Utah State Office of Education
Elementary STEM Endorsement Course Framework
Nature of Science and Engineering

Course Description:

In this course participants will experience introductory explorations of the nature of science using science and engineering principles, practices, and processes. Applications to Science, Technology, Engineering and Mathematics will be explored using learner-based pedagogy. Participants will develop teaching practices to assist them in educating K-6 students in selected Earth and Life Science Standards.

Course Objectives:

- Objective #1: Content Knowledge: Develop a deeper understanding the nature of science and engineering.
    - Climate change and natural selection require scientific understanding and engineering solutions
    - Science is a way of knowing and assumes an order and consistency in natural systems.
    - Science addresses questions about the natural and material world while engineering addresses human problems in the natural and material world
    - Scientific knowledge and engineering solutions are based on empirical evidence
- Objective #2: Cross Cutting Concept: Explain that stability and change are present in all natural and built systems. Conditions of stability and rates of change or evolution of a system are critical elements of study.
    - Natural climate cycles and natural selection are supported by evidence.
    - Rate of change of any natural or built system impacts evolutionary change.
    - Scientific argumentation must be supported by evidence.
- Objective #3: Connect theory and practice through reflection, teaching, scholarship, and STEM educational action research. Including traditionally under-represented groups that consider students of diverse backgrounds and perspectives.
    - Have capacity and confidence to run a student inquiry-based classroom.
    - Integrate cross curricular learning.
- Objective #4: Demonstrate proficiency with STEM content, skills, and practices and teach those to students.
    - Communicate using multiple forms of discourse.
    - Develop reasoning and problem solving practices.

    - Facilitate effective collaboration and communication among the students.
    - Demonstrate proficiency in STEM content.
- Objective #5: Explore and implement innovative, research-based, engaging curriculum, especially around the Utah Core academic standards and college and career readiness, geared towards increasing student achievement.
    - Apply the disciplinary core ideas when planning lessons and teaching.
    - Use cross-cutting concepts when planning lessons and teaching.
    - Implement scientific practices into lesson planning and teaching.

Course Construction Recommendation:

- It is recommended that this be the first course taught in the elementary STEM endorsement focusing on conceptual change of instructional strategies.
- Compare and contrast theory development with the engineering cycle. (New evidence to change theory, [Pluto], Design, test, redesign [bow and arrow]. Iterative nature of both processes should be highlighted.
- Participants will visit a scientist or engineer in their place of work. This experience should provide opportunity for the teacher to engage in scientific and engineering practices in the field.
- The participants are presented with an engineering challenge where they develop a viable solution given specific constraints and requirements.
- Using natural selection and global climate change, investigate scientific theory formation.
- Conceptually understand that theories are explanations for observable phenomena and scientific theory is based on a body of evidence developed over time.

Course Topics:

Engineering Process Knowledge

3-5-ETS1-1. Define a simple design problem reflecting a need or a want that includes specified criteria for success and constraints on materials, time, or cost.

3-5-ETS1-2. Generate and compare multiple possible solutions to a problem based on how well each is likely to meet the criteria and constraints of the problem.

Nature of Science

Please see Addendum A for a more detailed outline of topics for science content that would support the main ideas highlighted below.

- Scientific Investigations Use a Variety of Methods
- Scientific Knowledge is Based on Empirical Evidence
- Scientific Knowledge is Open to Revision in Light of New Evidence
- Scientific Models, Laws, Mechanisms, and Theories Explain Natural Phenomena
- Science is a Way of Knowing
- Scientific Knowledge Assumes an Order and Consistency in Natural Systems
- Science is a Human Endeavor
- Science Addresses Questions About the Natural and Material World

Pedagogical Focus of Course:

The purpose of this course is to ensure that practicing teachers can apply the pedagogical content knowledge needed to teach STEM concepts to students in the elementary grades. Teachers must also, however, know how to transfer that content knowledge and the conceptual understandings inherent in the content to students. An understanding of sound pedagogical practice is essential to that transfer. There are a variety of pedagogical concepts and strategies that should be infused into the courses to aid teachers in student instruction. These concepts should never be taught in isolation, but should be modeled throughout the course to create a student-centered learning environment in which students use hands-on investigations, engineer solutions to problems, and construct evidence-based explanations of real-world phenomena.

Knowledge of STEM for course participants:

- **Patterns**
  Observed patterns of forms and events guide organization and classification, and they prompt questions about relationships and the factors that influence them.
- **Cause and Effect:**
  Mechanism and Explanation. Events have causes, sometimes simple, sometimes multifaceted. A major activity of science is investigating and explaining causal relationships and the mechanisms by which they are mediated. Such mechanisms can then be tested across given contexts and used to predict and explain events in new contexts.
- S**cale, Proportion, and Quantity**
  In considering phenomena, it is critical to recognize what is relevant at different measures of size, time, and energy and to recognize how changes in scale, proportion, or quantity affect a system's structure or performance.
- **Systems and System Models**
  Defining the system under study—specifying its boundaries and making explicit a model of that system—provides tools for understanding and testing ideas that are applicable throughout science and engineering.

- **Energy and Matter: Flows, cycles and conservations.**
  Defining the system under study—specifying its boundaries and making explicit a model of that system—provides tools for understanding and testing ideas that are applicable throughout science and engineering.
- **Structure and Function**
  The way in which an object or living thing is shaped and its substructure determine many of its properties and functions.
- **Stability and Change**
  For natural and built systems alike, conditions of stability and determinants of rates of change or evolution of a system are critical elements of study.

Effective STEM teaching practices:

- Ability to Ask Scientific Questions and Define Problems
- Ability to Plan and Carry Out Investigations
- Ability to Analyze, Interpret Data, and Make Predictions
- Ability to Develop and Use Models
- Ability to Construct Explanations and Design Solutions
- Ability to Engage in Argument from Evidence
- Ability to Use Mathematical and Computational Thinking
- Ability to Obtain, Evaluate and Communicate Information

Knowledge of STEM curriculum and assessment:

1. Understandings of science content and process knowledge and skills
2. Abilities to think critically and solve simple to complex problems
3. Capabilities of designing scientific experiments, analyzing data, and drawing conclusions
4. Capacities to see and articulate relationships between science topics and real-world issues and concerns
5. Skills using mathematics as a tool for science learning

(Above are from NSTA position statement on assessment)

6. Demonstrate creative thinking, construct knowledge, and develop innovative products and processes using technology.
7. Apply digital tools to gather, evaluate, and use information
8. Use digital media and environments to communicate and work collaboratively, including at a distance, to support individual learning and contribute to the learning of others.
9. Use critical thinking skills to plan and conduct research, manage projects, solve problems, and make informed decisions using appropriate digital tools and resources.

10. Understand human, cultural, and societal issues related to technology and practice legal and ethical behavior.
11. Demonstrate a sound understanding of technology concepts, systems, and operations.

(Above are from ISTE student standards)

12. Select, use, adapt and determine the suitability of STEM curricula and teaching materials (e.g., textbooks, technology, manipulatives) for particular learning goals.
13. Be cognizant of a formative assessment cycle (administering a formative assessment, analyzing student work from the assessment, using that analysis to enhance teacher knowledge, and designing and teaching re-engagement lessons) and resources.
14. Provide appropriate interpretations of assessment results, and communicate results (in context) to specific individuals and groups (e.g., students, parents, caregivers, colleagues, administrators, policy makers, community members).

(Above are from AMTE Standards for Elementary Mathematics Specialists)

Possible Assignments:

- Participants will visit a scientist or engineer in their place of work and engage in discourse and activities.
- Investigate human impacts on the environment. Identify ways to collect data and design an engineering solution to mediate negative impacts.
- Collect and analyze data that provides evidence of science phenomenon such as natural selection, inheritance of traits, climate change, biodiversity etc.
- Develop evidence based arguments to justify theories of natural selection, inheritance of traits, climate change, biodiversity etc.
- Design engineering solutions related to human impact on Earth systems, including climate change and reduced biodiversity.
- Implementation of 3 of the “model lessons” in teachers’ classrooms. Followed by a reflection, including pictures.
- Reflection paper documenting the observed activities of the professional/ practitioner and the science/engineering practices presented in class.
- Reading research – choose from possible articles and do an assignment based on the article; discussions, agreement/disagreement, impact in classrooms.

Possible Internships or Experiential Learning Recommendations:

- It is suggested that the internship experience consists of opportunities to interact with a science/engineering professional. This experience should provide opportunity for the teacher to engage in scientific and engineering practices in the field.

Suggested Resources:

DeJarnette, N. E. D. (2012). America's Children: Providing Early Exposure to STEM (Science, Technology, Engineering, and Math) Initiatives. [Journal]. *Education 133*(1).

National Research Council. (2012). A frameworkfor K-12 science education: Practices, crosscutting concepts, and core ideas. Washington, DC: National Academy Press.

Science and Engineering. In S. J. a. W. Ceci, W. M. (Ed.), Why Aren't More Women in Science? (pp. 199-210).

Washington DC: American Psychological Association. *Educate to Innovate*. (2009). White House: Retrieved from http://www.whitehouse.gov/issues/education/k-12/educate-innovate.

Michaels, Sarah, Shouse, Andrew W., Schweingruber, Heidi A. " Front Matter ." *Ready, Set, SCIENCE!: Putting Research to Work in K-8 Science Classrooms* . Washington, DC: The National Academies Press, 2007 .

NGSS Lead States. (2013). *Next generation science standards: For states, by state*s. Washington, DC: The National Academies Press.

Addendum A:

Nature of Science Progression: (Appendix H - Nature of Science from Next Generation Science standards, available at http://www.nextgenscience.org/sites/ngss/files/Appendix%20H%20-%20The%20Nature%20of%20Science%20in%20the%20Next%20Generation%20Science%20Standards%204.15.13.pdf

Overview

One goal of science education is to help students understand the nature of scientific knowledge. This matrix presents eight major themes and grade level understandings about the nature of science. Four themes extend the scientific and engineering practices and four themes extend the crosscutting concepts. These eight themes are presented in the left column. The matrix describes learning outcomes for the themes at grade bands for K-2, 3-5, middle school, and high school. Appropriate learning outcomes are expressed in selected performance expectations and presented in the foundation boxes throughout the standards.

Understandings about the Nature of Science

Categories	K-2	3-5	Middle School	High School
Scientific Investigations Use a Variety of Methods	▪ Science investigations begin with a question. ▪ Scientist use different ways to study the world.	▪ Science methods are determined by questions. ▪ Science investigations use a variety of methods, tools, and techniques.	▪ Science investigations use a variety of methods and tools to make measurements and observations. ▪ Science investigations are guided by a set of values to ensure accuracy of measurements, observations, and objectivity of findings. ▪ Science depends on evaluating proposed explanations. ▪ Scientific values function as criteria in distinguishing between science and non-science.	▪ Science investigations use diverse methods and do not always use the same set of procedures to obtain data. ▪ New technologies advance scientific knowledge. ▪ Scientific inquiry is characterized by a common set of values that include: logical thinking, precision, open-mindedness, objectivity, skepticism, replicability of results, and honest and ethical reporting of findings. ▪ The discourse practices of science are organized around disciplinary domains that share exemplars for making decisions regarding the values, instruments, methods, models, and evidence to adopt and use. ▪ Scientific investigations use a variety of methods, tools, and techniques to revise and produce new knowledge.
Scientific Knowledge is Based on Empirical Evidence	▪ Scientists look for patterns and order when making observations about the world.	▪ Science findings are based on recognizing patterns. ▪ Scientists use tools and technologies to make accurate measurements and observations.	▪ Science knowledge is based upon logical and conceptual connections between evidence and explanations. ▪ Science disciplines share common rules of obtaining and evaluating empirical evidence.	▪ Science knowledge is based on empirical evidence. ▪ Science disciplines share common rules of evidence used to evaluate explanations about natural systems. ▪ Science includes the process of coordinating patterns of evidence with current theory. ▪ Science arguments are strengthened by multiple lines of evidence supporting a single explanation.
Scientific Knowledge is Open to Revision in Light of New Evidence	▪ Science knowledge can change when new information is found.	▪ Science explanations can change based on new evidence.	▪ Scientific explanations are subject to revision and improvement in light of new evidence. ▪ The certainty and durability of science findings varies. ▪ Science findings are frequently revised and/or reinterpreted based on new evidence.	▪ Scientific explanations can be probabilistic. ▪ Most scientific knowledge is quite durable but is, in principle, subject to change based on new evidence and/or reinterpretation of existing evidence. ▪ Scientific argumentation is a mode of logical discourse used to clarify the strength of relationships between ideas and evidence that may result in revision of an explanation.
Science Models, Laws, Mechanisms, and Theories Explain Natural Phenomena	▪ Scientists use drawings, sketches, and models as a way to communicate ideas. ▪ Scientists search for cause and effect relationships to explain natural events.	▪ Science theories are based on a body of evidence and many tests. ▪ Science explanations describe the mechanisms for natural events.	▪ Theories are explanations for observable phenomena. ▪ Science theories are based on a body of evidence developed over time. ▪ Laws are regularities or mathematical descriptions of natural phenomena. ▪ A hypothesis is used by scientists as an idea that may contribute important new knowledge for the evaluation of a scientific theory. ▪ The term "theory" as used in science is very different from the common use outside of science.	▪ Theories and laws provide explanations in science, but theories do not with time become laws or facts. ▪ A scientific theory is a substantiated explanation of some aspect of the natural world, based on a body of facts that has been repeatedly confirmed through observation and experiment, and the science community validates each theory before it is accepted. If new evidence is discovered that the theory does not accommodate, the theory is generally modified in light of this new evidence. ▪ Models, mechanisms, and explanations collectively serve as tools in the development of a scientific theory. ▪ Laws are statements or descriptions of the relationships among observable phenomena. ▪ Scientists often use hypotheses to develop and test theories and explanations.

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NEXT GENERATION SCIENCE STANDARDS For States, By States

Understandings about the Nature of Science

Categories	K-2	3-5	Middle School	High School
Science is a Way of Knowing	▪ Science knowledge helps us know about the world.	▪ Science is both a body of knowledge and processes that add new knowledge. ▪ Science is a way of knowing that is used by many people.	▪ Science is both a body of knowledge and the processes and practices used to add to that body of knowledge. ▪ Science knowledge is cumulative and many people, from many generations and nations, have contributed to science knowledge. ▪ Science is a way of knowing used by many people, not just scientists.	▪ Science is both a body of knowledge that represents a current understanding of natural systems and the processes used to refine, elaborate, revise, and extend this knowledge. ▪ Science is a unique way of knowing and there are other ways of knowing. ▪ Science distinguishes itself from other ways of knowing through use of empirical standards, logical arguments, and skeptical review. ▪ Science knowledge has a history that includes the refinement of, and changes to, theories, ideas, and beliefs over time.
Scientific Knowledge Assumes an Order and Consistency in Natural Systems	▪ Science assumes natural events happen today as they happened in the past. ▪ Many events are repeated.	▪ Science assumes consistent patterns in natural systems. ▪ Basic laws of nature are the same everywhere in the universe.	▪ Science assumes that objects and events in natural systems occur in consistent patterns that are understandable through measurement and observation. ▪ Science carefully considers and evaluates anomalies in data and evidence.	▪ Scientific knowledge is based on the assumption that natural laws operate today as they did in the past and they will continue to do so in the future. ▪ Science assumes the universe is a vast single system in which basic laws are consistent.
Science is a Human Endeavor	▪ People have practiced science for a long time. ▪ Men and women of diverse backgrounds are scientists and engineers.	▪ Men and women from all cultures and backgrounds choose careers as scientists and engineers. ▪ Most scientists and engineers work in teams. ▪ Science affects everyday life. ▪ Creativity and imagination are important to science.	▪ Men and women from different social, cultural, and ethnic backgrounds work as scientists and engineers. ▪ Scientists and engineers rely on human qualities such as persistence, precision, reasoning, logic, imagination and creativity. ▪ Scientists and engineers are guided by habits of mind such as intellectual honesty, tolerance of ambiguity, skepticism and openness to new ideas. ▪ Advances in technology influence the progress of science and science has influenced advances in technology.	▪ Scientific knowledge is a result of human endeavor, imagination, and creativity. ▪ Individuals and teams from many nations and cultures have contributed to science and to advances in engineering. ▪ Scientists' backgrounds, theoretical commitments, and fields of endeavor influence the nature of their findings. ▪ Technological advances have influenced the progress of science and science has influenced advances in technology. ▪ Science and engineering are influenced by society and society is influenced by science and engineering.
Science Addresses Questions About the Natural and Material World.	▪ Scientists study the natural and material world.	▪ Science findings are limited to what can be answered with empirical evidence.	▪ Scientific knowledge is constrained by human capacity, technology, and materials. ▪ Science limits its explanations to systems that lend themselves to observation and empirical evidence. ▪ Science knowledge can describe consequences of actions but is not responsible for society's decisions.	▪ Not all questions can be answered by science. ▪ Science and technology may raise ethical issues for which science, by itself, does not provide answers and solutions. ▪ Science knowledge indicates what can happen in natural systems—not what should happen. The latter involves ethics, values, and human decisions about the use of knowledge. ▪ Many decisions are **not** made using science alone, but rely on social and cultural contexts to resolve issues.

☐ Nature of Science understandings most closely associated with Practices

☐ Nature of Science understandings most closely associated with Crosscutting Concepts

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Below are suggested course topics to help contextualize discussions about the nature of science.

ESS3.C Human impacts on Earth systems

- (K-2) Things people do can affect the environment but they can make choices to reduce their impacts.
- (3-5) Things people do can affect the environment but they can make choices to reduce their impacts.
- (6-8) Human activities have altered the biosphere, sometimes damaging it, although changes to environments can have different impacts for different living things. Activities and technologies can be engineered to reduce people's impacts on Earth.

ESS3.D Global climate change

- (6-8) Human activities affect global warming. Decisions to reduce the impact of global warming depend on understanding climate science, engineering capabilities, and social dynamics.

LS2.C Ecosystem dynamics, functioning and resilience

- (K-2) NA
- (3-5) When the environment changes some organisms survive and reproduce, some move to new locations, some move into the transformed environment, and some die.
- (6-8) Ecosystem characteristics vary over time. Disruptions to any part of an ecosystem can lead to shifts in all of its populations. The completeness or integrity of an ecosystem's biodiversity is often used as a measure of its health.

LS2.D Social interactions and group behavior

- (K-2) N/A
- (3-5)Being part of a group helps animals obtain food, defend themselves, and cope with changes.
- (6-8) NA

LS3.A Inheritance of traits LS3.B Variation of traits

- (K-2) Young organisms are very much, but not exactly, like their parents and also resemble other organisms of the same kind.
- (3-5)Different organisms vary in how they look and function because they have different inherited information; the environment also affects the traits that an organism develops.
- (6-8) Genes chiefly regulate a specific protein, which affect an individual's traits.
- In sexual reproduction, each parent contributes half of the genes acquired by the offspring resulting in variation between parent and offspring. Genetic information can be altered because of mutations, which may result in beneficial, negative, or no change to proteins in or traits of an organism.

LS4.A Evidence of common ancestry and diversity

- (K-2) NA
- (3-5)Some living organisms resemble organisms that once lived on Earth. Fossils provide evidence about the types of organisms and environments that existed long ago.

- (6-8) The fossil record documents the existence, diversity, extinction, and change of many life forms and their environments through Earth's history . The fossil record and comparisons of anatomical similarities between organisms enables the inference of lines of evolutionary descent.

LS4.B Natural selection

- (K-2) NA
- (3-5)Differences in characteristics between individuals of the same species provide advantages in surviving and reproducing.
- (6-8) Both natural and artificial selection result from certain traits giving some individuals an advantage in surviving and reproducing, leading to predominance of certain traits in a population.

LS4C Adaptation

- (K-2) NA
- (3-5)Particular organisms can only survive in particular environments.
- (6-8) Species can change over time in response to changes in environmental conditions through adaptation by natural selection acting over generations. Traits that support successful survival and reproduction in the new environment become more common.

LS4.D Biodiversity and Humans

- (K-2) A range of different organisms lives in different places.
- (3-5)Populations of organisms live in a variety of habitats. Change in those habitats affects the organisms living there.
- (6-8) Changes in biodiversity can influence humans' resources and ecosystem services they rely on.