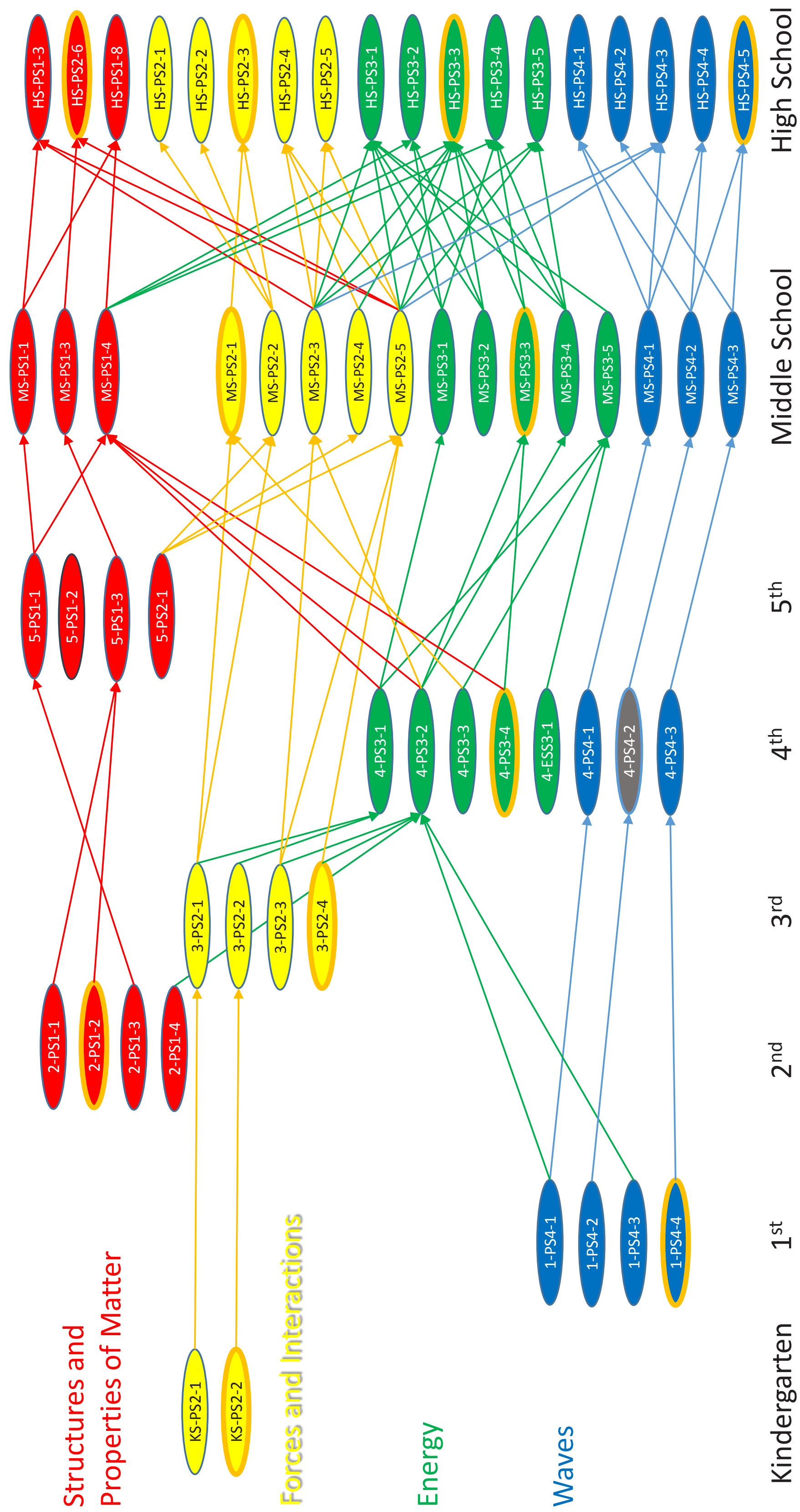
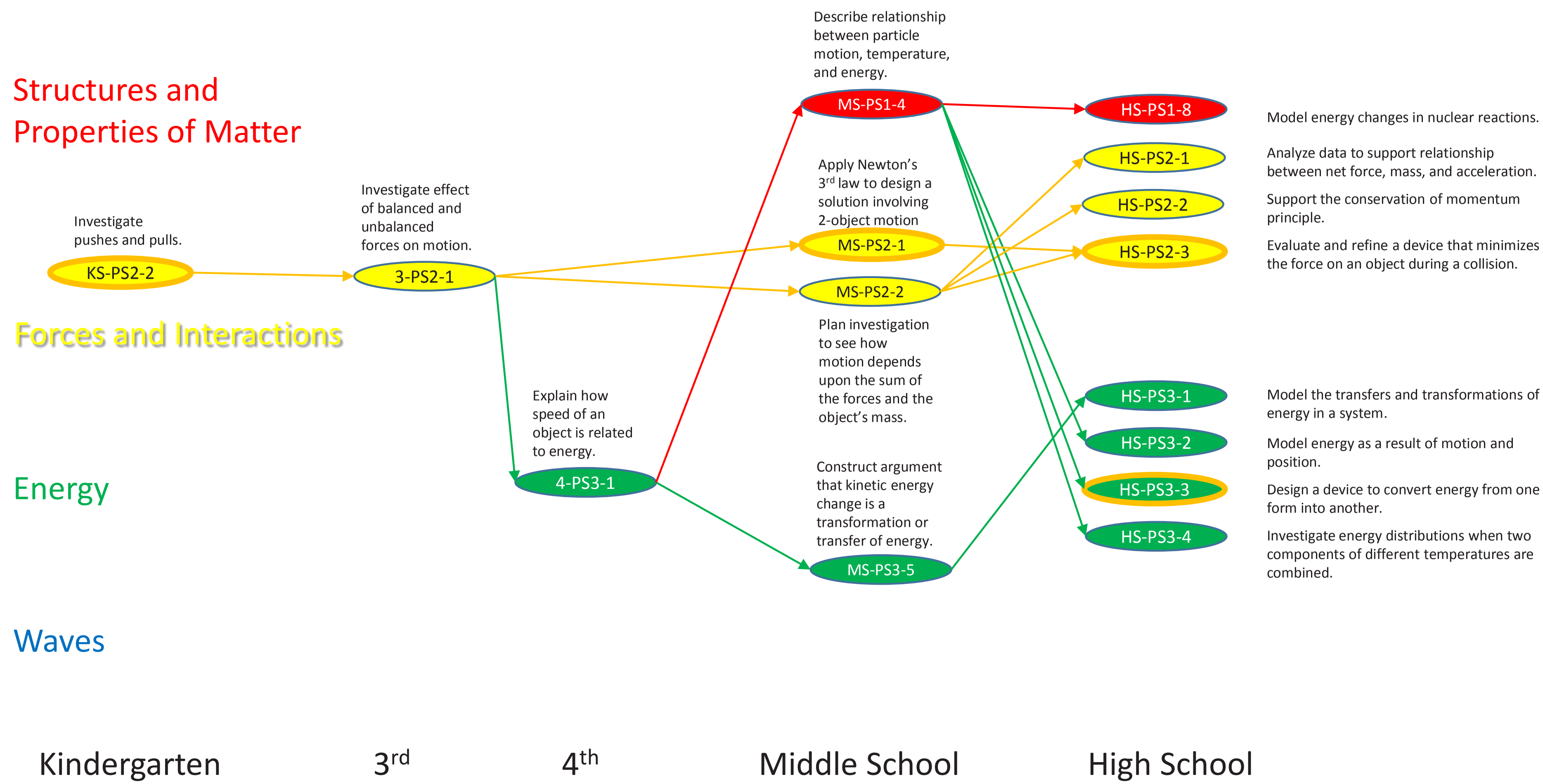


Figure 3 : Sample Pathway of a Single DCI



Resources for Implementing the NGSS

Historical Overview of the Development of the NGSS

The following documents from the American Association for the Advancement of Science (AAAS) spearheaded the Project 2061 initiative to improve science literacy for all by providing broad descriptive and unifying themes of natural, mathematical, and social sciences, goals for student achievement, and atlases that displayed the deep interconnectedness of the sciences.

- Science for All Americans (AAAS & Rutherford, Science for all Americans, 1991)
- Benchmarks for Science Literacy (AAAS, 1994)
- Atlas of Science Literacy, Vols. 1 & 2 (AAAS, 2001)

The **National Research Council (NRC)** of the National Academies took inspiration from some of the above documents to formalize the first set of National Science Education Standards (NSES), with guidelines for how to teach science inquiry. Although the NSES were used as a guiding document for many states, most states still retained their own standards. The Framework for K-12 Science Education was an attempt to more closely describe the practices of inquiry, while more explicitly mapping the interconnections between the sciences.

- National Science Education Standards (National Academies, 1996)
- Inquiry and the National Science Education Standards (National Academies, 2000)
- A Framework for K-12 Science Education (National Academies, 2012)

General Resources

To facilitate the implementation of the NGSS in classrooms, the National Academies continue to support the publication of a variety of guides, such as those below:

- Developing Assessments for the Next Generation Science Standards (National Academies, 2014)
- Literacy for Science: Exploring the Intersection of the Next Generation Science Standards and Common Core for ELA Standards - a Workshop Summary (National Academies, 2014)
- A Guide to Implementing the Next Generation Science Standards (National Academies, 2015)

Physics Education Resources

AAPT's ComPADRE supports implementation of the NGSS through the creation of curated collections of resources aligned with NGSS. Visit http://www.aapt.org/k12 to learn more.

AAPT's Role in the NGSS

The AAPT aims to support all teachers of physics, regardless of adoption of the NGSS. The AAPT works to make curricular and instructional resources available to its members and to the general public through online sharing as well as through face-to-face professional gatherings, including annual conferences, workshops, and institutes.

Please visit aapt.org to learn more.

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