Statement of Competencies in the Natural Sciences Expected of Entering Freshmen

ADOPTED SPRING 2016

INTERSEGMENTAL COMMITTEE OF THE ACADEMIC SENATES OF THE CALIFORNIA COMMUNITY COLLEGES
THE CALIFORNIA STATE UNIVERSITY, AND THE UNIVERSITY OF CALIFORNIA

STATEMENT OF COMPETENCIES IN THE NATURAL SCIENCES EXPECTED OF ENTERING FRESHMEN

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Intersegmental Committee of The Academic Senates of The California Community Colleges
The California State University, and The University of California

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ICAS

Academic Senate
for California Community Colleges

INTERSEGMENTAL COMMITTEE OF ACADEMIC SENATES

February 17, 2016

Dear Colleagues:

We are pleased to transmit to you the 2015 Statement on Competencies in the Natural Sciences Expected of Entering Freshmen. This document is the result of collaboration among college and university science faculty to address the changes in high school science education as a result of the revised California Science Standards adopted by the California Department of Education in September 2013. It replaces the previous competency statement produced in 1986. The document is structured around concepts that are common to all scientific disciplines to allow students to explore similar ideas from different perspectives.

The Intersegmental Committee of Academic Senates (ICAS), representing the academic senates of the three segments of California's higher education system, sponsored the efforts that produced this document. The Academic Senates of the California Community Colleges, the California State University, and the University of California all have endorsed this document and offer it as their official recommendation on preparation in the natural sciences to the K-12 sector, to students and their parents, to teachers and administrators, and to public policy makers.

Please share this statement with your colleagues, distribute it widely, or refer interested parties to the ICAS website to download the document: http://icas-ca.org/.

Sincerely,

David W. Morse

J. Daniel Hare

David Morse, President	Steven Filing, Chair	J. Daniel Hare, Chair
CCC Academic Senate	CSU Academic Senate	UC Academic Senate

INTRODUCTION

In 2013, California adopted revised standards for education in the natural sciences based on the **Next Generation Science Standards (NGSS)**. These new standards were designed to move away from an exhaustive list of content toward a greater focus on outcomes that would indicate a deeper understanding of underlying scientific phenomena. This **Statement of Competencies in the Natural Sciences Expected of Entering Freshmen** is intended to update the 1988 **Statement on Natural Science Expected of Entering Freshmen** in order to reflect this shift in science education in California. The Intersegmental Committee of Academic Senates (ICAS) appointed faculty from the California Community Colleges, California State University, and the University of California to a task force charged with updating the previous statement to reflect current practices in science education.

California only requires students to complete two years of science while in high school. With that fact in mind, the task force spent significant time considering the creation of two sets of expectations, one for those students planning to pursue a degree in science, technology, engineering, or mathematics (STEM) and one for students planning to pursue other degree options. Instead, ICAS encourages high schools to emphasize the value of taking more science courses. More extensive education in science will help students build important skills like analytic problem solving, organization, teamwork, and study skills and will not limit the possible majors available when students are applying for admission.

This document consists of two distinct sections. The first section describes the benefits of scientific literacy beyond understanding the individual scientific discipline, the incorporation and exploration of engineering practices within scientific disciplines, the importance of technology with an emphasis on the skills developed during science courses, and a description of several common elements that are woven through all scientific disciplines. The second section is divided into four scientific disciplines, with each discipline providing a summary of performance expectations and examples of how each of the common elements relate to those disciplines. The four disciplines are as follows:

- **Chemistry**
- **Earth & Space Sciences**
- **Life Sciences**
- **Physics**

This document does not make any recommendations regarding the way high schools should structure their science courses. Each school serves a unique student population, has different resources, and should create a course structure that maximizes those resources in serving its students. Every student graduating from high school that plans to attend a college or university is expected to achieve all of the performance expectations outlined in NGSS and this document.

Research from American College Testing (ACT) shows that students are more prepared for college when they take more science courses. ACT found that 13% of students taking less than three years of high school science are prepared on the ACT Readiness Benchmark in Science. Forty-five percent of students taking a course in biology, chemistry, or physics were found to be prepared (ACT, 2006). Harvard tells hopeful applicants, "The natural sciences help to explain, to predict, and sometimes to control, the processes responsible for phenomena that we observe. They constitute a large and growing portion of human knowledge important to everyone. Even if you have no intention of becoming a scientist, an engineer, or a physician, you should study science throughout secondary school" (Donaldson, 2013). The University of California A-G subject requirements strongly encourage students to take three years of a laboratory science. Ultimately, the number of years that a student spends taking science courses will depend on the structure of the high school's curriculum, but taking more science has clear benefits for all students.

To ensure that all entering freshman are prepared to complete their degrees in a minimum number of units, this document is based upon the following recommendation:

For proper preparation for baccalaureate level course work, all students should be enrolled in a science course in each year of high school. All students benefit from the knowledge acquired and skills developed through completion of additional science courses. These skills will be invaluable in assisting students with the completion of their degrees, no matter what major they choose.

Many students may consider taking an Advanced Placement (AP) science course while in high school. AP courses can help students build upon skills gained in previous science courses, but taking a second course in one discipline should not replace a course in another. Students should be encouraged to take AP science courses only if they do not conflict with the completion of all of the performance expectations listed in NGSS.

SECTION 1

Humans are extremely curious. A child's natural curiosity is the same curiosity that has driven many scientists to dedicate their lives to looking for answers to the questions of how everything in nature has come to be. When young students first come to school and are exposed to the wonders of science, they are amazed by possibilities. Science teachers see that excitement every day from students. As the children's understanding of the universe grows, so does their desire to explore other aspects of the world. Science education is an opportunity to help students explore their natural curiosity and build skills that will allow them to become productive members of society that critically analyze situations and determine the best course of action.

When young children are exposed to scientific experiments, they are instantly fascinated and want to learn more. Bombarding students with an endless collection of facts they are expected to memorize can diminish the sense of wonder that students have during a demonstration or experiment. While covering facts cannot be eliminated, educators hope to give our students more than just answers to trivia questions. We want students to be able to collect information, assess the validity of that information, determine which facts are pertinent to a problem, and try to formulate a solution. We want them to develop skills that will be useful in their education and their careers.

The Next Generation Science Standards (NGSS) were designed to focus on what students should be able to do instead of a list of things that students should know. NGSS was created through broad collaboration between K-12 teachers, university professors, and practicing scientists. These new standards are designed to help students develop the skills that scientists and engineers use every day. The new standards outline performance expectations in the following areas:

- Physical Sciences
- Life Science
- Earth and Space Sciences
- Engineering, Technology, and Applications of Science

ENGINEERING

The inclusion of engineering in NGSS might seem strange, since few high schools have the necessary resources to offer engineering courses to students; however, science courses also introduce many of the skills that are used by engineers. Engineering focuses on the analysis of a particular situation or problem and determining what solutions might be possible. Engineering solutions often include improving existing technology or creating something that has never existed. Engineering requires the ability to break down complex problems into more manageable pieces and the ability to apply classroom knowledge to verify a hypothesis. To accomplish such outcomes, engineering majors take a collection of specific courses that apply to a specialized field of inquiry. For example, engineering majors might be exposed to techniques that can be applied to a particular field like circuit design, designing a jet engine, or creating the next miracle drug. These specialized courses are not appropriate for high school students, but science courses introduce students to many of the skills necessary to be a successful engineer.

The design of complex systems like a fighter jet or a smartphone might appear to be an impossible task, but engineers understand that massive projects like these are really hundreds of smaller, more manageable pieces that will be combined to create the full solution. Engineering involves looking at a complex problem, breaking that problem into different pieces, and bringing all of those pieces back together to complete the project. This skill is not limited to engineering; it is used in mathematics, the natural sciences, the social sciences, and the humanities. Real world problems often involve many different scientific phenomena combining together to form a single system. Students will learn how the individual pieces come together to build more complex problems. Once students are exposed to the ways smaller problems combine to form a more complex system, they will be more prepared to analyze real world problems and break them into more manageable pieces.

Science courses include the opportunity for students to verify hypotheses through various laboratory experiments. Laboratory work is essential to students in science and engineering, but such work helps students build teamwork skills that are valuable in any field of study. Laboratory experiments will force students to follow instructions, learn to use various types of scientific equipment, reach consensus on how to approach an assigned task, divide tasks among the group members, collect and analyze data, and agree on whether the goals of the experiment have been achieved. As students gain more experience in a laboratory environment, they will learn to create their own experiments to verify a stated hypothesis. Students are often presented with "facts" that they need to assess the validity of. Whether they use a laboratory experiment or do other research into the facts, the ability to test the validity of assumptions is essential for any entering freshman.

TECHNOLOGY

Technology has become an integral part of everyday life, and the types of technology are constantly changing. Students have been exposed to technology since birth and will continue to use different types of technology throughout their lives. For students to be successful in the classroom and the workforce, they must have the ability to adapt and use new technologies as they are developed. Technology is not limited to the natural sciences, but science courses provide students with an opportunity to work with a variety of different technologies that they may have no experience with.

Technology has been an integral part of science from its beginnings. Technology provides scientists with the ability to measure, and measurements form the basis for any scientific experiment. Measurement devices have continued to evolve and become more precise. While this improved technology provides more accurate results and opens the door to new experiments, the technology is often more complicated than it was previously. In the past, students might have measured the time for a car to travel a given distance using a stopwatch. Later, they were able to use timers with infrared sensors that automatically record the time as the car finishes the trip. While the infrared timer is more accurate, it requires students to work with technology that is more complicated to set up and they may have no prior experience with. Through different laboratory experiments, students will gain exposure to a wide range of technology and will be expected to use that technology immediately. Students will develop the ability to adapt to different types of technology and use it in any situation.

Measurement is at the heart of all of the natural sciences, and technology makes these measurements possible. The instrumentation and tools available inform the character, quantity, and quality of evidence, which in turn informs scientific understandings. As technology advances and computational capacity increases, the ability of scientists to address more complex problems increases. Different technologies are used by each discipline, but each different type of technology gives students additional opportunities to improve their skill.

Ultimately, students need exposure to modern measurement techniques; however, the ability to adapt to new technologies is paramount. Therefore, science education should emphasize an understanding of how to acquire new information and to troubleshoot different types of technology. These skills will help students adapt to various types of technology that they will use throughout the rest of their education and during their careers.

SCIENTIFIC DISCIPLINES AND CROSSCUTTING CONCEPTS

Science instruction is typically broken up into disciplines like biology, chemistry, and physics. This structure might give the impression that scientific disciplines are not related, but the NGSS includes crosscutting concepts that illustrate the connections that exist between different scientific disciplines. Mastery of these concepts helps students view the sciences as a unified field of study and helps them develop an understanding of looking at the same idea from different perspectives. Many ideas have several different facets, and students need to develop the skills to meld those different facets together to complete their understanding of each concept. The skills developed through the mastery of the crosscutting concepts will help students succeed in any environment that requires them to assimilate differing perspectives to reach evidence based conclusions.

Scientific instruction assists students with the development and strengthening of skills that they will use throughout their studies. All science courses require students to apply skills that they acquired in math courses, such as graphing, error analysis, finding solutions to algebraic equations, and extracting pertinent information from word problems.

Science courses are often the first time that students see that the concepts they learned in math classes will be applied in other areas. Students also continue to develop and enhance skills that can be used throughout their high school and university studies. These skills include improved study habits, the ability to read and extract information from technical textbooks, and organizational skills from problem solving to managing a heavy course load. These skills are not exclusive to science courses, but all of them will help students complete their baccalaureate degrees.

This revised competency statement summarizes the performance expectations, crosscutting concepts, and technological integration for the four scientific disciplines. With the adoption of the California Science Standards, students are expected to complete all of the expectations included in NGSS. These performance expectations are listed at the end of this document. While the California Science Standards are broken up into four disciplines, life science, earth and space sciences, physical sciences, and engineering technology, Section 2 of this document is divided into four scientific disciplines:

- Chemistry
- Earth and Space Sciences
- Life Science
- Physics

These disciplines were chosen over the four listed in the California Science Standards because many high schools already have courses in these areas and it is too soon to know how high schools might modify their curriculum to address the new engineering expectations. As previously indicated in this section, integrating engineering concepts into existing science courses appears to be the most likely means of implementation.

Each one of these scientific disciplines includes a summary of the performance expectations and a set of nine crosscutting concepts that are common to all scientific and engineering disciplines. The nine crosscutting concepts included for each discipline area are as follows:

- Uncertainty and weighing evidence
- Systems and system modeling
- Structure and function
- Stability and change
- Energy and matter
- Scale and proportionality
- Synthesis of information and how it contributes to the “big picture”
- Visualization of data
- Human and global impact

Completion of all of the performance expectations will require students to master the crosscutting concepts, develop problem-solving skills, and be able to adapt to various types of technology. These skills combined with the scientific knowledge gained will prepare students to be successful in any major.

SECTION 2

CHEMISTRY

Guiding Principles Leading to Performance Expectations

Students will develop an understanding of the common elements of the sciences as well as those pertaining to chemistry. Chemistry involves the identification of the substances that matter is composed of, the examination of their properties, and the way these properties can change or be manipulated to form new substances. Chemistry can be explored on four basic levels: organic, inorganic, analytical, and physical. This paper redefines and organizes nine common elements with special attention to the four basic levels of chemistry.

Examples have been divided into the basic levels of chemistry to adequately cover the breadth and depth of experience for high school students. These levels include the chemistry of carbon and its reactions and interactions (organic), descriptive chemistry of the main group and transition metal elements (inorganic), quantitative laboratory methods applied to main group and transition metal chemistry (analytical), and periodicity, atomic/molecular structure, and mathematical relationships of physical properties pertaining to various molecules and atoms (physical).

The California Science Standards include two standards in chemistry. These standards focus on 1) the structure and properties of atoms, molecules, and compounds including electrostatics forces and radioactive decay and 2) chemical reactions including the prediction of energy released or absorbed, products produced, and predicting the rate at which the reaction occurs.

Common elements of the sciences pertaining to chemistry	**Scope and application** **students should demonstrate the ability to**	**Specific examples – These represent topical examples at four chemistry levels. Not all examples are expected but serve to typify depth and breadth of the elements at four chemical levels.**
Uncertainty and weighing evidence	Distinguish scientific evidence from opinion and to determine credibility of various sources of information Identify reputable sources Differentiate between scientific information and political platforms or social beliefs	**Organic –** combustion of fossil fuels and the production of CO2 from human activities **Inorganic –** mercury and lead toxicity in oceanic and drinking water **Analytical –** laboratory practices for identifying and quantifying chemical reactions based on the scientific method **Physical –** the role of molecular properties in their manifestation as greenhouse gases
Systems and system modeling	Apply the periodic table to the description of atoms and molecules Differentiate chemical reactions based on periodicity and reactivity Use mathematical modeling in experimental investigations Use mathematical modeling in theoretical investigations	**Organic –** using molecular models to visualize organic molecules **Inorganic –** describing the observed oxidation states of main group elements and transition metals based on periodicity **Analytical –** Beer's Law analysis on the absorption of light by colored solutions **Physical –** ideal gas laws

Common elements of the sciences pertaining to chemistry	**Scope and application** **students should demonstrate the ability to**	**Specific examples – These represent topical examples at four chemistry levels. Not all examples are expected but serve to typify depth and breadth of the elements at four chemical levels.**
Structure and function	Characterize the relationship between structure and function Discuss how the arrangements of atoms leads to observed bulk scale crystal or lattice structures Discuss how the arrangements of atoms leads to different phases of matter	**Organic –** putting together larger structures of organic molecules based on simple structures such as methane or water **Inorganic –** extrapolating the molecular structure of salts/minerals from the atomic scale to the bulk scale (i.e. crystal/lattice structure) **Analytical –** measured observations of reactivity based on molecular structure **Physical –** the description of solids, liquids, and gases based on structural details of the arrangement of atoms
Stability and change	Describe a chemical reaction as a re-arrangement of atoms in a molecule Understand the role of structural stability or instability leading to a chemical reaction Demonstrate a general understanding of the time sequence of a chemical reactions (i.e. molecules must first collide before reacting)	**Organic –** reactions with carbon **Inorganic –** reactions with main group elements and transition metals (i.e. qualitative analysis) **Analytical –** using laboratory techniques to quantify the total change of a reaction (i.e. titrations) **Physical –** understanding rates of chemical reactions using the collision model

Common elements of the sciences pertaining to chemistry	Scope and application students should demonstrate the ability to	Specific examples – These represent topical examples at four chemistry levels. Not all examples are expected but serve to typify depth and breadth of the elements at four chemical levels.
Energy and matter	Demonstrate understanding that mass is conserved in chemical reactions Demonstrate understanding of heat, energy, and work and their conservation Understand a view of heat and work as processes that are direction specific (i.e. system vs. surroundings)	**Organic –** the notion of exothermic and endothermic reactions of carbon containing molecules **Inorganic –** the notion of exothermic and endothermic reactions of main group elements and transition metals **Analytical –** calorimetry experiments **Physical –** the laws of thermodynamics and conservation of mass
Scale and proportionality	Assess the magnitude and effect of size from the atomic scale and manifestations on the bulk scale Compare the size of atoms based on periodicity Compare the size of larger, biologically relevant molecules such as proteins to smaller molecules such as water	**Organic –** the size of proteins, DNA, etc. in relation to the size of a cell or larger biological entities **Inorganic –** lattice constants **Analytical –** solution concentrations, pH scale, equilibrium constants, etc. **Physical –** atomic and ionic trends in size

Common elements of the sciences pertaining to chemistry	**Scope and application** **students should demonstrate the ability to**	**Specific examples – These represent topical examples at four chemistry levels. Not all examples are expected but serve to typify depth and breadth of the elements at four chemical levels.**
Synthesis of information and how it contributes to the "big picture"	Debate topics dealing with ethics of chemistry, such as pharmaceuticals Analyze economic and sociopolitical situations Communicate science clearly	**Organic** – synthesis of pharmaceuticals using organic molecules **Inorganic** – synthesis of pharmaceuticals using main group and transition metal elements **Analytical** – cost of laboratory procedures, job market for chemists, etc. **Physical** – energy requirements for large scale production of pharmaceuticals
Visualization of data	Convert and display data collected into graphs and tables Comprehend and use tables and graphs to draw conclusions Interpret images of macroscopic and microscopic structure Employ mathematical modeling to solve problems	**Organic** – observe 3D images of organic molecules converted into data streams **Inorganic** – observe 3D images of inorganic molecules converted into data streams **Analytical** – converting experimental observations into graphs, tables, charts, etc. **Physical** – analyze experimental data with respect to fundamental laws and relationships

Common elements of the sciences pertaining to chemistry	Scope and application students should demonstrate the ability to	Specific examples – These represent topical examples at four chemistry levels. Not all examples are expected but serve to typify depth and breadth of the elements at four chemical levels.
Human and global impact	Develop confidence in formulating questions and providing supporting evidence Weigh costs and benefits of chemical interventions and solutions Demonstrate and understand probability in human and global applications Analyze and create solutions to long-term sustainability of life on earth	**Organic** – understanding the difference between "organic food" and pesticides being organic molecules **Inorganic** – metal contamination from industrial processes **Analytical** – conducting measurements on the global scale, such as ocean pH monitoring or atmospheric CO2 monitoring **Physical** – using fundamental relationships scaled up to predict global affects.

EARTH AND SPACE SCIENCES

Guiding Principles Leading to Performance Expectations

The fields of earth and space sciences were not included in the 1986 competency statement, and the multidisciplinary nature that characterizes these fields was underemphasized in that document. Public interest in earth science in particular has gained momentum through increasing concern about climate change, pollution, and the availability of natural resources. The study of earth and space sciences allows students the opportunity to integrate information and practices from physics, chemistry, and biology.

Earth and space science encompasses the study of earth and planetary systems, earth's place in the universe, and interactions between humans and earth systems. This area of study includes but is not limited to the subdisciplines of geology, astronomy, atmospheric science, oceanography, hydrology, and civil and environmental engineering. In the earth and space sciences, scientists investigate the formation and evolution of the earth, planets, stars, the solar system, galaxies, and the universe. Scientists examine the complex processes through which change occurs on varied temporal and spatial scales to elucidate the mechanisms that govern the systems' functioning and to predict outcomes to perturbations to these systems. Engineering related to earth and space sciences includes designing solutions to environmental problems and creation of technology to observe, explore, and analyze earth and space.

The California Science Standards include three standards in earth and space sciences. These focus on the following areas: 1) Earth's place in the universe, including Big Bang, formation of celestial bodies, and working of solar systems; 2) the components, interactions, and feedbacks in earth systems; and 3) connections between earth systems and human activities.

Common elements of the sciences pertaining to earth and space sciences	Scope and application students should demonstrate the ability to	Specific examples
Uncertainty and weighing evidence	Describe how small sample sizes can obscure causes and effects Demonstrate how unpredictable behaviors can create uncertainty in outcomes Distinguish scientific evidence from opinion and determine the credibility of various sources of information	Climate models produce projections of future climate with inherent uncertainty due to differences in how inputs, interactions, and feedbacks are quantified and the uncertainty in how possible contributory factors may change in the future. Records of Earth's past and models of Earth's structure are constructed based on proxies and other analytic techniques such as isotopic and elemental composition and seismic waves. Multiple approaches are used to decrease uncertainty in reconstructions
Systems and system modeling	Identify the main components of earth and space systems Predict interactions between components of earth and space systems, including feedbacks	Global climate models are used to simulate atmosphere-ocean interactions that affect potential changes in global temperature. Models of interactions between planetary bodies in the solar system are used to plot trajectories of objects in space, including space vehicles.

Common elements of the sciences pertaining to earth and space sciences	**Scope and application** **students should demonstrate the ability to**	**Specific examples**
Structure and function	Characterize geological and hydrological formations and their behavior over time Describe how energy is absorbed, reflected, and reemitted from the Earth and sun	Some areas are more susceptible to seismic activity due to their location on tectonic plates and their ground stability The large heat capacity of water allows the oceans to fluctuate less in temperature on diurnal and seasonal cycles and mitigate temperature change on longer timescales. Construction of large water projects such as dams on the Sacramento and American rivers change the deposition of silt in the Sacramento Delta, influencing diversion of freshwater to Southern California.
Stability and change	Describe long term changes including the expansion of the universe and orbital cycles Describe equilibrium and perturbed carbon and hydrologic cycling	Earth's position and distance in relation to the sun affects the intensity and distribution of radiation reaching the Earth, causing both seasonal changes and changes in climate on larger timescales. The equilibrium carbon cycle is currently being perturbed on short timescales by burning of fossil fuels and deforestation.
Energy and matter	Describe the transfer and conservation of energy, carbon, and water throughout earth systems Calculate the energy budget of earth system, including radiative forcings	Decay of radioactive isotopes in the Earth's mantle generates thermal energy, driving tectonic movement Movement and changes in the phase of water are connected to movement of energy and mass throughout the earth system.

Common elements of the sciences pertaining to Earth and space sciences	**Scope and application** **students should demonstrate the ability to**	**Specific examples**
Scale and proportionality	Describe the mechanisms that affect equilibrium across time-scales Identify different mechanisms present in an experiment and determine which mechanism is dominant Explain how small changes can have amplified effects while large changes may have negligible effects	Weather involves changes in meteorological parameters on short timescales, whereas climate involves averaged change over decadal or longer timescales. Geologic processes occur through rapid and slow processes such as erosion, volcanic eruptions, earthquakes, and seafloor spreading. Storms can form in a particular location due to subtle changes in conditions. Changes in temperature can cause feedbacks in sea ice extent and other ice surfaces that amplify or mitigate temperature changes, resulting in a seemingly disproportional response.
Synthesis of information and how it contributes to the “big picture”	Show how information from physics, chemistry, and biology integrate to explain complex systems.	Determining precipitation, like the drought in California, requires connecting many variables, including atmospheric water content, snowpack, and human activities. Integrating satellite measurements including radar, LIDAR, sea level, and images increase the reliability of weather predictions.
Visualization of data	Analyze data using time-series and spatial representations Model 3-dimensional systems using 2-dimensional descriptions.	Plots of atmospheric greenhouse gas concentrations allow for analysis of trends and patterns. Geographic Information Systems (GIS) is used to look at relationships between human activities, land cover, and topography.

Common elements of the sciences pertaining to Earth and space sciences	Scope and application students should demonstrate the ability to	Specific examples
Human and global impact	Describe the effects of mankind on environmental systems through pollution, land use change, resource extraction, and geochemical cycling	Land use policies such as deforestation influence the atmospheric chemical composition, energy balance, and rainfall patterns. Release of ozone depleting substances increases UV penetration in the atmosphere and affects cancer rates in some areas. Improved and sustainable agricultural practices can increase food production efficiency and decrease global hunger.

LIFE SCIENCE

Guiding Principles Leading to Performance Expectations

Students should have developed understanding of the common elements of the sciences pertaining to life science. Life science involves the study of living things and will be explored on three levels: population, organismal, and cellular/molecular.

Life science is a rapidly growing and expanding field. For example, since the previous paper, significant advancement has occurred in applications of recombinant DNA and other emerging technologies. Growing evidence also indicates the importance of microbial communities on our planet and in our bodies. Areas of novel and innovative development in the field of biology and the merging of engineering, computer science, and biology have given rise to new directions such as bioinformatics and nanotechnology.

Examples have been divided into levels of biological information to adequately cover the breadth and depth of experience for high school students. These biological levels include the chemistry of life typically referred to as cellular and molecular biology, the energetics of physiology, behavior and homeostasis of individual organisms referred to as organismal biology, and the complex interactions between and among living things, populations, and the inanimate world typically referred to as an ecosystem. Since mathematics, chemistry, and physics are all integral to life science, ICAS recommends that the high school life science course be taken after these courses.

The California Science Standards includes five standards in life science. These standards focus on 1) the structure and organization of cells and organisms; 2) energy conversion in biological systems; 3) inheritance of biological traits; 4) ecosystems and the effects of human interaction on the environment and biodiversity; and 5) natural selection and evolution.

Common Elements of Science Pertaining to Life Science

Common elements of the sciences pertaining to life science	**Scope and application** **students should demonstrate the ability to**	**Specific examples – These represent topical examples, which may themselves be quickly outdated, at three biological levels and do not include all examples expected but serve to typify depth and breadth of the element at three biological levels.**
Uncertainty and weighing evidence	Distinguish scientific evidence from opinion and to determine credibility of various sources of information Identify reputable sources Differentiate between scientific information and political platforms or social beliefs	**Cell and molecular level** – identifying common supportable data e.g. stem cells and cloning. **Organismal level** – accessing and evaluating controversial information related to individual organisms e.g. the use of vaccines and claims of autism or dietary supplements and health. **Ecosystems & populations** – describing verifiable information about human impact on ecosystems e.g. global warming
Systems and system modeling	Describe the organization and classification of biomolecules Distinguish between eukaryotic and prokaryotic cells Differentiate cell types and major tissues types Identify the main components and levels of biological systems Describe the complex interactions and adaptations. Use mathematical modeling	**Cell and molecular level** – describing the organization and classification of biomolecules, cells, and tissues **Organismal level** – identifying the metabolic processes and hierarchy fundamental to basic physiology of organisms e.g. health and the role of nutrition and exercise **Ecosystems & populations** – delineating the basic model of an ecosystem e.g. food webs and recycling of matter and energy

Common elements of the sciences pertaining to life science	**Scope and application** **students should demonstrate the ability to**	**Specific examples – These represent topical examples, which may themselves be quickly outdated, at three biological levels and do not include all examples expected but serve to typify depth and breadth of the element at three biological levels.**
Structure and function	Characterize the relationship between structure and function Describe components of inheritance, growth, and development	**Cell and molecular level** – describing how the molecular shape of DNA, RNA and proteins relate to the function of these biomolecules. e.g. immunoglobulins **Organismal level** – comparing and contrasting the relationship between anatomy and physiology **Ecosystems & populations** – exploring and describing ecosystems and communities e.g. biofilms, quorums, and ecological succession
Stability and change	Construct classical inheritance trait patterns Differentiate factors associated with variation of traits, adaptation, and mutation Provide examples of diversity and natural selection Describe mechanisms of evolution	**Cell and molecular level** – describing the role of mutation in molecular change and evolution e.g. development of bacterial antibiotic resistance **Organismal level** – Examining homeostasis and osmoregulation **Ecosystems & populations** – Describing key factors in regulating ecosystem balance, natural selection, and population growth and decline
Energy and matter	Explain the role of conservation and recycling Describe factors affecting energy flow at various biological levels	**Cell and molecular level**– explaining the flow of energy through respiration and photosynthesis **Organismal level** –characterizing energy metabolism in organisms and imbalances e.g. diabetes **Ecosystems & populations** –Describing biological dependence upon natural resources, energy flow through ecosystems, and natural cycles e.g. carbon, nitrogen, and water cycles

Common elements of the sciences pertaining to life science	**Scope and application** **students should demonstrate the ability to**	**Specific examples – These represent topical examples, which may themselves be quickly outdated, at three biological levels and do not include all examples expected but serve to typify depth and breadth of the element at three biological levels.**
Scale and proportionality	Assess the magnitude and effect of size from molecular to population levels Describe the impact of small molecular changes on the characteristics of an organism Evaluate organismal actions on the characteristics of populations Use mathematical modeling to understand comparative or proportional effects	**Cell and molecular level** –Comparing and contrasting surface area, volume, and size of components of various biological elements e.g. a comparison of sperm and an egg **Organismal level** – Evaluating differences of magnitude in size ranging from prokaryotic and eukaryotic e.g. trillions of microbes present on the human body **Ecosystems & populations** – Modeling specific examples of biomagnification, extinction, and threatened species e.g. effects of DDT
Synthesis of information and how it contributes to the “big picture”	Debate bioethical topics Analyze economic and sociopolitical situations Communicate science clearly	**Cell and molecular level** –exploring genomics and gene therapy e.g. gene therapy for primary immunodeficiency **Organismal level** – investigating regenerative medicine and stem cell biology e.g. bone marrow transplants **Ecosystems & populations** – studying preservation and global warming e.g. limited resources, sanctuaries and parks, vaccinations, population control

Common elements of the sciences pertaining to life science	**Scope and application** **students should demonstrate the ability to**	**Specific examples – These represent topical examples, which may themselves be quickly outdated, at three biological levels and do not include all examples expected but serve to typify depth and breadth of the element at three biological levels.**
Visualization of data	Convert and display data collected into graphs and tables Comprehend and use tables and graphs to draw conclusions Interpret images of macroscopic and microscopic structure Employ mathematical modeling to solve problems	**Cell and molecular level** – observing 3D images of biomolecules **Organismal level** – interpreting graphs and images of physiological function present on the human body **Ecosystems & populations** – Modeling population growth curves incorporating variables e.g. disease, competition, food supply
Human and global impact	Develop confidence in formulating questions and providing supporting evidence Weigh costs and benefits of biological interventions Demonstrate and understand probability in human and global applications Analyze and create solutions to long-term sustainability of life on earth	**Cell and molecular level** – Understanding probability and its role in interpretation of sequenced genomes **Organismal level** – Analyzing the effects of bioengineering on the food supply e.g. GMOs **Ecosystems & populations** – Modeling population growth and exploring eugenics

PHYSICS

Guiding Principles Leading to Performance Expectations

Physics is an experimental science that provides a systematic understanding of the fundamental laws that govern physical, chemical, biological, terrestrial, and astronomical processes. Because physics is a foundational science, it bears on a wide variety of fields, including engineering and technology.

Physics may be presented using algebra, trigonometry, or calculus, but students should all understand the fundamental principles of motion, forces and interactions, conservation laws, and fundamental forces like gravity and electrostatic attraction and repulsion. Through the investigation of these topics, students will explore scales from atomic to galactic, the structure of matter from atoms to planets, and how energy is converted from one form to another. The table on the next page provides the scope and application along with specific examples, which are based on five main physics classifications: mechanics, thermodynamics, electricity and magnetism, light and optics, and modern physics.

The California Science Standards include three standards in physics. These standards focus on 1) forces, Newton's 2nd law, and accelerated motion, 2) different forms of energy and conservation of energy and momentum, and 3) wave motion including mechanical waves, sound, and electromagnetic waves.

Common elements of the sciences pertaining to physics	Scope and application – students should demonstrate the ability to	Examples
Uncertainty and weighing evidence	Distinguish scientific evidence from opinion and to determine credibility of various sources of information Measure and distinguish between precision and accuracy Objectively apply the process of scientific inquiry; distinguish between hypothesis, theory, and law Construct experimental replications pertaining to the validation of evidence	Develop experimental strategies for measuring and quantifying data. Accuracy of different measurement devices. How does uncertainty in multiple measurements affect the certainty of a calculated result? Plan and conduct an experiment to produce data that can be assessed for reliability and accuracy. Data collection through experiments can be accomplished in the classroom and at home. Analyze claims to determine their validity based on an analysis of the evidence cited. Evaluate news stories to determine if the conclusions presented are supported by evidence.
Systems and system modeling	Evaluate consistency between physical reality and theoretical predictions. Explain how models can be used to simulate physical systems and interactions, including energy, matter, and information transfer, within and between systems at different spatial and temporal scales	Explain the effect that separation distance has on various forces and how these forces lead to the structure of atoms, objects, solar systems, and galaxies. Gravitational Forces Attraction between atoms to form stars and planets. Attraction between planets to form solar systems Electric Forces Attraction between protons and electrons to form atoms. Differentiate between direct and indirect observations of objects and structure. A solid can be seen with our eyes. The solid is composed of molecules

Common elements of the sciences pertaining to physics	**Scope and application – students should demonstrate the ability to**	**Examples**
Structure and function	Characterize the relationship between structure and function of matter and physical systems Predict the interactions between objects and within systems of objects	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 Conduct experiments to show how forces acting on systems relate to cause and effect
Stability and change	Explain how positive and negative feedbacks can stabilize or destabilize a system Quantify using models how change and rates of change operate over short and long periods of time and over small to large spatial scales Explain the relationship between a perturbation to a system and the system's response in terms of stability or instability	Use mathematical modeling to understand comparative or proportional effects Design experiments that demonstrate how forces acting on a system can affects stability and change over different space and time scales
Energy and matter	Explain the principles of energy conservation and energy transformation Explain how energy drives the cycling of matter within and between systems	Make observations to provide evidence that sound, light, heat, and electric currents can transfer energy from place to place. Show that energy is conserved using experiments like calorimetry, Hooke's Law, or linear motion on an inclined plane. Apply scientific ideas to design, test, and refine a device that converts energy from one form to another

Common elements of the sciences pertaining to physics	Scope and application – students should demonstrate the ability to	Examples
Scale and proportionality	Assess the magnitude and effect of different sizes of matter and systems, ranging from the from molecular to bulk scales Use mathematical modeling to understand comparative or proportional effects	Comparison of varying size objects to compare the difference in size between very small objects (electrons, protons, atoms), everyday objects (people, cars, buildings), and large-scale objects (planets, stars, galaxies).
Synthesis of information and how it contributes to the "big picture"	Clearly communicate physical principles and technical information in multiple formats, including orally, graphically, textually, and mathematically Construct explanations based on physical laws and reliable evidence obtained from models, theories, and experiments	Communicate technical information, such as how some technological devices use the principles of wave behavior and wave interactions with matter to transmit and capture information and energy (e.g., solar cells absorbing light to convert to electricity)
Visualization of data	Convert and display data collected into graphs and tables Comprehend and use tables and graphs to draw conclusions Employ mathematical modeling to solve problems	Graphing of experimental data including linear, parabolic, exponential, and logarithmic functions that include proper titles and labels that explain the experiment performed to produce it. Creating best-fit lines and curves and use those graphs to compare results to theoretical predictions.
Human and global impact	Develop skills and confidence in formulating questions and providing evidence to support conclusions	Demonstrate how waves interacting with matter are used in everyday applications (e.g., medical imaging, communications, scanners etc.)

HS Structure and Function	
HS-LS 1-1	Construct an explanation based on evidence for how the structure of DNA determines the structure of proteins which carry out the essential functions of life through systems of specialized cells.
HS-LS 1-2	Develop and use a model to illustrate the hierarchical organization of interacting systems that provide specific functions within multicellular organisms.
HS-LS 1-3	Plan and conduct an investigation to provide evidence that feedback mechanisms maintain homeostasis.
HS Matter and Energy in Organisms and Ecosystems	
HS-LS 1-5	Use a model to illustrate how photosynthesis transforms light energy into stored chemical energy.
HS-LS 1-6	Construct and revise an explanation based on evidence for how carbon, hydrogen, and oxygen from sugar molecules may combine with other elements to form amino acids and/or other large carbon-based molecules.
HS-LS 1-7	Use a model to illustrate that cellular respiration is a chemical process whereby the bonds of food molecules and oxygen molecules are broken and the bonds in new compounds are formed resulting in a net transfer of energy.
HS-LS 2-3	Construct and revise an explanation based on evidence for the cycling of matter and flow of energy in aerobic and anaerobic conditions.
HS-LS 2-4	Use mathematical representations to support claims for the cycling of matter and flow of energy among organisms in an ecosystem.
HS-LS 2-5	Develop a model to illustrate the role of photosynthesis and cellular respiration in the cycling of carbon among the biosphere, atmosphere, hydrosphere, and geosphere.
HS Inheritance and Variation of Traits	
HS-LS 1-4	Use a model to illustrate the role of cellular division (mitosis) and differentiation in producing and maintaining complex organisms.
HS-L S3-1	Ask questions to clarify relationships about the role of DNA and chromosomes in coding the instructions for characteristic traits passed from parents to offspring.
HS-LS 3-2	Make and defend a claim based on evidence that inheritable genetic variations may result from: (1) new genetic combinations through meiosis, (2) viable errors occurring during replication, and/or (3) mutations caused by environmental factors.
HS-LS 3-3	Apply concepts of statistics and probability to explain the variation and distribution of expressed traits in a population.

California Science Standards Performance Expectations for Grades Nine through Twelve

HS Independent Relationships in Ecosystems	
HS-LS 2-1	Use mathematical and/or computational representations to support explanations of factors that affect carrying capacity of ecosystems at different scales.
HS-LS 2-2	Use mathematical representations to support and revise explanations based on evidence about factors affecting biodiversity and populations in ecosystems of different scales.
HS-LS 2-6	Evaluate the claims, evidence, and reasoning that the complex interactions in ecosystems maintain relatively consistent numbers and types of organisms in stable conditions, but changing conditions may result in a new ecosystem.
HS-LS 2-7	Design, evaluate, and refine a solution for reducing the impacts of human activities on the environment and biodiversity.
HS-LS 2-8	Evaluate the evidence for the role of group behavior on individual and species' chances to survive and reproduce.
HS-LS 4-6	Create or revise a simulation to test a solution to mitigate adverse impacts of human activity on biodiversity.
HS Natural Selection and Evolution	
HS-LS 4-1	Communicate scientific information that common ancestry and biological evolution are supported by multiple lines of empirical evidence.
HS-LS 4-2	Construct an explanation based on evidence that the process of evolution primarily results from four factors: (1) the potential for a species to increase in number, (2) the heritable genetic variation of individuals in a species due to mutation and sexual reproduction, (3) competition for limited resources, and (4) the proliferation of those organisms that are better able to survive and reproduce in the environment.
HS-LS 4-3	Apply concepts of statistics and probability to support explanations that organisms with an advantageous heritable trait tend to increase in proportion to organisms lacking this trait.
HS-LS 4-4	Construct an explanation based on evidence for how natural selection leads to adaptation of populations.
HS-LS 4-5	Evaluate the evidence supporting claims that changes in environmental conditions may result in: (1) increases in the number of individuals of some species, (2) the emergence of new species over time, and (3) the extinction of other species.

HS Space Systems	
HS-ESS 1-1	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.
HS-ESS 1-2	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.
HS-ESS 1-3	Communicate scientific ideas about the way stars, over their life cycle, produce elements.
HS-ESS 1-4	Use mathematical or computational representations to predict the motion of orbiting objects in the solar system.
HS History of Earth	
HS-ESS 1-5	Evaluate evidence of the past and current movements of continental and oceanic crust and the theory of plate tectonics to explain the ages of crustal rocks.
HS-ESS 1-6	Apply scientific reasoning and evidence from ancient Earth materials, meteorites, and other planetary surfaces to construct an account of Earth's formation and early history.
HS-ESS 2-1	Develop a model to illustrate how Earth's internal and surface processes operate at different spatial and temporal scales to form continental and ocean-floor features.
HS Earth's Systems	
HS-ESS 2-2	Analyze geoscience data to make the claim that one change to Earth's surface can create feedbacks that cause changes to other Earth systems.
HS-ESS 2-3	Develop a model based on evidence of Earth's interior to describe the cycling of matter by thermal convection.
HS-ESS 2-5	Plan and conduct an investigation of the properties of water and its effects on Earth materials and surface processes.
HS-ESS 2-6	Develop a quantitative model to describe the cycling of carbon among the hydrosphere, atmosphere, geosphere, and biosphere.
HS-ESS 2-7	Construct an argument based on evidence about the simultaneous coevolution of Earth's systems and life on Earth.
HS Weather and Climate	
HS-ESS 2-4	Use a model to describe how variations in the flow of energy into and out of Earth's systems result in changes in climate.
HS-ESS 3-5	Analyze geoscience data and the results from global climate models to make an evidence-based forecast of the current rate of global or regional climate change and associated future impacts to Earth systems.

HS Human Sustainability	
HS-ESS 3-1	Construct an explanation based on evidence for how the availability of natural resources, occurrence of natural hazards, and changes in climate have influenced human activity.
HS-ESS 3-2	Evaluate competing design solutions for developing, managing, and utilizing energy and mineral resources based on cost-benefit ratios.
HS-ESS3-3	Create a computational simulation to illustrate the relationships among management of natural resources, the sustainability of human populations, and biodiversity.
HS-ESS3-4	Evaluate or refine a technological solution that reduces impacts of human activities on natural systems.
HS-ESS 3-6	Use a computational representation to illustrate the relationships among Earth systems and how those relationships are being modified due to human activity.
HS Structure and Properties of Matter	
HS-PS 1-1	Use the periodic table as a model to predict the relative properties of elements based on the patterns of electrons in the outermost energy level of atoms.
HS-PS 1-3	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.
HS-PS 1-8	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.
HS-PS 2-6	Communicate scientific and technical information about why the molecular-level structure is important in the functioning of designed materials.
HS Chemical Reactions	
HS-PS 1-2	Construct and revise an explanation for the outcome of a simple chemical reaction based on the outermost electron states of atoms, trends in the periodic table, and knowledge of the patterns of chemical properties.
HS-PS 1-4	Develop a model to illustrate that the release or absorption of energy from a chemical reaction system depends upon the changes in total bond energy.

HS-PS 1-5	Apply scientific principles and evidence to provide an explanation about the effects of changing the temperature or concentration of the reacting particles on the rate at which a reaction occurs.
HS-PS 1-6	Refine the design of a chemical system by specifying a change in conditions that would produce increased amounts of products at equilibrium.
HS-PS 1-7	Use mathematical representations to support the claim that atoms, and therefore mass, are conserved during a chemical reaction.
HS Forces and Interactions	
HS-PS 2-1	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.
HS-PS 2-2	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.
HS-PS 2-3	Apply scientific and engineering ideas to design, evaluate, and refine a device that minimizes the force on a macroscopic object during a collision.
HS-PS 2-4	Use mathematical representations of Newton's Law of Gravitation and Coulomb's Law to describe and predict the gravitational and electrostatic forces between objects.
HS-PS 2-5	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.
HS Energy	
HS-PS 3-1	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 energy flows in and out of the system are known.
HS-PS 3-2	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 position of particles (objects).
HS-PS 3-3	Design, build, and refine a device that works within given constraints to convert one form of energy into another form of energy.
HS-PS 3-4	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 (second law of thermodynamics).
HS-PS 3-5	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.

HS Waves and Electromagnetic Radiation	
HS-PS 4-1	Use mathematical representations to support a claim regarding relationships among the frequency, wavelength, and speed of waves traveling in various media.
HS-PS 4-2	Evaluate questions about the advantages of using a digital transmission and storage of information.
HS-PS 4-3	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.
HS-PS 4-4	Evaluate the validity and reliability of claims in published materials of the effects that different frequencies of electromagnetic radiation have when absorbed by matter.
HS-PS 4-5	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.
HS Engineering Design	
HS-ETS 1.1	Analyze a major global challenge to specify qualitative and quantitative criteria and constraints for solutions that account for societal needs and wants.
HS-ETS 1.2	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-ETS 1.3	Evaluate a solution to a complex real-world problem based on prioritized criteria and trade-offs that account for a range of constraints, including cost, safety, reliability, and aesthetics, as well as possible social, cultural, and environmental impacts.
HS-ETS 1.4	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.

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