Summary of the Materials Science Classroom Kit lessons and the inclusion of Next Generation Science Standards (NGSS)

The framework of the NGSS is three-dimensional and includes core ideas (physical sciences, engineering technology, etc.) crosscutting concepts, and practices.

- This document breaks down each lesson of the Materials Science Classroom Kit in terms of the NGSS and provides a short description of how each applicable standard could be applied to the lesson.
- Also included is a list of crosscutting concepts and science and engineering practices. Since these are generally considered applicable for all of the lessons, they are not repeated in each lesson subsection.
- The focus audience of the kit is middle school (7^{th} and 8^{th} grades) and high school (9^{th} through 12^{th} grades) students. Only standards at these grade levels, therefore, will be discussed.

Crosscutting concepts

- Patterns
- Cause and effect/mechanism and explanation
- Scale, proportion, and quantity
- Systems and system models
- Energy and matter flows, cycles, and conservation
- Structure and function
- Stability and change

Science and Engineering Practices

- Asking questions and defining problems
- Developing and using models
- Planning and carrying out investigations
- Analyzing and interpreting data
- Using mathematics and computational thinking
- Constructing explanations and designing solutions
- Engaging in argument from evidence
- Obtaining, evaluating, and communicating information

Lessons from the Materials Science Classroom Kit

Candy Fiber Pull

1. MS-PS1-4 Develop a model that predicts and describes changes in particle motion, temperature, and state of a pure substance when thermal energy is added or removed.
   - The experiment itself can be a model showing what happens when the structure of a material changes with varying temperatures.
2. MS-PS3-4 Plan an investigation to determine the relationships among the energy transferred, the type of matter, the mass, and the change in the average kinetic energy of the particles as measured by the temperature of the sample.
   - Discuss how the structure of candy changes to a more liquid-like state when hot (atoms are more mobile due to higher energy input) and then becomes glass-like (brittle) when cooled quickly.

Hot or Not

1. MS-PS3-3 Apply scientific principles to design, construct, and test a device that either minimizes or maximizes thermal energy transfer.
   - This lesson minimizes thermal energy transfer and explains how the structure of the refractory brick decreases thermal conductivity.
2. MS-PS3-4 Plan an investigation to determine the relationships among the energy transferred, the type of matter, the mass, and the change in the average kinetic energy of the particles as measured by the temperature of the sample.
   - This lesson explains how heat is transferred through a solid material and explains why refractories reduce heat transfer. It can easily be expanded to explain why non-refractory metals are good at conducting heat.

Piezoelectric Materials

MS-PS2-3 Ask questions about data to determine the factors that affect the strength of electric and magnetic forces.

- The piezoelectric response is caused by applying a physical force to the material that results in the output of an electrical charge. This lesson could be modified to test the correlation between force and charge output.

Shape Memory Alloys

1. MS-PS1-1 Develop models to describe the atomic composition of simple molecules and extended structures.
   - This lesson discusses the unit cell of two different phases of Nitinol which, when repeated, creates the bulk structure.
2. PS1.A Structure and Properties of Matter
   - This lesson also explains how the change in crystallographic structure causes the shape-memory properties.
3. HS-PS2-6 Communicate scientific and technical information about why the molecular-level structure is important in the functioning of designed materials.
   - This lesson shows that the arrangement of atoms, which defines the phase of the material, corresponds to different material properties.

Thermal Shock

1. MS-PS1-4 Develop a model that predicts and describes changes in particle motion, temperature, and state of pure substance when thermal energy is added or removed.
   - This lesson elucidates the effects of thermal conductivity by showing that the porous refractory brick, which contains air, is an excellent insulator compared to relative to other materials.
2. HS-PS2-6 Communicate scientific and technical information about why the molecular-level structure is important in the functioning of designed materials.
   - This lesson asks students to think about how the nature of air (very little matter, which is thinly dispersed) contributes to the thermal conductivity of a materials (or lack thereof).
3. HS-PS3-4 Energy: Plan and conduct an investigation to provide evidence that the transfer of thermal energy when two components of different temperatures are combined within a closed system results in a more uniform energy distribution among the components in the system (second law of thermodynamics).
   - This lesson asks students to design a simple experiment that would definitively show how heat and energy transfer between material points of contact.

Glass Bead on a Wire

1. PS1.A Structure and Properties of Matter
   - This lesson explains the various structures of matter.
2. MS-PS1-4 Develop a model that predicts and describes changes in particle motion, temperature, and state of pure substance when thermal energy is added or removed.
   - This experiment can be thought of as a model that explains the various structures or states of glass, crystalline, and semi-crystalline materials, and how temperature has an effect on the corresponding structure.
3. MS-PS1-2 Analyze and interpret data on properties of substances before and after the substances interact to determine if a chemical reaction occurs.
   - The background information section of the lesson explains what is happening when the borax and metal wires are heated; the students can determine if this is a chemical reaction.

Engineered Concrete

1. MS-PS1-2 Analyze and interpret data on properties of substances before and after the substances interact to determine if a chemical reaction occurs.
   - Hydration of the cement (i.e., adding water to the cement powder and allowing it to cure) can be discussed in terms of what type of reaction occurs.
2. HS-PS1-5 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.
   - This lesson asks students to change the amount of components in the cement composites and test their strength. This can be expanded to observe the time it takes for the hydration to occur with difference amounts of components.
3. ETS1.B and C Develop possible solutions and optimize the design solution
   - This project walks students through experimental design, testing, revisiting the data, and refining solutions.
4. MS-ETS1-1 to 4 Engineer design criteria for middle school curriculum
   - This lesson allows for the discussion of engineering design of the cement composites. Specifically, focus can be placed on which properties are desired and how changing the components of the system may control those properties.

Thermal Processing of Bobby Pins

1. MS-PS1-4 Develop a model that predicts and describes changes in particle motion, temperature, and state of pure substance when thermal energy is added or removed.
   - The thermal processing induces solid phase transformations in the bobby pins.
2. PS1.A Structure and Properties of Matter
   - The main concept of this experiment is determining how a change in the phase or atomic structure of the bobby pin has an effect on the properties of the pin.
3. MS-PS1-2 Analyze and interpret data on properties of substances before and after the substances interact to determine if a chemical reaction occurs.
   - Discuss how to distinguish a solid phase change from a chemical reaction.
4. HS-PS2-6 Communicate scientific and technical information about why the molecular-level structure is important in the functioning of designed materials.
   - The main concept of this experiment is determining how a change in the phase or atomic structure of the bobby pin has an effect on the properties of the pin.
5. MS-PS2-4 Construct and present arguments using evidence to support the claim that gravitational interactions are attractive and depend on the masses of interacting objects.
   - In this lab, the force, moment of inertia, and deflection of the pins are calculated.

How Strong is Your Chocolate?

1. MS-PS2-4 Construct and present arguments using evidence to support the claim that gravitational interactions are attractive and depend on the masses of interacting objects.
   - The portion of the lesson in which weights are added to the chocolate bar to make it fracture can be discussed in terms of gravitational interactions, if desired.
2. PS1.A Structure and Properties of Matter
   - The basic concept of this experiment is to analyze how the structure of the chocolate affects the strength of each bar.

Additional Materials Science Lessons from The American Ceramic Society

Fun with Liquid Nitrogen

1. MS-PS1-4 Develop a model that predicts and describes changes in particle motion, temperature, and state of pure substance when thermal energy is added or removed.
   - This lesson demonstrates the effects of thermal energy on the elastic and plastic deformation of materials.
2. HS-PS2-6 Communicate scientific and technical information about why the molecular-level structure is important in the functioning of designed materials.
   - The main concept of this experiment is determining how a change in thermal energy of the material changes the way a material elastically or plastically deforms. Materials with less available energy are less likely to accommodate large strains and thus fail catastrophically.

Superconductivity

1. MS-PS1-4 Develop a model that predicts and describes changes in particle motion, temperature, and state of a pure substance when thermal energy is added or removed.
   - The experiment itself supports the theory developed by famous physicists John Bardeen, Leon Cooper, and John Schrieffer that the nature of the electron movement in the superconductor changes below a critical temperature.
2. MS-PS2-3 Ask questions about data to determine the factors that affect the strength of electric and magnetic forces.
   - Students should assess the effect of using different magnets on the levitation of the superconductor.

Cold and Hot Processing of Materials

1. MS-PS1-4 Develop a model that predicts and describes changes in particle motion, temperature, and state of pure substance when thermal energy is added or removed.
   - Students will assess the effect of adding liquid nitrogen to a system (and thus reducing its thermal energy) on the cream and other contents.
2. ETS1.B and C Develop possible solutions and optimize the design solution.
   - This project walks students through experimental design, testing, revisiting the data, and refining solutions (by assessing the optimal amount of liquid nitrogen necessary to achieve the desired consistency of cream content).
3. MS-PS1.4 Structure and Properties of Matter
   - Students will need to explain on an atomic level the nature of each of the three main phases (solid, liquid, gas).

The Building Blocks of Ceramics

1. MS-PS1-1 Develop models to describe the atomic composition of simple molecules and extended structures.
   - Students will study and build atomic structures using ball-and-stick models. The activities will give insight about the attendant properties of materials.
2. HS-PS2-6 Communicate scientific and technical information about why the molecular-level structure is important in the functioning of designed materials.
   - This lesson shows that the arrangement of atoms, which defines the phase of the material, corresponds to different material properties. Students will be able to explain the different types of chemical bonds which give rise to material properties.

Sintering: Grain Boundaries, Interfaces, and Porosity

1. MS-PS1-1 Develop models to describe the atomic composition of simple molecules and extended structures.
   - Students will study changes in microstructure of materials. Various routes of microstructural development will be assessed.
2. HS-PS2-6 Communicate scientific and technical information about why the molecular-level structure is important in the functioning of designed materials.
   - This lesson shows that the arrangement of atoms, which defines the phase of the material, corresponds to different material properties. Students will study the densification of materials (through diffusion), and how the process can affect properties such as strength, toughness, and ductility.

Slip Casting

1. ETS1.B and C Develop possible solutions and optimize the design solution
   - This project walks students through experimental design, testing, revisiting the data, and refining solutions. Students will critically evaluate the feasibility of certain ceramics processing methods associated with slip casting, or the forming of complex ceramic parts using slip (liquid) and molds.
2. MS-ETS1-1 to 4 Engineer design criteria for middle school curriculum
   - This lesson allows for the discussion of engineering design of the complex ceramic parts. Students will assess the utility of such methods and explain the need for slip casting.