Learning Module Map and STEM Standards for Microcantilevers

Learning Module: Microcantilevers

Learning Module units (8):

- Microcantilevers Knowledge Probe (Pre-test)
- Microcantilevers Applications Overview Primary Knowledge (PK)
- Chemical Sensor Arrays (PK)
- Atomic Force Microscopes (AFMs)
- How Does a Cantilever Work? (PK)
- Microcantilever Model Activity: Resonant Frequency vs. Mass (SCME Kit Available)
- Microcantilevers Terminology and Research Activity
- Assessment

Following is a suggested map on the implementation of this learning module.

IMPORTANT STEPS	KEY POINTS	REASONS
Pre-test (Optional): Microcantilevers Knowledge Probe	Issue the participants the Knowledge Probe.	As a pre-test and then again as a post-test, you can determine the effectiveness of this learning module. This knowledge probe also identifies what the participants may or may not know about cantilevers.
Microcantilevers Applications Overview (PK)	An overview of the various applications of microcantilevers.	An introduction into the applications of microcantilevers leads to a higher understanding and success of related activities.
Chemical Sensor Arrays (PK)	A specific application of microcantilevers that is widely used in many fields.	This unit leads to a higher understanding of microcantilevers and success in related activities.

Atomic Force Microscopes (AFMs) - PK	An overview of the various types of AFMS, their applications and how they use microcantilevers.	This unit leads to a higher understanding of microcantilevers and success in related activities.
How Does a Cantilever Work?	Participants should read the PK.	An introduction into how cantilevers work will lead to more effective learning and understanding in the related activities, specifically the Microcantilever Model Activity.
Activity 1: "Microcantilever Model Activity". *There is a SCME kit for this activity that can be ordered through scme-nm.org.*	Participants work together to explore the operation of dynamic cantilevers.	This activity leads to a better understanding of how microcantilevers work in the dynamic mode of operation. The Post-Activity questions allow the opportunity to explore the applications of dynamic microcantilevers.
Activity: Terminology and Research "Microcantilevers Terminology and Research Activity"	Participants complete a crossword puzzle related to microcantilevers and answer Post-activity questions that require additional research on microcantilever applications and operations.	This activity enhances the participants' knowledge and understanding of microcantilevers and the related terminology.
Final Assessment		Participants are evaluated on what they have learned about microcantilevers, how they work, and where they are used in MEMS.

Adapted from Graupp, P. & Wrona, R. (2006) The TWI Workbook: Essential Skills for Supervisors. New York, NY. Productivity Press.

The Instructor Guides and the Participant Guides for all of these units can be downloaded from the SCME website – Educational Materials. The Participant Guides are available to the public; however, the Instructor Guides and supporting presentations and animations can be downloaded by registered users only.

STEM Standards and Benchmarks for Microcantilevers
STEM (Science, Technology, Engineering and Mathematics)

Strand I: Scientific Thinking and Practice
Standard I: Understand the processes of scientific investigations and use inquiry and scientific ways of observing, experimenting, predicting, and validating to think critically. B 1, Use accepted scientific methods to collect, analyze, and interpret data and observations and to design and conduct scientific investigations and communicate results.
Performance Standards
1. Describe the essential components of an investigation, including appropriate methodologies, proper equipment, and safety precautions.
2. Design and conduct scientific investigations that include the following:
   - testable hypotheses
   - controls and variables
   - methods to collect, analyze, and interpret data
   - results that address hypotheses being investigated
   - predictions based on results
   - re-evaluation of hypotheses and additional experimentation as necessary
   - error analysis
3. Use appropriate technologies to collect, analyze, and communicate scientific data (e.g., computers, calculators, balances, microscopes).
4. Convey results of investigations using scientific concepts, methodologies, and expressions, including the following:
   - scientific language and symbols
   - diagrams, charts, and other data displays
   - mathematical expressions and processes (e.g., mean, median, slope, proportionality)
   - clear, logical, and concise communication
   - reasoned arguments
5. Understand how scientific theories are used to explain and predict natural phenomena (e.g., plate tectonics, ocean currents, structure of atom).

Strand I: Scientific Thinking and Practice
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Benchmark II: Understand that scientific processes produce scientific knowledge that is continually evaluated, validated, revised, or rejected.
Performance Standards
1. Understand how scientific processes produce valid, reliable results, including the following:
   - consistency of explanations with data and observations
   - openness to peer review
   - full disclosure and examination of assumptions
   - testability of hypotheses
   - repeatability of experiments and reproducibility of results
3. Understand how new data and observations can result in new scientific knowledge.

4. Critically analyze an accepted explanation by reviewing current scientific knowledge.
5. Examine investigations of current interest in science (e.g., superconductivity, molecular machines, age of the universe).
6. Examine the scientific processes and logic used in investigations of past events (e.g., using data from crime scenes, fossils), investigations that can be planned in advance but are only done once (e.g., expensive or time-consuming experiments such as medical clinical trials), and investigations of phenomena that can be repeated easily and frequently.

Strand I: Scientific Thinking and Practice
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Benchmark III: Use mathematical concepts, principles, and expressions to analyze data, develop models, understand patterns and relationships, evaluate findings, and draw conclusions.
Performance Standards
1. Create multiple displays of data to analyze and explain the relationships in scientific investigations.
2. Use mathematical models to describe, explain, and predict natural phenomena.
3. Use technologies to quantify relationships in scientific hypotheses (e.g., calculators, computer spreadsheets and databases, graphing software, simulations, modeling).
4. Identify and apply measurement techniques and consider possible effects of measurement errors.
5. Use mathematics to express and establish scientific relationships (e.g., scientific notation, vectors, dimensional analysis).

Strand II: The Content of Science
Standard I (Physical Science): Understand the structure and properties of matter, the characteristics of energy, and the interactions between matter and energy.
Benchmark I: Understand the properties, underlying structure, and reactions of matter.
Performance Standards
Properties of Matter
1. Classify matter in a variety of ways (e.g., element, compound, mixture; solid, liquid, gas; acidic, basic, neutral).
2. Identify, measure, and use a variety of physical and chemical properties (e.g., electrical conductivity, density, viscosity, chemical reactivity, pH, melting point).
3. Know how to use properties to separate mixtures into pure substances (e.g., distillation, chromatography, solubility).

Structure of Matter
5. Understand that matter is made of atoms and that atoms are made of subatomic particles.
6. Understand atomic structure, including the following:
   - most space occupied by electrons
   - nucleus made of protons and neutrons
   - isotopes of an element
   - masses of proton and neutron 2000 times greater than mass of electron
   - atom held together by proton-electron electrical forces.

7. Explain how electrons determine the properties of substances by
   - interactions between atoms through transferring or sharing valence electrons,
   - ionic and covalent bonds, and
   - the ability of carbon to form a diverse array of organic structures.
9. Understand how the type and arrangement of atoms and their bonds determine macroscopic properties (e.g., boiling point, electrical conductivity, hardness of minerals).
10. Know that states of matter (i.e., solid, liquid, gas) depend on the arrangement of atoms and molecules and on their freedom of motion.

Chemical Reactions

12. Know that chemical reactions involve the rearrangement of atoms, and that they occur on many timescales (e.g., picoseconds to millennia).
13. Understand types of chemical reactions (e.g., synthesis, decomposition, combustion, redox, neutralization) and identify them as exothermic or endothermic.

Strand II: The Content of Science
Standard I (Physical Science): Understand the structure and properties of matter, the characteristics of energy, and the interactions between matter and energy.
Benchmark II: Understand the transformation and transmission of energy and how energy and matter interact.
Performance Standards

Energy Transformation and Transfer

1. Identify different forms of energy, including kinetic, gravitational (potential), chemical, thermal, nuclear, and electromagnetic.
3. Understand that energy can change from one form to another (e.g., changes in kinetic and potential energy in a gravitational field, heats of reaction, hydroelectric dams) and know that energy is conserved in these changes.
5. Explain how heat flows in terms of the transfer of vibrational motion of atoms and molecules from hotter to colder regions.
6. Understand that the ability of energy to do something useful (work) tends to decrease (and never increases) as energy is converted from one form to another.

Interactions of Energy and Matter

7. Understand that electromagnetic waves carry energy that can be transferred when they interact with matter.
8. Describe the characteristics of electromagnetic waves (e.g., visible light, radio, microwave, X-ray, ultraviolet, gamma) and other waves (e.g., sound, seismic waves, water waves), including
   - origin and potential hazards of various forms of electromagnetic radiation, and
   - energy of electromagnetic waves carried in discrete energy packets (photons) whose energy is inversely proportional to wavelength.

Strand II: The Content of Science
Standard I (Physical Science): Understand the structure and properties of matter, the characteristics of energy, and the interactions between matter and energy.
Benchmark III: Understand the motion of objects and waves, and the forces that cause them.

Performance Standards

Forces

1. Know that there are four fundamental forces in nature: gravitation, electromagnetism, weak nuclear force, and strong nuclear force.
2. Know that every object exerts gravitational force on every other object, and how this force depends on the masses of the objects and the distance between them.
3. Know that materials containing equal amounts of positive and negative charges are electrically neutral, but that a small excess or deficit of negative charges produces significant electrical forces.
4. Understand the relationship between force and pressure, and how the pressure of a volume of gas depends on the temperature and the amount of gas.
5. Explain how electric currents cause magnetism and how changing magnetic fields produce electricity (e.g., electric motors, generators).
7. Know that when one object exerts a force on a second object, the second object exerts a force of equal magnitude and in the opposite direction on the first object (i.e., Newton's Third Law).

Motion

8. Apply Newton's Laws to describe and analyze the behavior of moving objects, including
   - displacement, velocity, and acceleration of a moving object,
   - Newton's Second Law, $F = ma$ (e.g., momentum and its conservation, the motion of an object falling under gravity, the independence of a falling object's motion on mass), and
   - circular motion and centripetal force.
9. Describe relative motion using frames of reference.
10. Describe wave propagation using amplitude, wavelength, frequency, and speed.
11. Explain how the interactions of waves can result in interference, reflection, and refraction.
12. Describe how waves are used for practical purposes (e.g., seismic data, acoustic effects, Doppler effect).

Strand II: The Content of Science
Standard II (Life Science): Understand the properties, structures, and processes of living things and the interdependence of living things and their environments.
Benchmark I: Understand how the survival of species depends on biodiversity and on complex interactions, including the cycling of matter and the flow of energy.
Performance Standards
Ecosystems

1. Know that an ecosystem is complex and may exhibit fluctuations around a steady state or may evolve over time.
4. Critically analyze how humans modify and change ecosystems (e.g., harvesting, pollution, population growth, technology).

Strand II: The Content of Science
Standard II (Life Science): Understand the properties, structures, and processes of living things and the interdependence of living things and their environments.
Benchmark II: Understand the genetic basis for inheritance and the basic concepts of biological evolution.
Performance Standards

Genetics

1. Know how DNA carries all genetic information in the units of heredity called genes, including
   - the structure of DNA **(**e.g., subunits A, G, C, T),
   - information-preserving replication of DNA, and
   - alteration of genes by inserting, deleting, or substituting parts of DNA.
4. Identify traits that can and cannot be inherited.

Strand II: The Content of Science

Standard II (Life Science): Understand the properties, structures, and processes of living things and the interdependence of living things and their environments.

Benchmark III: Understand the characteristics, structures, and functions of cells.

Performance Standards

1. Know that cells are made of proteins composed of combinations of amino acids.
2. Know that specialized structures inside cells in most organisms carry out different functions, including the following:
   - parts of a cell and their functions (e.g., nucleus, chromosomes, plasma, and mitochondria)
   - storage of genetic material in DNA
   - similarities and differences between plant and animal cells
   - prokaryotic and eukaryotic cells
3. Describe the mechanisms for cellular processes (e.g., energy production and storage, transport of molecules, waste disposal, synthesis of new molecules).
4. Know how the cell membrane controls which ions and molecules enter and leave the cell based on membrane permeability and transport (i.e., osmosis, diffusion, active transport, passive transport).

Biochemical Mechanisms

7. Describe how most cell functions involve chemical reactions, including
   - promotion or inhibition of biochemical reactions by enzymes,
   - processes of respiration (e.g., energy production, ATP), and
   - communication from cell to cell by secretion of a variety of chemicals (e.g., hormones).

Strand III: Science and Society

Standard I: Understand how scientific discoveries, inventions, practices, and knowledge influence, and are influenced by, individuals and societies.

Benchmark I: Examine and analyze how scientific discoveries and their applications affect the world, and explain how societies influence scientific investigations and applications.

Performance Standards

Science and Technology

1. Know how science enables technology but also constrains it, and recognize the difference between real technology and science fiction (e.g., rockets vs. antigravity machines; nuclear reactors vs. perpetual-motion machines; medical X-rays vs. Star-Trek tricorders).
2. Understand how advances in technology enable further advances in science (e.g., microscopes and cellular structure; telescopes and understanding of the universe).
3. Evaluate the influences of technology on society (e.g., communications, petroleum, transportation, nuclear energy, computers, medicine, genetic engineering) including both desired and undesired effects, and including some historical examples (e.g., the wheel, the plow, the printing press, the lightning rod).
4. Understand the scientific foundations of common technologies (e.g., kitchen appliances, radio,

television, aircraft, rockets, computers, medical X-rays, selective breeding, fertilizers and pesticides, agricultural equipment).

5. Understand that applications of genetics can meet human needs and can create new problems (e.g., agriculture, medicine, cloning).
6. Analyze the impact of digital technologies on the availability, creation, and dissemination of information.

Science and Society

9. Describe how scientific knowledge helps decision makers with local, national, and global challenges (e.g., Waste Isolation Pilot Project [WIPP], mining, drought, population growth, alternative energy, climate change).
10. Describe major historical changes in scientific perspectives (e.g., atomic theory, germs, cosmology, relativity, plate tectonics, evolution) and the experimental observations that triggered them.
11. Know that societal factors can promote or constrain scientific discovery (e.g., government funding, laws and regulations about human cloning and genetically modified organisms, gender and ethnic bias, AIDS research, alternative-energy research).
12. Explain how societies can change ecosystems and how these changes can be reversible or irreversible.
13. Describe how environmental, economic, and political interests impact resource management and use in New Mexico.

Science and Individuals

15. Identify how science has produced knowledge that is relevant to individual health and material prosperity.