United States next generation science standards: impact on education and useable guide

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The Next Generation Science Standards is the latest iteration of a set of standards that go back several decades to the beginning of the 1970's in the United States. In 1994, the original standards were written in response to a generally perceived lack of rigor in American education, especially in the performance of students in science. In 2010, a draft Framework for K-12 Next Generation Science Education, was produced by the National Research Council and the final version was made available in 2012. In order to provide both practicing and pre-service science teachers with a more useable guide of the standards, a quick check chart was developed. In addition, a comparison and contrast of the 1994 and the new 2012 standards was done and provided in chart form.

Science, standards, engineering, teachers, inquiry, framework

Background

The Next Generation Science Standards is the latest iteration of a set of standards that go back several decades to the beginning of the 1970's in the United States. The original standards were written in response to a generally perceived lack of rigor in American education, especially in the performance of students in science. The response challenged science and mathematics educators in our public schools to develop more rigorous methods in order to achieve and maintain a position of leadership among the nations of the world.

In 1989, the National Governor's Association endorsed the development of national educational goals designed to specifically outline the goals and methods for producing a generation of students capable of demonstrating understanding of the methods as well as the content of science and mathematics. In 1989, the first set of standards in mathematics was written by the National Council for the Teaching of Mathematics. These standards had a significant impact on the teaching of mathematics at all levels of schooling. Also in 1989, the American Association for the Advancement of Science (AAAS) put forth their publication *Project 2061: Science for All Americans.* This program focused on science literacy for all. The American Association for the Advancement of Science summed up the publication by stating that "A fundamental premise of Project 2061 is that the schools do not need to be asked to teach more and more content, but rather focus on what is essential to scientific literacy and to teach it more effectively (AAAS, 1989)." The report made recommendations to: "(a) reduce the amount of material covered; (b) weaken the subject matter boundaries; (c) heighten the connections between science, mathematics, and technology; (d) present the scientific endeavor as a social enterprise; and (e) foster scientific ways of thinking" (Bazler, Charles 1992). The National Science Teachers Association followed with publishing *Scope, Sequence and Coordination* suggesting eliminating the words biology, physics, and chemistry and instead suggesting that students take a integrated science in each year with each class decreasing biology and increasing chemistry and physics during the four years of high school. Many schools in the United States responded by creating courses in unified science that followed this model. These science curricula were not separated by content but were designed to integrate all science content as needed in developing concepts and methods. The premise behind their idea was that physics should be taught later due to its abstract nature and that all students need to take physics. '

Even earlier than this, professional groups like the American Chemical Society, Biological Sciences Curriculum Study, and Harvard Project Physics produced various creative, innovative science curricula. These projects were heavily funded by the National Science Foundation and were developed by university professors as well as teachers in the field. Along with this funding came significant programs throughout the universities in the United States to retrain teachers in methods of teaching science in our schools. This science curriculum reform was aimed at children from Kindergarten through Grade 12.

In 1991, with the encouragement of the National Science Teachers Association, the American Association for the Advancement of Science and the National Academy of Sciences, with funding from the National Science Foundation, the National Research Council of the National Academies ultimately developed a set of national science standards that were finally published in 1994. The standards were composed of eight areas with relevant sub groupings listed below:

Science as inquiry

- understanding of scientific concepts
- appreciation of "how we know" what we know in science
- understanding the nature of science
- skills necessary to become independent inquirers about the natural world
- Dispositions needed to use the skills, abilities and attitudes associated with science. standards
- Physical Science

Life Science

Earth and Space Science

Science and Technology

- Science in Personal and Social Perspectives
- History and Nature of Science

Unifying Concepts and Processes.

- Systems Order and organization
- Evidence
- Models and explanations - change constancy and measurement
- Evolution and equilibrium
- form and function

Most states used these standards to develop their own Core Curricular Science Standards which are currently being used today. And so with so many voices speaking in concert about the need for science literacy in our school population, the Next Generation Standards/Framework were produced.

The Framework

A draft Framework for K-12 Next Generation Science Education, was produced by the National Research Council, with the help of eighteen science experts drawn from all disciplines. It was published in 2010. In 2012, the National Research Center announced the final version of the Next Generation Science Standards (NGSS). This final version concentrated on three dimensions of science curricula. These three dimensions included:

Dimension I-Scientific and Engineering Practices

Dimension II-Crosscutting Concepts

Dimension III-Disciplinary Core Ideas (Physical Sciences, Life Sciences, Earth and Space Sciences, Engineering, Technology and Application)

Each of the Dimensions was then subdivided into Core Ideas/ Practices/ Concepts and finally subdivided again into topics and specific outcomes in specific grades. In 2013, input from all concerned was solicited and resulted in the final version of the Next Generation Science Standards published in 2013. These standards and their impact on science education complete with a shortened useable chart are the subject of this paper.

In order to compare the former science standards with the Next Generation Standards, a group of science educators reviewed these standards in order to shorten the three hundred and ninety four (394) page document into a reasonable chart format for ease of access by science educators and to allow educators to visually compare the old standards with the new. This shortened tabulated format shows the relationship between content and concepts and illustrates how restructuring the curriculum could be accomplished to conform to the Next Generation Standards. The following procedure was used to develop a useable chart which the authors have dubbed a *Quick Check Chart for High School Science*.

Method

In order to provide both practicing and pre-service science teachers with a useable, quick check chart for use when reviewing curriculum, the following procedure was used. The first step was to isolate all high school science outcomes for all three Dimensions and place into one document. Then, since the outcomes were in paragraph form, all outcomes were subdivided and identified with bullets. Each bulleted outcome was shortened while maintaining the integrity of the expressed ideas. A similar table was found for the former science standards which is listed in Table 1 (Appendix).

A chart was then designed for the new NGSS so that a quick comparison between the old and the new could be made and the new quick check chart could then be used to revise curriculum. Table 2 (Appendix) is the complete quick check chart for high school science. Colleagues in high school and colleges were asked to review the shortened, interpreted outcomes for accuracy and completeness.

Discussion

Comparing the 9-12 science content goals as indicated in Table 3 (Appendix), the obvious difference between the former science standards of 1994 and the NGSS 2013 is the absence of the word "engineering" in the past. Notably, there is also no mention of waves and their application in technologies for information transfer in the former standards. There are subtle changes of moving goals from content topics to other content topics or from dimension to different topic. For instance, life science now includes ecosystems: Interactions, energy and dynamics which was addressed more in personal and social perspectives in the older standards.

Another major addition is found in Dimension I that focuses on specifics about engineering and scientific investigations where the former standards are limited to evidence, models, and measurement, abilities to do scientific inquiry/technological design, and understanding of scientific inquiry/science and technology. The NGSS now uses specific words like planning, analyzing, interpreting, constructing, engaging, and evaluating in the outcomes. Another addition to the NGSS lacking in the former standards is found in Dimension III that focuses on engineering design and the links between engineering, design and society. Also, another major difference between the former science standards and the NGSS is the development of specific science outcomes for each grade level grouping. Using the quick-check chart found in Table 2, the NGSS now includes specific outcomes with the general goals found in the former standards. Dimension I specifically outlines the processes that need to be stressed, the dilemmas that need to be resolved, and the formulations that need to be designed by all students. The specificities of the scientific/engineering process in this dimension is extensive and complete beginning at the developmental stage, surging through the planning and implementation focusing on processing and interpreting the data, and finally, including the defense, argument and communication of the results. Dimension II again focuses on the research design and explanation of the system including reviewing patterns, cause and effect, application of mathematics and identifying assumptions which includes limitations and reliability analysis. This dimension also includes a focus on energy and matter, energy flow cycles and conservation, structure and function and historical explanations of things. Dimension III is divided into four idea areas and also provides sub topics with precise outcomes for each topic. New to the physical science area is the addition of wave properties, electromagnetic radiation, and information technologies and instrumentation. Added to the life science area is an emphasis on ecosystems: interactions, energy and dynamics. The earth science area now includes the role of weather and climate as well as biogeology. Also added to this area is an emphasis on earth and human activity. The last area of engineering, technology, and application focuses on engineering design with understanding constraints, problem solving and optimization which is missing in the former standards. Also new in this area is the linking of engineering, technology and society.

In former *Benchmarks,* a major section about doing science was called “science as inquiry.” The NGSS now addresses science practices in Dimension 1. NGSS uses specific word phrases like asking questions and defining problems, developing and using models, and engaging in argument from evidence in the outcomes for understanding science practices. Former versions of standards focused on notions of inquiry within the sciences such as abilities to do scientific inquiry.

Conclusion

The NGSS are now formally published and beginning to be implemented in the majority of states. This Quick Check Chart itemizes the outcomes for 9-12 high school science in the United States. The chart could be used in workshops comparing the old standards to the new outcomes. In addition, a teacher could review curriculum in order to determine if changes are necessary in order to adjust the curriculum to the new standards. Pre-service teachers of high school science could use the chart in order to add these new standards to their lesson plans. It is evident that The NGSS has made a number of notable changes including but not limited to the recognition of engineering and mathematics as partners in research. This chart was designed to aid all educators of science in their processes of updating their curriculum.

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Appendices

Table 1: Former 1994 Science CONTENT STANDARDS, GRADES 9-12 (NSES, page 111)

UNIFYING CONCEPTS AND PROCESSES	SCIENCE AS INQUIRY	PHYSICAL SCIENCE	LIFE SCIENCE	EARTH AND SPACE SCIENCE	Science and Technology	Science in Social and Personal Perspectives	History and Nature of Science
Systems, order, and organization	Abilities necessary to do scientific inquiry	Structure of atoms	The cell	Energy in the earth system	Abilities of Technological Change	Personal and Community health	Science as a human endeavor
Evidence, models, and explanation	Understandings about scientific inquiry	Structure and properties of matter	Molecular basis of heredity	Geochemical cycles	Understandings about science and technology	Population growth	Nature of scientific knowledge
Change, constancy, and measurement		Chemical reactions	Biological evolution	Origin and evolution of the earth systems		Natural Resources	Historical perspectives
Evolution and equilibrium		Motions and forces	Interdependence of organisms			Environmental Quality	
Form and function		Conservation of energy and increase in disorder Interactions of energy and matter	Matter, energy, and organization in living systems Behavior of organisms			Nature and human induced hazards	

Table 2 Quick Check Chart; High School Science

Dimension	***General Practices/Concepts/Core Ideas***	***Core Ideas/Practices/ Concepts***	***Topics***	***Outcomes by grade 12***		
Dimension I	**Scientific and Engineering Practices**	**I) Asking Questions and defining problems**		**-ask questions about the natural and human-built worlds** **-distinguish a scientific question from a non scientific one**	**-Formulate, refine questions and use them in inquiry or solution** **-ask, refine probing questions, challenge the interpretation of data**	**-note features, patterns, or contradictions in observations** **-ask questions, define constraints and specifications for a solution**
		2)Developing and using models		**-construct drawings or diagrams as representations of events or systems**	**-discuss the limitations and precision of a model and suggest ways to improve**	**-use computer simulations** **-make and use a model to test a design**

				-represent and explain phenomena with multiple types of models	**-refine a model**	
		3)Planning and carrying out investigations		**-formulate a question** **-decide what data, tools, and measurement are to be gathered**	**-decide how much data are needed** **-plan experimental or field-research procedures**	**-consider possible confounding variables or effects**
		4)Analyzing and interpreting data		**-analyze data systematically**	**-recognize when data are in conflict and consider revisions**	
		5)Using mathematics and computational thinking		**-recognize dimensional quantities and use mathematical formulas and graphs**	**-express relationships and quantities in appropriate mathematical or algorithmic forms**	

		6)Constructing explanations and designing solutions		**-construct explanations of phenomena** **-use primary or secondary scientific evidence and models**	**-offer causal explanations** **-identify gaps or weaknesses in explanatory accounts** **-solve design problems**	**-undertake design projects** **-construct a device or implement a design solution** **-evaluate and critique competing design solutions**
		7)Engaging in argument from evidence		**-construct a scientific argument** **-identify possible weaknesses in argument**	**-identify flaws in own arguments and modify** **-recognize the major features in scientific arguments** **-explain the nature of the controversy**	**-articulate the merits and limitations of peer review and critical replication** **-read media reports of science or technology critically**
		8)Obtaining, evaluating, and		**-use words, tables, diagrams, graphs and**	**-recognize the major features of scientific/engine**	**-engage in critical reading of primary**

		communicating information		**mathematical expressions** **-read scientific and engineering text**	**ering writing and produce written and illustrated text or oral presentations**	**scientific literature**
Dimension II	**Crosscutting Concepts**	**1)Patterns**		**-patterns observed at each scale of a system**	**-classifications used at one scale may fail and need revision**	
		2)Cause and effect: Mechanism and explanation		**-explanation of cause and effect explain causal mechanisms in systems**	**-strategies include arguments from evidence**	
		3)Scale, proportion, and quantity		**-application of math to examine scientific data used to make predictions**	**-advanced math and statistics used to interpret data**	
		4)Systems and system models		**-identify assumptions and discuss**	**-discussion of interactions within a system**	**-modeling development reveal problems or progress in**

				limits and reliability		**conceptions of system**
		5)Energy and matter: Flows, cycles, and conservation		**-nuclear substructure and related conservation laws for nuclear processes**		
		6)Structure and function		**-recognize how a system works by examining its parts**	**-building requires structure and function**	
		7)Stability and change		**-construct historical explanations of how things evolved**	**-model complex systems**	
Dimension III	**Disciplinary Core Ideas/Physical Science**	**PS1:Matter and its interactions**	**PS1.A:Structure and properties of matter**	**-structure of an atom** **-periodic table**	**-effects of electrons** **-stable forms of matter**	**-stable molecules have less energy**
			PS1.B:Chemical Reactions	**-molecules, bonding, and energy**	**-stoichiometry** **-chemical reactions**	**-chemical processes related to**

						biology and geophysics
			PS1.C:Nuclear processes	**-nuclear processes** **-number of neutrons and protons**	**-nuclear stability and processes** **-radioactive decay law**	**-radiometric dating** **-death of stars** **-supernova processes**
		PS2:Motion and stability: forces and interactions	**PS2.A:Forces and motion**	**Newton's second law** **-momentum**	**-conservation of matter**	**-law of conservation of matter**
			PS2.B:Types of interactions	**-newton and coulomb's laws** **-explanation of forces**	**-difference between magnetic and electrical fields**	**-strong and weak nuclear interactions**
			PS2.C:Stability and instability in physical science	**-systems change in predictable ways**	**-prediction of system decreases with more components**	**-predictions of systems average** **-systems may evolve in unpredictable ways**

		PS3:Energy	**PS3.A:Definitions of energy**	**-energy depends on motion and interactions of matter and radiation** **-total energy conserved**	**-energy manifests itself in multiple ways** **-mechanical energy refers to motion and stored energy**	**-definition of chemical and electrical energy**
			PS3.B:Conservation of energy and energy transfer	**-conservation of energy** **-laws of energy**	**-mathematical expressions of energy** **-energy limits**	**-energy distribution** **-energy unstability**
			PS3.C:Relatinship between energy and forces	**-force fields contain and transmit energy**	**-energy storage**	**-energy of force interactions**
			PS3:D:Energy in chemical processes and everyday life	**-nuclear fusion and radiation** **-solar energy and photosynthesis**	**-energy of cells** **-electricity costs and benefits** **-inefficient machines produce waste**	**-conversion of energy** **-machines and energy** **-design for high efficiency**

		PS4:Waves and their applications in technologies for information transfer	**PS4.A:Wave properties**	**-wavelength and frequency of a wave related to speed of travel**	**-reflection, refraction and transmission of waves**	**-combining waves at different frequencies** **-information can be digitized**
			PS4.B:Electromagnetic radiation	**-electromagnetic radiation** **-wave model**	**-quantum theory**	**-visible light cannot be used to see such objects as individual**
			PS4.C:Information technologies and instrumentation	**-multiple technologies based on the understanding of waves**	**-tools for producing, transmitting, and capturing signals and for storage**	**-quantum physics used to develop semiconductors, computer chips, and lasers**
	Disciplinary Core Ideas/Life Science	**LS1:From Molecules to Organisms: Structure and Processes**	**LS1.A:Structure and Function**	**-molecules of life** **-all cells have DNA**	**-transcriptions and translation** **-biological levels of organization**	**-homeostasis** **-positive and negative feedback**

			LS1.B:Growth and Development of organisms	**-cell cycle** **-mitosis**	**-differentiation** **-necessity of cell division**	**-meiosis**
			LS1.C:Organization for matter and energy flow in organisms	**-equation of photosynthesis** **-formation of organic molecules** **-atoms are rearranged**	**-energy transfer** **-cellular respiration aerobic** **-cellular respiration anaerobic**	**-thermal regulation** **-energy and matter are constant**
			LS1.D:Information processing	**-brain regions and functions of each**	**-emotions of species**	**-negative effects of brain trauma**
		LS2:Ecosystems: Interactions, energy, and dynamics	**LS2.A:Interdependent relationships in ecosystems**	**-carrying capacities of ecosystems**	**-resource limit population size**	
			LS2.B:Cycles of Matter and energy transfer in ecosystems	**-energy source reactions** **-base of food web**	**-pyramid of energy and numbers** **-recombination of elements**	**-change of matter** **-competition for matter**

						-carbon cycle
			LS2.C:Ecosystem dynamics, functioning, and resilience	**-interactions effect biodiversity**	**-ecosystem resilience**	**-human impact on biosphere**
			LS2.D:Social interactions and group behavior	**-negative impact of social isolation**	**-group affiliation in social animals**	**-group behavior increases fitness**
		LS3:Heredity: Inheritance and variation of traits	**LS3.A:Inheritance of traits**	**-chromosomes carry genetic information** **-chromosome composition**	**-organism development dependent on DNA**	**-cell dependent gene expression** **-functions of DNA**
			LS3.B:Variation of traits	**-DNA given from parent to offspring** **-crossing-over of chromosomes**	**-mutation yield genetic variations** **-causes of mutations**	**-genetic and environmental factors effect traits**

		LS4:Biological evolution: Unity and diversity	**LS4.A:Evidence of common ancestry and diversity**	**-fossil records support evolution**	**-molecular similarities between species**	
			LS4.B:Natural selection	**-natural selection dependent upon variation**	**-accumulation over-time of favorable traits**	**-**
			LS4.C:Adaptation	**-factors of natural selection** **-adaptation increases fitness**	**-fitness** **-adaptations are plastic**	**-population size linked with physical environment** **-survival of fittest**
			LS4.D:Biodiversity and humans	**-fluctuation of biodiversity** **-extinction reduces natural capitol**	**-human impact on biodiversity** **-human induced extinction**	**-preserving biodiversity** **-aesthetic value of biodiversity**
	Disciplinary Core Ideas/Earth and Space Science	**ESS1:Earth's place in the universe**	**ESS1.A:The universe and its stars**	**-sun is changing and will burn out** **-sun is one of 200 billion stars**	**-study of stars used to identify compositional elements of stars**	

				in Milky way galaxy		
			ESS1.B:Earth and the solar system	**-Kepler's laws**	**-orbits changes**	**-cyclical changes in the shape of earth's orbit effects**
			ESS1.C:The history of planet earth	**-radioactive decay and isotopic content in rocks use**	**-age of continental rocks** **-tectonic processes and geological processes and erosion**	**-objects in solar system provide information about earth's formation**
		ESS2:Earth's systems	**ESS2.A:Earth materials and systems**	**-earth's systems cause feedback effects** **-feedback information lacking**	**-model of earth and evidence for the model** **-earth's inner cores and mantle and crust**	**-geological record**
			ESS2.B:Plate tectonics and large-scale	**-radioactive decay of unstable**	**-plate tectonics expresses**	

			system interactions	**isotopes generates energy**	**mantle convection**	
			ESS2.C:The roles of water in earth's surface processes	**-liquid water of earth central to planet's dynamics**	**-properties of water effects on planet**	
			ESS2.D:Weather and climate	**-earth's global climate system and sun**	**-climate change** **-time scale of climate change**	**-effects of humans on climate**
			ESS2.E:Biogelogy	**-effects of feedbacks between biosphere and other earth systems**		
		ESS3:Earth and human activity	**ESS3.A:Natural Resources**	**-resource availability guided human society**	**-effects of energy production**	**-effects of technologies and regulations**
			ESS3.B:Natural hazards	**-effects of natural hazards, geological**	**-effects on sizes of human**	**-natural hazards**

				events on history	**populations and migrations**	**-human activities affects on hazards**
			ESS3.C:Human impacts on earth systems	**-sustainability and management of natural resources**	**-how scientists and engineers affect natural resources**	**-understanding environmental problems**
			ESS3:D:Global climate change	**-global climate models**	**-how humans model, predict, and manage**	**-computer simulations** **-science and engineering impacts**
	Disciplinary Core Ideas/Engineering, Technology, and Application	**ETS1:Engineering Design**	**ETS1.A:Defining and Delimiting an engineering problem**	**-design criteria and constraints** **-include requirements set by society**	**-global challenges**	**-define problem, specify criteria and constraints for potential solutions**
			ETS1.B:Developing possible solution	**-problems broken down into simpler components** **-solutions include cost,**	**-testing should lead to improvements** **-physical models and**	**-prototypes used to test ideas or materials. Computers can be used**

				safety, reliability, aesthetics, and all impacts	**computers can be used**	
			ETS1.C:Optimizing the design solution	**-engineering use is to find and design a solution** **-optimization can be complex**	**-criteria needs to be broken into steps** **-trade-off matrix useful in design**	**-evaluate a design against multiple criteria** **-testing should lead to design improvements**
		ETS2:Links among engineering, technology, science, and society	**ETS2.A:Interdependence of science, engineering, and technology**	**-research and development R&D is science and engineering working together**		
			ETS2.B:Influence of engineering, technology, and science on society and the natural world	**-modern civilization depends on technology** **-engineers modify technology using science**	**-technology dependent on society and market** **-new technology affects society**	**-technology use dependent on cost, environmental impacts, risks and benefits**

Table 3 shows the possible impact on science curricula.

Table 3 Comparison of the old Standards with the Next Generation Standards; Outstanding Differences

Item	**Former Benchmarks**	**Next Generation**	**Impact**
Technology	Science and Technology	Dimensions I and III	Stressed in NGSS
Processes	Unifying Concepts and Processes/Science as Inquiry	Dimension I and II	Specific research/engineering processes not addressed in Benchmarks
Content	Physical Science	Dimension III physical science	NGSS includes waves and application in technology
	Life Science	Dimension III life science	Benchmarks missing ecosystems and interaction of energy and dynamics
	Earth and Space Science	Dimension III Earth and Space Science	Benchmarks do not include climate, biogeology, and environmental
	Social and personal perspectives and history and nature of science	Engineering, Technology, and Application	Benchmarks include more specifics in human affects