Strand	Sub-Strand	Standard	No.	Benchmarks
1. The Nature of Science and Engineering	1. The Practice of Science	1. Science is a way of knowing about the natural world and is characterized by empirical criteria, logical argument and skeptical review.	9.1.1.1.1	Explain the implications of the assumption that the rules of the universe are the same everywhere and these rules can be discovered by careful and systematic investigation.
			9.1.1.1.2	Understand that scientists conduct investigations for a variety of reasons, including: to discover new aspects of the natural world, to explain observed phenomena, to test the conclusions of prior investigations, or to test the predictions of current theories.
			9.1.1.1.3	Explain how the traditions and norms of science define the bounds of professional scientific practice and reveal instances of scientific error or misconduct. *For example:* The use of peer review, publications and presentations.
			9.1.1.1.4	Explain how societal and scientific ethics impact research practices. *For example:* Research involving human subjects may be conducted only with the informed consent of the subjects.
			9.1.1.1.5	Identify sources of bias and explain how bias might influence the direction of research and the interpretation of data. *For example:* How funding of research can influence questions studied, procedures used, analysis of data, and communication of results.
			9.1.1.1.6	Describe how changes in scientific knowledge generally occur in incremental steps that include and build on earlier knowledge.
			9.1.1.1.7	Explain how scientific and technological innovations ─as well as new evidence─ can challenge portions of, or entire accepted theories and models including, but not limited to: cell theory, atomic theory, theory of evolution, plate tectonic theory, germ theory of disease, and the big bang theory.
1. The Nature of Science and Engineering	1. The Practice of Science	2. Scientific inquiry uses multiple interrelated processes to investigate and explain the natural world.	9.1.1.2.1	Formulate a testable hypothesis, design and conduct an experiment to test the hypothesis, analyze the data, consider alternative explanations and draw conclusions supported by evidence from the investigation.
			9.1.1.2.2	Evaluate the explanations proposed by others by examining and comparing evidence, identifying faulty reasoning, pointing out statements that go beyond the scientifically acceptable evidence, and suggesting alternative scientific explanations.
			9.1.1.2.3	Identify the critical assumptions and logic used in a line of reasoning to judge the validity of a claim.

			9.1.1.2.4	Use primary sources or scientific writings to identify and explain how different types of questions and their associated methodologies are used by scientists for investigations in different disciplines.
	2. The Practice of Engineering	1. Engineering is a way of addressing human needs by applying science concepts and mathematical techniques to develop new products, tools, processes and systems.	9.1.2.1.1	Understand that engineering designs and products are often continually checked and critiqued for alternatives, risks, costs and benefits, so that subsequent designs are refined and improved. *For example:* If the price of an essential raw material changes, the product design may need to be changed.
			9.1.2.1.2	Recognize that risk analysis is used to determine the potential positive and negative consequences of using a new technology or design, including the evaluation of causes and effects of failures. *For example:* Risks and benefits associated with using lithium batteries.
			9.1.2.1.3	Explain and give examples of how, in the design of a device, engineers consider how it is to be manufactured, operated, maintained, replaced and disposed of.
1. The Nature of Science and Engineering	2. The Practice of Engineering	2. Engineering design is an analytical and creative process of devising a solution to meet a need or solve a specific problem.	9.1.2.2.1	Identify a problem and the associated constraints on possible design solutions. *For example:* Constraints can include time, money, scientific knowledge and available technology.
			9.1.2.2.2	Develop possible solutions to an engineering problem and evaluate them using conceptual, physical and mathematical models to determine the extent to which the solutions meet the design specifications. *For example:* Develop a prototype to test the quality, efficiency and productivity of a product.
	3. Interactions Among Science, Technology, Engineering, Mathematics, and Society	1. Natural and designed systems are made up of components that act within a system and interact with other systems.	9.1.3.1.1	Describe a system, including specifications of boundaries and subsystems, relationships to other systems, and identification of inputs and expected outputs. *For example:* A power plant or ecosystem.
			9.1.3.1.2	Identify properties of a system that are different from those of its parts but appear because of the interaction of those parts.
			9.1.3.1.3	Describe how positive and/or negative feedback occur in systems. *For example:* The greenhouse effect.
		2. Men and women throughout the history of all cultures, including Minnesota American	9.1.3.2.1	Provide examples of how diverse cultures, including natives from all of the Americas, have contributed scientific and mathematical ideas and technological inventions.

		Indian tribes and communities, have been involved in scientific inquiry and engineering design.		*For example:* Native American understanding of ecology; Lisa Meitner's contribution to understanding radioactivity; Tesla's ideas and inventions relating to electricity; Watson, Crick and Franklin's discovery of the structure of DNA; or how George Washington Carver's ideas changed land use.
			9.1.3.2.2	Analyze possible careers in science and engineering in terms of education requirements, working practices and rewards.
1. The Nature of Science and Engineering	3. Interactions Among Science, Technology, Engineering, Mathematics, and Society	3. Science and engineering operate in the context of society and both influence and are influenced by this context.	9.1.3.3.1	Describe how values and constraints affect science and engineering. *For example*: Economic, environmental, social, political, ethical, health, safety and sustainability issues.
			9.1.3.3.2	Communicate, justify and defend the procedures and results of a scientific inquiry or engineering design project using verbal, graphic, quantitative, virtual or written means.
			9.1.3.3.3	Describe how scientific investigations and engineering processes require multi-disciplinary contributions and efforts. *For example:* Nanotechnology, climate change, agriculture or biotechnology.
		4. Science, technology, engineering and mathematics rely on each other to enhance knowledge and understanding.	9.1.3.4.1	Describe how technological problems and advances often create a demand for new scientific knowledge, improved mathematics and new technologies.
			9.1.3.4.2	Determine and use appropriate safety procedures, tools, computers and measurement instruments in science and engineering contexts. *For example:* Consideration of chemical and biological hazards in the lab.
			9.1.3.4.3	Select and use appropriate numeric, symbolic, pictorial, or graphical representation to communicate scientific ideas, procedures and experimental results.
			9.1.3.4.4	Relate the reliability of data to consistency of results, identify sources of error, and suggest ways to improve data collection and analysis. *For example*: Use statistical analysis or error analysis to make judgments about the validity of results.
			9.1.3.4.5	Demonstrate how unit consistency and dimensional analysis can guide the calculation of quantitative solutions and verification of results.
			9.1.3.4.6	Analyze the strengths and limitations of physical, conceptual, mathematical and computer models used by scientists and engineers.

2. Physical Science	1. Matter	1. The structure of the atom determines chemical properties of elements.	9.2.1.1.1	Describe the relative charges, masses, and locations of the protons, neutrons, and electrons in an atom of an element.
			9.2.1.1.2	Describe how experimental evidence led Dalton, Rutherford, Thompson, Chadwick and Bohr to develop increasingly accurate models of the atom.
			9.2.1.1.3	Explain the arrangement of the elements on the Periodic Table, including the relationships among elements in a given column or row.
			9.2.1.1.4	Explain that isotopes of an element have different numbers of neutrons and that some are unstable and emit particles and/or radiation. *For example:* Some rock formations and building materials emit radioactive radon gas. *Another example:* The predictable rate of decay of radioactive isotopes makes it possible to estimate the age of some materials, and makes them useful in some medical procedures.
		2. Chemical reactions involve the rearrangement of atoms as chemical bonds are broken and formed through transferring or sharing of electrons and the absorption or release of energy.	9.2.1.2.1	Describe the role of valence electrons in the formation of chemical bonds.
			9.2.1.2.2	Explain how the rearrangement of atoms in a chemical reaction illustrates the law of conservation of mass.
			9.2.1.2.3	Describe a chemical reaction using words and symbolic equations. *For example:* The reaction of hydrogen gas with oxygen gas can be written: $2H_2 + O_2 \rightarrow 2H_2O$.
			9.2.1.2.4	Relate exothermic and endothermic chemical reactions to temperature and energy changes.
	2. Motion	2. An object's mass and the forces on it affect the motion of an object.	9.2.2.2.1	Recognize that inertia is the property of an object that causes it to resist changes in motion.
			9.2.2.2.2	Explain and calculate the acceleration of an object subjected to a set of forces in one dimension (F=ma).
			9.2.2.2.3	Demonstrate that whenever one object exerts force on another, a force equal in magnitude and opposite in direction is exerted by the second object back on the first object.
2. Physical Science	2. Motion	2. Forces and object mass determine the motion of an object.	9.2.2.2.4	Use Newton's universal law of gravitation to describe and calculate the attraction between massive objects based on the distance between them. *For example:* Calculate the weight of a person on different planets in the solar system.
	3. Energy	2. Energy can be transformed within a system or transferred to other systems or the environment, but is always conserved.	9.2.3.2.1	Identify the energy forms and explain the transfers of energy involved in the operation of common devices. *For example*: Light bulbs, electric motors, automobiles or bicycles.
			9.2.3.2.2	Calculate and explain the energy, work and power involved in energy transfers in a mechanical system.

				For example: Compare walking and running up or down steps.
			9.2.3.2.3	Describe how energy is transferred through sound waves and how pitch and loudness are related to wave properties of frequency and amplitude.
			9.2.3.2.4	Explain and calculate current, voltage and resistance, and describe energy transfers in simple electric circuits.
			9.2.3.2.5	Describe how an electric current produces a magnetic force, and how this interaction is used in motors and electromagnets to produce mechanical energy.
			9.2.3.2.6	Compare fission and fusion in terms of the reactants, the products and the conversion from matter into energy. *For example:* The fusion of hydrogen produces energy in the sun. *Another example:* The use of chain reactions in nuclear reactors.
			9.2.3.2.7	Describe the properties and uses of forms of electromagnetic radiation from radio frequencies through gamma radiation. *For example:* Compare the energy of microwaves and X-rays.
2. Physical Science	4. Human Interaction with Physical Systems	1. There are benefits, costs and risks to different means of generating and using energy.	9.2.4.1.1	Compare local and global environmental and economic advantages and disadvantages of generating electricity using various sources or energy. *For example:* Fossil fuels, nuclear fission, wind, sun or tidal energy.
			9.2.4.1.2	Describe the trade-offs involved when technological developments impact the way we use energy, natural resources, or synthetic materials. *For example:* Fluorescent light bulbs use less energy than incandescent lights, but contain toxic mercury.
3. Earth and Space Science	1. Earth Structure and Processes	1. The relationships among earthquakes, mountains, volcanoes, fossil deposits, rock layers and ocean features provide evidence for the theory of plate tectonics.	9.3.1.1.1	Compare and contrast the interaction of tectonic plates at convergent and divergent boundaries. *For example:* Compare the kinds of magma that emerge at plate boundaries.
			9.3.1.1.2	Use modern earthquake data to explain how seismic activity is evidence for the process of subduction. *For example:* Correlate data on distribution, depth and magnitude of earthquakes with subduction zones.
			9.3.1.1.3	Describe how the pattern of magnetic reversals and rock ages on both sides of a mid-ocean ridge provides evidence of sea-floor spreading.

			9.3.1.1.4	Explain how the rock record provides evidence for plate movement. *For example:* Similarities found in fossils, certain types of rocks, or patterns of rock layers in various locations.
			9.3.1.1.5	Describe how experimental and observational evidence led to the theory of plate tectonics.
		3. By observing rock sequences and using fossils to correlate the sequences at various locations, geologic events can be inferred and geologic time can be estimated.	9.3.1.3.1	Use relative dating techniques to explain how the structures of the Earth and life on Earth have changed over short and long periods of time.
			9.3.1.3.2	Cite evidence from the rock record for changes in the composition of the global atmosphere as life evolved on Earth. *For example*: Banded iron formations as found in Minnesota's Iron Range.
3. Earth and Space Science	2. Interdepen-dence Within the Earth System	1. The Earth system has internal and external sources of energy, which produce heat and drive the motion of material in the oceans, atmosphere and solid earth.	9.3.2.1.1	Compare and contrast the energy sources of the Earth, including the sun, the decay of radioactive isotopes and gravitational energy.
			9.3.2.1.2	Explain how the outward transfer of Earth's internal heat drives the convection circulation in the mantle to move tectonic plates.
		2. Global climate is determined by distribution of energy from the sun at the Earth's surface.	9.3.2.2.1	Explain how Earth's rotation, ocean currents, configuration of mountain ranges, and composition of the atmosphere influence the absorption and distribution of energy, which contributes to global climatic patterns.
			9.3.2.2.2.	Explain how evidence from the geologic record, including ice core samples, indicates that climate changes have occurred at varying rates over geologic time and continue to occur today.
		3. The cycling of materials through different reservoirs of the Earth's system is powered by the Earth's sources of energy.	9.3.2.3.1	Trace the cyclical movement of carbon, oxygen and nitrogen through the lithosphere, hydrosphere, atmosphere and biosphere. *For example:* The burning of fossil fuels contributes to the greenhouse effect.
	3. The Universe	2. The solar system, sun, and Earth formed over billions of years.	9.3.3.2.1	Describe how the solar system formed from a nebular cloud of dust and gas 4.6 billion years ago.
			9.3.3.2.2.	Explain how the Earth evolved into its present habitable form through interactions among the solid earth, the oceans, the atmosphere and organisms.
			9.3.3.2.3.	Compare and contrast the environmental conditions that make life possible on Earth with conditions found on the other planets and moons of our solar system.
		3. The big bang theory states that the universe expanded from a hot, dense chaotic mass, after which chemical elements formed and clumped together to eventually form stars and galaxies.	9.3.3.3.1	Explain how evidence, including the Doppler shift of light from distant stars and cosmic background radiation, is used to understand the composition, early history and expansion of the universe.
			9.3.3.3.2	Explain how gravitational clumping leads to nuclear fusion, producing energy and the chemical elements of a star.

3. Earth and Space Science	4. Human Interactions with the Earth System	1. People consider potential benefits, costs and risks to make decisions on how they interact with natural systems.	9.3.4.1.1	Analyze the benefits, costs, risks and tradeoffs associated with natural hazards, including the selection of land use and engineering mitigation. *For example:* Determining land use in floodplain and areas prone to landslides.
			9.3.4.1.2	Explain how human activity and natural processes are altering the hydrosphere, biosphere, lithosphere and atmosphere, including pollution, topography and climate. *For example:* Active volcanoes and the burning of fossil fuels contribute to the greenhouse effect.
4. Life Science	1. Structure and Function in Living Systems	1. Organisms use the interaction of cellular processes as well as tissues and organ systems to maintain homeostasis.	9.4.1.1.1	Explain how cell processes are influenced by internal and external factors, such as pH and temperature, and how cells and organisms respond to changes in their environment to maintain homeostasis.
			9.4.1.1.2	Describe how the functions of individual organ systems are integrated to maintain homeostasis in an organism.
		2. Cells and cell structures have specific functions that allow an organism to grow, survive and reproduce.	9.4.1.2.1	Recognize that cells are composed primarily of a few elements (carbon, hydrogen, oxygen, nitrogen, phosphorus, and sulfur), and describe the basic molecular structures and the primary functions of carbohydrates, lipids, proteins and nucleic acids.
			9.4.1.2.2	Recognize that the work of the cell is carried out primarily by proteins, most of which are enzymes, and that protein function depends on the amino acid sequence and the shape it takes as a consequence of the interactions between those amino acids.
			9.4.1.2.3	Describe how viruses, prokaryotic cells and eukaryotic cells differ in relative size, complexity and general structure.
4. Life Science	1. Structure and Function in Living Systems	2. Cells and cell structures have specific functions that allow an organism to grow, survive and reproduce.	9.4.1.2.4	Explain the function and importance of cell organelles for prokaryotic and/or eukaryotic cells as related to the basic cell processes of respiration, photosynthesis, protein synthesis and cell reproduction.
			9.4.1.2.5	Compare and contrast passive transport (including osmosis and facilitated transport) with active transport, such as endocytosis and exocytosis.
			9.4.1.2.6	Explain the process of mitosis in the formation of identical new cells and maintaining chromosome number during asexual reproduction.
	2. Interdepen-dence Among Living Systems	1. The interrelationship and interdependence of organisms generate dynamic biological communities in ecosystems.	9.4.2.1.1	Describe factors that affect the carrying capacity of an ecosystem and relate these to population growth.
			9.4.2.1.2	Explain how ecosystems can change as a result of the introduction of one or more new species. *For example:* The effect of migration, localized evolution or disease organisms.

		2. Matter cycles and energy flows through different levels of organization of living systems and the physical environment, as chemical elements are combined in different ways.	9.4.2.2.1	Use words and equations to differentiate between the processes of photosynthesis and respiration in terms of energy flow, beginning reactants and end products.
			9.4.2.2.2	Explain how matter and energy is transformed and transferred among organisms in an ecosystem, and how energy is dissipated as heat into the environment.
	3. Evolution in Living Systems	1. Genetic information found in the cell provides information for assembling proteins, which dictate the expression of traits in an individual.	9.4.3.1.1	Explain the relationships among DNA, genes and chromosomes.
			9.4.3.1.2	In the context of a monohybrid cross, apply the terms phenotype, genotype, allele, homozygous and heterozygous.
			9.4.3.1.3	Describe the process of DNA replication and the role of DNA and RNA in assembling protein molecules.
4. Life Science	3. Evolution in Living Systems	2. Variation within a species is the natural result of new inheritable characteristics occurring from new combinations of existing genes or from mutations of genes in reproductive cells.	9.4.3.2.1	Use concepts from Mendel's Laws of Segregation and Independent Assortment to explain how sorting and recombination (crossing over) of genes during sexual reproduction (meiosis) increases the occurrence of variation in a species.
			9.4.3.2.2	Use the processes of mitosis and meiosis to explain the advantages and disadvantages of asexual and sexual reproduction.
			9.4.3.2.3	Explain how mutations like deletions, insertions, rearrangements or substitutions of DNA segments in gametes may have no effect, may harm, or rarely may be beneficial, and can result in genetic variation within a species.
		3. Evolution by natural selection is a scientific explanation for the history and diversity of life on Earth.	9.4.3.3.1	Describe how evidence led Darwin to develop the theory of natural selection and common descent to explain evolution.
			9.4.3.3.2	Use scientific evidence, including the fossil record, homologous structures, and genetic and/or biochemical similarities, to show evolutionary relationships among species.
			9.4.3.3.3	Recognize that artificial selection has led to offspring through successive generations that can be very different in appearance and behavior from their distant ancestors.
			9.4.3.3.4	Explain why genetic variation within a population is essential for evolution to occur.
			9.4.3.3.5	Explain how competition for finite resources and the changing environment promotes natural selection on offspring survival, depending on whether the offspring have characteristics that are advantageous or disadvantageous in the new environment.
			9.4.3.3.6	Explain how genetic variation between two populations of a given species is due, in part, to different selective pressures acting

				independently on each population and how, over time, these differences can lead to the development of new species.
4. Life Science	4. Human Interactions with Living Systems	1. Human activity has consequences on living organisms and ecosystems.	9.4.4.1.1	Describe the social, economic and ecological risks and benefits of biotechnology in agriculture and medicine. *For example:* Selective breeding, genetic engineering, and antibiotic development and use.
			9.4.4.1.2	Describe the social, economic and ecological risks and benefits of changing a natural ecosystem as a result of human activity. *For example:* Changing the temperature or composition of water, air or soil; altering populations and communities; developing artificial ecosystems; or changing the use of land or water.
			9.4.4.1.3	Describe contributions from diverse cultures, including Minnesota American Indian tribes and communities, to the understanding of interactions among humans and living systems. *For example:* American Indian understanding of sustainable land use practices.
		2. Personal and community health can be affected by the environment, body functions and human behavior.	9.4.4.2.1	Describe how some diseases can sometimes be predicted by genetic testing and how this affects parental and community decisions.
			9.4.4.2.2	Explain how the body produces antibodies to fight disease and how vaccines assist this process.
			9.4.4.2.3	Describe how the immune system sometimes attacks some of the body's own cells and how some allergic reactions are caused by the body's immune responses to usually harmless environmental substances.
			9.4.4.2.4	Explain how environmental factors and personal decisions, such as water quality, air quality and smoking affect personal and community health.
			9.4.4.2.5	Recognize that a gene mutation in a cell can result in uncontrolled cell division called cancer, and how exposure of cells to certain chemicals and radiation increases mutations and thus increases the chance of cancer.