Lesson Title: What’s so bad about hitting rock bottom?

Unit: Living Breakwaters (LB) Curriculum: Restoration and Resilience in Raritan Bay
Sub-Unit: LB Energy Webs Series: Which critters do you hope to find at the Living Breakwaters?

LESSON OVERVIEW

Grade: 6-8  Class Periods: 1-2  Setting: classroom  Subject Area(s): science, ELA

Lesson Summary
Students model a mostly-hypothetical energy web of Raritan Bay ecosystems over hard, rocky bottom -- a habitat that will be a lot more plentiful after the Living Breakwaters are installed. They compare that to the energy web they developed in the previous lesson based on soft-bottom habitats -- which are already plentiful in Raritan Bay, prior to the installation of the Living Breakwaters. Finally, students evaluate an intermediate-type bottom habitat: gravel and loose shell.

Objective(s)
- Identify the organisms of Raritan Bay that inhabit hard, rocky bottomed areas during particular life stages.
- Characterize energy webs -- for example by species richness, number of trophic levels, etc.
- Compare and contrast features of soft-bottom and hard-bottom energy webs of Raritan Bay.
- Draw inferences about an intermediate case: bottom habitats that consist of gravel and loose shell.

MATERIALS & RESOURCES

Supplies
- String (depending on how many students you have you may need a couple hundred yards and it’s always good to have extra)
- Clipboards (one for every student)
- Scissors
- Basic classroom supplies like markers and paper

Handouts
- Energy Web Sketch
- Inhabitants Cards: Raritan Bay -- one card per student, selected as follows:
  - To make the energy webs work, be sure to use the cards for the Sun
- Detritus
- and bacteria

You will only use the cards for critters that can inhabit hard-bottom habitats (rocks, shipwrecks, submerged subway cars -- that’s a thing). You might ask students to figure out which critters those are. For reference:

- The following critters require rocky or hard bottom and should be included in the activity:
  - Oyster settler larva
  - Oyster spat
  - Oyster adult
  - Feather blenny embryo inside egg
  - Feather blenny juvenile
  - Feather blenny adult
  - Blue mussel
  - Barnacle
  - Cunner
  - Naked goby
  - Sea lettuce
  - Bladderwrack
  - Tubular hydroid
  - Oyster drills
  - Oyster toadfish
  - Ghost anemone

- The following critters technically do not require hard bottom, but they will need it very soon, so they should be included in the activity:
  - Oyster embryo inside egg
  - Oyster free-swimming larva
  - Atlantic striped bass feeding & settling larva
  - Feather blenny yolk-sac larva
  - Feather blenny feeding larva

- The following critters can at least tolerate hard bottom, and they might eat something they can find there, so they should be included in the activity:
  - Blue crab megalops settler larva
  - Blue crab juvenile
  - Blue crab adult
  - Atlantic striped bass juvenile
  - Atlantic striped bass adult
  - Eel elver juvenile
  - Tautog
  - Black sea bass
  - Atlantic Menhaden
  - Bay anchovy
  - Bluefish adult

- The following critters are not particular about the type of bottom, but they are critical links in the energy web and must be included in the activity:
  - Diatoms
  - Dinoflagellates
At least a few top predators other than fish, such as:
- Double-crested cormorant
- Humpback whale
- Harbor seal
- Humans (there is no card for humans, though)

All or most of the primary consumers and detritivores:
- Calanoid copepod
- Gammarid amphipod
- Caprellid amphipod
- Isopods
- Bristleworms

Include lion’s mane jellyfish, because they dominate our waters when our ecosystem management fails, we overfish from the higher trophic levels, and there is a shortage of apex predators

The following critters need soft bottom but not necessarily mud or sand. They can do well over loose shell or gravel. For a more complex discussion, include them as options that your students can choose to discuss. For a more straightforward discussion, exclude them from the activity.
- Summer flounder

The following critters can technically tolerate hard bottom, but they will need soft bottom very soon, so they should probably not be included in the activity:
- Eelgrass mature seed

For your reference, the following critters require soft bottom on at least a daily basis, and should not be used in this exercise:
- Eelgrass embryo inside egg
- Eelgrass seedling
- Eelgrass adult
- Hard clam
- American sand lance
- Winter flounder

Lesson Materials
- Optional: to follow up on the question of climate vulnerability in the Extend section of the lesson, students can access NOAA’s Northeast Fish and Shellfish Climate Vulnerability Assessment for 82 species.

BEFORE YOU GET STARTED

Tips for Teachers
- The method of creating a full-class energy web is the same in this lesson and in Who are the muckety-mucks in Raritan Bay? The difference is that this lesson models an energy web in a hard-bottom habitat in Raritan Bay, whereas the ‘muck’ lesson models an energy web in a soft-bottom habitat in Raritan Bay.

- If you have not taught Who are the muckety-mucks of Raritan Bay? or for any other reason your students do not have sketches of soft-bottom energy webs, skip the Elaborate section of this lesson.
Preparation

● If you taught *Who are the muckety-mucks of Raritan Bay*? and your students developed improvements to the simple model we presented -- in which one piece of string shows the path of energy transfer, but there is no indication of the *amount* of energy transfer, or even of the dissipation of energy as heat at every step -- prepare the materials the class will need to create a new energy web in this lesson, using their improved approach to modeling an energy web.

● If you taught *Who are the muckety-mucks of Raritan Bay*? and your students sketched the soft-bottom energy web, they will need those sketches for comparison in the *Elaborate* section of this lesson.

● You will need enough space to get your whole class standing in a circle, with nothing in the middle of the circle. You could move desks out of the way in the classroom, go outdoors, or go into a gymnasium.

● Cards should be printed with the photograph on one side of the card and the information on the other side of the card.

● All cards should be laminated, hole punched and strung, so they hang around a student’s neck. This allows the students to be hands-free during the activity.

● Decide beforehand if you or your students will pick out the relevant *Inhabitant Cards: Raritan Bay*: the ones that inhabit sandy and/or muddy bottoms,

● Remember to include bacteria, the Sun, and detritus.

● Decide in advance how you will assign each student their card. Randomly? Based on students’ prior questions or interest?

**INSTRUCTION PLAN**

**Engage**

1. Except for three, each student selects one *Inhabitants of Raritan Bay Card* for a critter that can inhabit a place with a HARD or ROCKY bottom.
   ○ The other three students the Sun card, the detritus card, and the bacteria card.

2. Each student wears their card around their neck, and the students form a circle, facing inward.

3. Explain: You are going to model an energy web. The string represents the *path of energy transfer* through the ecosystem.

4. ‘The Sun’ gets the end of the string because it is the ultimate source of all the energy in Raritan Bay ecosystems.
   ○ The students look at their cards to figure out who gets energy from the Sun.
   ○ Based on the responses, connect the string to an organism - and then another that gets its energy by consuming the first, and another, and another - until you get to a
what feels to the students like a stopping point -- most likely a top-level consumer or a decomposer.

Explore

1. Ask: What should happen to the string now?
   - If necessary explain: In this food chain, the energy that was originally captured from the Sun by a primary producer (plant or algae) is mostly needed by that primary producer to live its life, but whoever eats the plant or algae can get some of that energy. That animal needs most of that energy, but another animal can get a little of it by consuming that organism. And this continues until we get to our apex predator.

   As the organisms live and their bodies are digested, all of that energy eventually dissipates as heat -- into the water, sediment, air, etc. Ultimately that heat will leave the Earth as radiation into outer space, in the same way that the energy traveled to the Earth system as radiation from the Sun.

   The string represents the path of energy transfer, so there must be places where the string exits the energy web, to make its way to outer space. For now let’s cut the string, leaving a frayed piece hanging down, to represent energy leaving the ecosystem.

   Ask: can you find a place where some energy should exit the energy web? [The correct answer is: at every step, but it’s ok if the students don’t get to that right away They might suggest the apex predator or the decomposer, and they are not wrong.]

2. Cut the string and use a new piece of string to start at ‘The Sun’. Note that this is a different path of energy transfer, and it represents a different little packet of energy from the Sun, or, if you like, a different ray of sunshine -- from a different place, or a different moment in time, or both.

3. Continue with this process until everyone in the class is holding at least one piece of string. (It’s okay if some students are connected to the web multiple times, and some are only connected once).

4. If it has not already come up, discuss decomposers (i.e. bacteria) in more detail and allow students to ask questions. If necessary, explain:
   - Sometimes decomposers don’t act quickly, and dead organic matter stays in undigested pieces -- that’s detritus.

5. Explain: We have just created a representation - a model - of how energy moves through an ecosystem, starting from the Sun, through a series of organisms, and eventually into outer space.

6. Ask: What are the benefits and limitations of this model? What parts of the energy transfer
process does it help us understand better”? What parts of the process are still unclear or confusing?

7. If necessary, clarify now: The energy transfer in this web is represented by the string, and we’ve made it seem like a unit of solar energy can be captured by a photosynthesizer and passed all the way up the food chain. That can’t be right, because organisms use energy to live (if they couldn’t use the energy, why would they go after it?). As they use the energy to live their lives, most of it dissipates from their bodies as heat.

8. Ask:
   - What can we change about our model that would show the energy dissipation (energy exiting the web) during the life of each organism -- before that organism gets eaten by a predator?
   - Students work in small groups to create a visual representation of the dissipation as heat of energy during each organism’s life
     ■ The use basic classroom supplies like markers, paper and scissors to prompt some creative thinking about how to represent energy dissipation.

9. Groups take turns and present their visual representation of the dissipation of energy by each critter -- energy that does not get transferred to the critter’s consumers.

**Explain**

1. Hand out a clipboard to each student.
2. Ask students to secure their string(s) in the clip of the clipboard.
3. On the count of three, the students put their clipboards down at their feet, thereby putting the entire food web down on the ground.
4. Students get into pairs or small groups and complete the *Energy Web Questions* worksheet.
5. Circle up again to look at the food web and review the worksheet.
6. Consider asking the following types of questions:
   - In this energy web, where does the energy originate? (the sun)
   - What types of organisms can get their energy directly from the sun? (photosynthesizers, including plants, phytoplankton, and macroalgae)
   - How do the other organisms in this food web obtain energy? (predation)
   - Once an organism has energy where does the energy go and what is it used for? (used for growth and other life processes, and eventually dissipates as heat energy that ultimately leaves the Earth as radiation)
7. Each student completes an *Energy Web Sketch* of the Hard Bottom Energy Web model
they've created. Be sure that the students are using labels on their sketch.

- This would be a good time to break until the next class period, so you can select and distribute a couple of the students' Soft Bottom Energy Web Sketches

**Elaborate**

1. Students review their Soft Bottom Energy Web sketch to their Hard Bottom energy web sketch. They try to add ALL the connections that can be made in each web before going on to compare them to one another.

2. Students can figure out how to compare and contrast the two energy webs. And/or you can ask questions like:
   - Which do you think would be the best place to go fishing?
   - Which do you think would be the best place to go swimming, boating, snorkeling, or diving?
   - If you list the critters in each habitat side-by-side, what do you notice?
   - If you count the types of critters in each habitat what do you notice? Note: this is essentially 'species richness', one measure of biodiversity
   - If you look up which animal phyla are represented in each energy web, what do you notice?
   - How tightly-linked does each web seem to be? Would it be fair to say that one looks 'looser' than the other?
     - Is that an abiding characteristic of this web, or just an artifact of the way it is drawn? How could we check?
   - And so on, e.g.:
     - which types of photosynthesizers (plants, macroalgae, microalgae aka phytoplankton, and/or bacteria)
     - Number of connections in the whole web
     - Number of connections per critter -- average number, typical number, and/or the distribution of the number of connections per critter
     - Number of steps from primary producer to top predator 'number of trophic levels'
     - Proportion of critters that have more than one source of energy, more than two sources, etc. 'generalists' have many energy sources, while 'specialists' have fewer.
- Proportion of critters that are competing with other critters for the same energy sources
  - competition ‘pressure’

- Proportion of critters that have multiple predators
  - Note: these may be more ‘vulnerable’ to disruptions in their populations.

- Do you think one of the webs is more vulnerable to climate change? Would you guess that one of them is especially resilient to climate change?
  - Note: if this question stirs up some interest, consider teaching “Extension 1” from the Extend section of the lesson, in which students research the climate vulnerability of individual critters, and then apply that information to make predictions about Raritan Bay energy webs in the future under climate change.

- In general, what would you guess would make an energy web more resilient to changes in the environment, and/or changes in the populations of critters in the webs?
  - Note: there is no clear right answer to this question.

  In general,
  - we know that networks are more stable when they have redundant connections.
  - we know that the extreme case of species poverty, monoculture, is very sensitive to disruption (not resilient)
  - there is evidence that biodiversity contributes to the resilience of ecosystems.

But ecosystems are much too complex to follow simple rules, so it is not surprising that there are also plenty of documented cases where biodiversity by itself did not increase an ecosystem’s resilience to disruption. This is an active topic of contemporary research!

Evaluate

1. Say:
   - In some ways, gravel and loose shell represent a bottom type that is in between soft bottom (tiniest particles of rock) and hard bottom (largest pieces of rock). Individual shells, and individual pieces of gravel are medium-sized

   - Do you think that means that gravel and shell would be the best possible habitat for Raritan Bay?
     - Is gravel/shell the best of both worlds?
     - The worst of both worlds?
     - Neither?
     - What additional information would make you more confident about your answer?”
2. Ask:
   ○ Why do you think it is common for hobbyists to include gravel in their fish tanks?
   ○ Do you think we should have gravel and/or loose shells in our oyster tank?
     ■ What difference do you think it could make either way?
     ■ Why do you think so?
   ○ Do we need mud and/or sand in our oyster tank?
   ○ Do we need to provide hard surfaces and/or rocks in our oyster tank?

Extend
Extension 1:
1. Students research the climate vulnerability of selected critters, available through NOAA’s Northeast Fish and Shellfish Climate Vulnerability Assessment. To access each species report, scroll down to “Species-Specific Results”. There, hover over: “Coastal Fish”, “Diadromous Fish”, “Pelagic Fish and Cephalopods”, and “Benthic Invertebrates” for reports on relevant species. From this lesson’s list of soft-bottom inhabitants, they can find reports on:
   ● Blue crab
   ● Striped bass
   ● American eel
   ● Hard clam (which NOAA lists as Northern Quahog)
   ● Tautog
   ● Black sea bass
   ● Sandlance
   ● Anchovies
   ● Blue mussel
   ● Summer flounder
   ● Winter flounder
   ● Bluefish
   ● Blood worm (one type of bristleworm)

2. Based on their research, students modify their energy webs to reflect predicted changes in populations of these species.

Extension 2:
Ask:
● Why do you think that the English-language expression ‘to hit rock bottom’ has strong negative connotations, when there are so many organisms that need that rocky bottom?

● What kinds of things could have happened to people, to make them think about hitting rock bottom as the worst moment in a person’s life?

● What’s so different about these critters compared with humans (who invent English), that makes rock bottom a neutral, positive, or even necessary thing in those critters’ lives?
Featured image:

Featured image credit:
Model Image produced with FoodWeb3D, written by R.J. Williams and provided by the Pacific Ecoinformatics and Computational Ecology Lab (www.foodwebs.org, Yoon et al. 2004).

Photograph of oyster toadfish in Raritan Bay rocky environment courtesy of SeArc Ecological Marine Consulting

Standards --
NYC Scope and Sequence Grade 5

Crosscutting Concepts
● A system can be described in terms of its components and their interactions. (5-LS2-1)

Science and Engineering Practices
● Develop a model to describe phenomena. (5-PS1-1), (5-LS2-1)
● Use models to describe phenomena. (5-PS3-1)
● critiquing the scientific explanations or solutions proposed by peers by citing relevant evidence about the natural and designed world(s). Support an argument with evidence, data, or a model.

Grade 5 Unit 2: Matter and Energy in Ecosystems -- How do matter and energy flow through ecosystems?

Disciplinary Core Ideas organized by Performance Expectations
● 5-PS3-1. Use models to describe that energy in animals’ food (used for body repair, growth, motion, and to maintain body warmth) was once energy from the Sun.
   ○ Emphasis should be on plants converting light energy by photosynthesis into usable energy. Examples of models could include diagrams and flow charts.
● 5-LS1-1. Support an argument that plants get the materials they need for growth chiefly from air and water.
   ○ Emphasis is on the idea that plant matter comes mostly from air and water, not from the soil.
● 5-LS2-1. Develop a model to describe the movement of matter among plants (producers), animals (consumers), decomposers, and the environment.
   ○ Emphasis is on the flow of energy and cycling of matter in systems such as organisms, ecosystems, and/or Earth.
   ○ Assessment does not include molecular explanations.
   ○ LS2.A: Interdependent Relationships in Ecosystems
     ■ The food of almost any kind of animal can be traced back to plants. Organisms are related in food webs in which some animals eat plants for food and other animals eat the animals that eat plants. Some organisms, such as fungi and
bacteria, break down dead organisms (both plants or plant parts and animals) and therefore operate as “decomposers.” Decomposition eventually restores (recycles) some materials back to the soil. Organisms can survive only in environments in which their particular needs are met. A healthy ecosystem is one in which multiple species of different types are each able to meet their needs in a relatively stable web of life. Newly introduced species can damage the balance of an ecosystem. (5-LS2-1)

NYC Scope and Sequence Science 6-8

Science and Engineering Practices

- extending quantitative analysis to investigations, distinguishing between correlation and causation, and basic statistical techniques of data and error analysis
- Construct an explanation that includes qualitative or quantitative relationships between variables that predict phenomena
  - supported by multiple sources of evidence consistent with scientific ideas, principles, and theories.
- Develop and use a model to describe, test, and predict more abstract phenomena
- argument that supports or refutes claims for either explanations or solutions about the natural and designed world(s).

Crosscutting Concepts

- Patterns can be used to identify cause and effect relationships. (MS-LS2-2)
- Cause and effect relationships may be used to predict phenomena in natural or designed systems. (MS-LS2-1)
- The transfer of energy can be tracked as energy flows through a natural system. (MS-LS2-3)
- Small changes in one part of a system might cause large changes in another part. (MS-LS2-4), (MS-LS2-5)
- Phenomena may have more than one cause, and some cause and effect relationships in systems can only be described using probability. (MS-LS1-4), (MS-LS1-5)
- Structures… can be visualized… and used to describe how their function depends on the shapes, composition, and relationships among their parts (MS-LS3-1)

Grade 6, Unit 3: Ecosystems -- Why does the Earth never run out of matter or energy?

Disciplinary Core Ideas organized by Performance Expectations

- MS-LS2-1. Analyze and interpret data to provide evidence for the effects of resource availability on organisms and populations of organisms in an ecosystem.
  - Emphasis is on cause and effect relationships between resources and growth of individual organisms and the numbers of organisms in ecosystems during periods of abundant and scarce resources.
  - Growth of organisms and population increases are limited by access to resources. (MS-LS2-1)
  - In any ecosystem, organisms and populations with similar requirements for food, water, oxygen, or other resources may compete with each other for limited resources, access to which consequently constrains their growth and reproduction. (MS-LS2-1)
  - Organisms, and populations of organisms, are dependent on their environmental interactions both with other living things and with nonliving factors. (MS-LS2-1)
• MS-LS2-2. Construct an explanation that predicts patterns of interactions among organisms in a variety of ecosystems.
  ○ Emphasis is on predicting patterns of interactions such as competition, predation, mutualism, and parasitism in different ecosystems in terms of the relationships among and between organisms.
  ○ Predatory interactions may reduce the number of organisms or eliminate whole populations of organisms. Mutually beneficial interactions, in contrast, may become so interdependent that each organism requires the other for survival. Although the species involved in these competitive, predatory, and mutually beneficial interactions vary across ecosystems, the patterns of interactions of organisms with their environments, both living and nonliving, are shared. (MS-LS2-2)

• MS-LS2-3. Develop a model to describe the cycling of matter and flow of energy among living and nonliving parts of an ecosystem.
  ○ Emphasis is on describing the conservation of matter and flow of energy associated with ecosystem, and on defining the boundaries of the ecosystem.
  ○ Assessment does not include the use of chemical reactions to describe the processes.
  ○ Food webs are models that demonstrate how matter and energy is transferred between producers, consumers, and decomposers as the three groups interact within an ecosystem. Transfers of matter into and out of the physical environment occur at every level. Decomposers recycle nutrients from dead plant or animal matter back to the soil in terrestrial environments or to the water in aquatic environments. The atoms that make up the organisms in an ecosystem are cycled repeatedly between the living and nonliving parts of the ecosystem. (MS-LS2-3)

• MS-LS2-4. Construct an argument supported by empirical evidence that changes to physical or biological components of an ecosystem affect populations.
  ○ Emphasis is on recognizing patterns in data and making warranted inferences about shifts in populations due to changes in the ecosystem.
  ○ Ecosystems are dynamic in nature; their characteristics can vary over time. Disruptions to any physical or biological component of an ecosystem can lead to shifts in all its populations. (MS-LS2-4)

• MS-LS2-5. Evaluate competing design solutions for maintaining biodiversity and protecting ecosystem stability.
  ○ Examples of ecosystem protections could include water purification, waste management, nutrient recycling, prevention of soil erosion, and eradication of invasive species. Examples of design solution constraints could include scientific, economic, and social considerations.
  ○ Biodiversity describes the variety of species found in Earth’s ecosystems. The completeness or integrity of an ecosystem’s biodiversity is often used as a measure of its health. (MS-LS2-5)
  ○ Changes in biodiversity can influence humans’ resources, such as food, energy, and medicines, as well as ecosystem services that humans rely on—for example, water purification and recycling. (secondary to MS-LS2-5)
  ○ Humans impact biodiversity both positively and negatively. (secondary to MS-LS2-5)
Influence of Science, Engineering, and Technology on Society and the Natural World

- The use of technologies and any limitations on their use are driven by individual or societal needs, desires, and values; by the findings of scientific research; and by differences in such factors as climate, natural resources, and economic conditions. Thus technology use varies from region to region and over time. (MS-LS2-5)

Science Addresses Questions About the Natural and Material World

- Scientific knowledge can describe the consequences of actions but does not necessarily prescribe the decisions that society takes. (MS-LS2-5)

Grade 8, Unit 3: Growth, Development, and Reproduction of Organisms

Disciplinary Core Ideas organized by Performance Expectations

- MS-LS1-4. Use argument based on empirical evidence and scientific reasoning to support an explanation for how characteristic animal behaviors and specialized plant structures affect the probability of successful reproduction of animals and plants, respectively.
  - Clarification Statement: Examples of behaviors that affect the probability of animal reproduction could include nest building to protect young from cold, herding of animals to protect young from predators, and vocalization of animals and colorful plumage to attract mates for breeding. Examples of animal behaviors that affect the probability of plant reproduction could include transferring pollen or seeds, and creating conditions for seed germination and growth. Examples of plant structures could include bright flowers attracting butterflies that transfer pollen, flower nectar and odors that attract insects that transfer pollen, and hard shells on nuts that squirrels bury.
  - Animals engage in characteristic behaviors that increase the odds of reproduction. (MS-LS1-4)
  - Plants reproduce in a variety of ways, sometimes depending on animal behavior and specialized features for reproduction. (MS-LS1-4)

- MS-LS1-5. Construct a scientific explanation based on evidence for how environmental and genetic factors influence the growth of organisms.
  - Examples of local environmental conditions could include availability of food, light, space, and water. Examples of genetic factors could include the genes responsible for size differences in different breeds of dogs. Examples of evidence could include drought decreasing plant growth, fertilizer increasing plant growth, different varieties of plant seeds growing at different rates in different conditions, and fish growing larger in large ponds than they do in small ponds.
  - Assessment does not include genetic mechanisms, gene regulation, biochemical processes, or natural selection.
  - Genetic factors as well as local conditions affect the growth of the adult plant. (MS-LS1-5)

Grade 8, Unit 4: Evolution, Natural Selection, and Adaptations

Disciplinary Core Ideas organized by Performance Expectations

- MS-LS4-3. Analyze displays of pictorial data to compare patterns of similarities in the embryological development across multiple species to identify relationships not evident in the fully formed anatomy.
  - Emphasis is on inferring general patterns of relatedness among embryos of different organisms by comparing the macroscopic appearance of diagrams or pictures.
Assessment of comparisons is limited to gross appearance of anatomical structures in embryological development.

Comparison of the embryological development of different species also reveals similarities that show relationships not evident in the fully-formed anatomy. (MS-LS4-3)

NYS NGSS -- what will be part of Living Environment

Science and Engineering Practices
- Develop a model based on evidence to illustrate the relationships between systems or components of a system. (HS-LS2-5)
- Use mathematical representations of phenomena or design solutions to support claims. (HS-LS2-4)
- Construct and revise an explanation based on valid and reliable evidence obtained from a variety of sources

Crosscutting Concepts
- Models (e.g., physical, mathematical, computer models) can be used to simulate systems and interactions—including energy, matter, and information flows—within and between systems at different scales. (HS-LS2-5)
- Energy drives the cycling of matter within and between systems. (HS-LS2-3)

Disciplinary Core Idea
- LS2.B: Cycles of Matter and Energy Transfer in Ecosystems
  Plants or algae form the lowest level of the food web. At each link upward in a food web, only a small fraction of the matter consumed at the lower level is transferred upward, to produce growth and release energy in cellular respiration at the higher level. Given this inefficiency, there are generally fewer organisms at higher levels of a food web. The chemical elements that make up the molecules of organisms pass through food webs and into and out of the atmosphere and soil, and they are combined and recombined in different ways. At each link in an ecosystem, matter and energy are conserved. (HS-LS2-4)

Connection to the Nature of Science
- Most scientific knowledge is quite durable, but is, in principle, subject to change based on new evidence and/or reinterpretation of existing evidence. (HS-LS2-3)

NGSS High School standards

Disciplinary Core Ideas
- LS1.A Structure and function
  Systems of specialized cells within organisms help perform essential functions of life. Any one system in an organism is made up of numerous parts. Feedback mechanisms maintain an organism’s internal conditions within certain limits and mediate behaviors
- LS1.B Growth and development of organisms
  Growth and division of cells in organisms occurs by mitosis and differentiation for specific cell
LS2.A Interdependent relationships within ecosystems
   The fundamental tension between resource availability and organism populations affects
   the abundance of species in any given ecosystem.

LS2.B Cycles of matter and energy transfer in ecosystems
   Photosynthesis and cellular respiration provide most of the energy for life processes. Only a
   fraction of matter consumed at the lower level of a food web is transferred up, resulting in
   fewer organisms at higher levels. At each link in an ecosystem elements are combined in
   different ways and matter and energy are conserved. Photosynthesis and cellular respiration
   are key components of the global carbon cycle.

LS2.D Social interactions and group behavior
   Group behavior has evolved because membership can increase the chances of survival for
   individuals and their genetic relatives.

LS3.A Inheritance of traits
   DNA carries instructions for forming species’ characteristics. Each cell in an organism has the
   same genetic content, but genes expressed by cells can differ.

LS4.A Evidence of common ancestry and diversity
   The ongoing branching that produces multiple lines of descent can be inferred by comparing
   DNA sequences, amino acid sequences, and anatomical and embryological evidence of
   different organisms.

LS4.B Natural selection
   Natural selection occurs only if there is variation in the genes and traits between organisms in
   a population. Traits that positively affect survival can become more common in a population.

LS4.C Adaptation
   Evolution results primarily from genetic variation of individuals in a species, competition for
   resources, and proliferation of organisms better able to survive and reproduce.

Crosscutting Concepts

Patterns
   In grades 9-12, students observe patterns in systems at different scales and cite patterns as
   empirical evidence for causality in supporting their explanations of phenomena. They
   recognize classifications or explanations used at one scale may not be useful or need revision
   using a different scale; thus requiring improved investigations and experiments. They use
   mathematical representations to identify certain patterns and analyze patterns of performance
   in order to reengineer and improve a designed system.

Cause and effect
   In grades 9-12, students understand that empirical evidence is required to differentiate
   between cause and correlation and to make claims about specific causes and effects. They
   suggest cause and effect relationships to explain and predict behaviors in complex natural and
designed systems. They also propose causal relationships by examining what is known about smaller scale mechanisms within the system. They recognize changes in systems may have various causes that may not have equal effects.

- Scale, proportion, and quantity
  In grades 9-12, students understand the significance of a phenomenon is dependent on the scale, proportion, and quantity at which it occurs. They recognize patterns observable at one scale may not be observable or exist at other scales, and some systems can only be studied indirectly as they are too small, too large, too fast, or too slow to observe directly. Students use orders of magnitude to understand how a model at one scale relates to a model at another scale. They use algebraic thinking to examine scientific data and predict the effect of a change in one variable on another (e.g., linear growth vs. exponential growth).

- Systems and system models
  In grades 9-12, students can investigate or analyze a system by defining its boundaries and initial conditions, as well as its inputs and outputs. They can use models (e.g., physical, mathematical, computer models) to simulate the flow of energy, matter, and interactions within and between systems at different scales. They can also use models and simulations to predict the behavior of a system, and recognize that these predictions have limited precision and reliability due to the assumptions and approximations inherent in the models. They can also design systems to do specific tasks.

- Energy and matter: flows, cycles, and conservation
  In grades 9-12, students learn that the total amount of energy and matter in closed systems is conserved. They can describe changes of energy and matter in a system in terms of energy and matter flows into, out of, and within that system. They also learn that energy cannot be created or destroyed. It only moves between one place and another place, between objects and/or fields, or between systems. Energy drives the cycling of matter within and between systems....

- Structure and function
  In grades 9-12, students investigate systems by examining the properties of different materials, the structures of different components, and their interconnections to reveal the system’s function and/or solve a problem. They infer the functions and properties of natural and designed objects and systems from their overall structure, the way their components are shaped and used, and the molecular substructures of their various materials.

- Stability and change
  In grades 9-12, students understand much of science deals with constructing explanations of how things change and how they remain stable. They quantify and model changes in systems over very short or very long periods of time. They see some changes are irreversible, and negative feedback can stabilize a system, while positive feedback can destabilize it. They recognize systems can be designed for greater or lesser stability.

Science and Engineering Practices
- Asking questions (for science) and defining problems (for engineering)
  ...in 9–12 progresses to formulating, refining, and evaluating empirically testable questions and design problems using models and simulations.
○ Ask questions
  ■ that arise from careful observation of phenomena, or unexpected results, to clarify and/or seek additional information.
  ■ that arise from examining models or a theory, to clarify and/or seek additional information and relationships.
  ■ to determine relationships, including quantitative relationships, between independent and dependent variables.
  ■ to clarify and refine a model, an explanation, or an engineering problem.
○ Evaluate a question to determine if it is testable and relevant.
○ Ask questions that can be investigated within the scope of the school laboratory, research facilities, or field (e.g., outdoor environment) with available resources and, when appropriate, frame a hypothesis based on a model or theory.
○ Ask and/or evaluate questions that challenge the premise(s) of an argument, the interpretation of a data set, or the suitability of a design.
○ Define a design problem that involves the development of a process or system with interacting components and criteria and constraints that may include social, technical, and/or environmental considerations.

● Developing and using models
...in 9-12 progresses to using, synthesizing, and developing models to predict and show relationships among variables between systems and their components in the natural and designed worlds.
○ Evaluate merits and limitations of two different models of the same proposed tool, process, mechanism or system in order to select or revise a model that best fits the evidence or design criteria.
○ Design a test of a model to ascertain its reliability.
○ Develop, revise, and/or use a model based on evidence to illustrate and/or predict the relationships between systems or between components of a system.
○ Develop and/or use multiple types of models to provide mechanistic accounts and/or predict phenomena, and move flexibly between model types based on merits and limitations.
○ Develop a complex model that allows for manipulation and testing of a proposed process or system.
○ Develop and/or use a model (including mathematical and computational) to generate data to support explanations, predict phenomena, analyze systems, and/or solve problems.

● Planning and carrying out investigations
...in 9-12 progresses to include investigations that provide evidence for and test conceptual, mathematical, physical, and empirical models.
○ Plan an investigation or test a design individually and collaboratively to produce data to serve as the basis for evidence as part of building and revising models, supporting explanations for phenomena, or testing solutions to problems. Consider possible confounding variables or effects and evaluate the investigation’s design to ensure variables are controlled.
○ Plan and conduct an investigation individually and collaboratively to produce data to serve as the basis for evidence, and in the design: decide on types, how much, and accuracy of data needed to produce reliable measurements and consider limitations on
the precision of the data (e.g., number of trials, cost, risk, time), and refine the design accordingly.

- Plan and conduct an investigation or test a design solution in a safe and ethical manner including considerations of environmental, social, and personal impacts.
- Select appropriate tools to collect, record, analyze, and evaluate data.
- Make directional hypotheses that specify what happens to a dependent variable when an independent variable is manipulated.
- Manipulate variables and collect data about a complex model of a proposed process or system to identify failure points or improve performance relative to criteria for success or other variables.

- Analyzing and interpreting data
  ...in 9-12 progresses to introducing more detailed statistical analysis, the comparison of data sets for consistency, and the use of models to generate and analyze data.
  - Analyze data using tools, technologies, and/or models (e.g., computational, mathematical) in order to make valid and reliable scientific claims or determine an optimal design solution.
  - Apply concepts of statistics and probability (including determining function fits to data, slope, intercept, and correlation coefficient for linear fits) to scientific and engineering questions and problems, using digital tools when feasible.
  - Consider limitations of data analysis (e.g., measurement error, sample selection) when analyzing and interpreting data.
  - Compare and contrast various types of data sets (e.g., self-generated, archival) to examine consistency of measurements and observations.
  - Evaluate the impact of new data on a working explanation and/or model of a proposed process or system.
  - Analyze data to identify design features or characteristics of the components of a proposed process or system to optimize it relative to criteria for success.

- Using mathematics and computational thinking
  ...in 9-12 progresses to using algebraic thinking and analysis, a range of linear and nonlinear functions including trigonometric functions, exponentials and logarithms, and computational tools for statistical analysis to analyze, represent, and model data. Simple computational simulations are created and used based on mathematical models of basic assumptions.
  - Create and/or revise a computational model or simulation of a phenomenon, designed device, process, or system.
  - Use mathematical, computational, and/or algorithmic representations of phenomena or design solutions to describe and/or support claims and/or explanations.
  - Apply techniques of algebra and functions to represent and solve scientific and engineering problems.
  - Use simple limit cases to test mathematical expressions, computer programs, algorithms, or simulations of a process or system to see if a model “makes sense” by comparing the outcomes with what is known about the real world.
  - Apply ratios, rates, percentages, and unit conversions in the context of complicated measurement problems involving quantities with derived or compound units (such as mg/mL, kg/m³, acre-feet, etc.)
- Constructing explanations (for science) and designing solutions (for engineering) ...in 9-12 progresses to explanations and designs that are supported by multiple and independent student-generated sources of evidence consistent with scientific ideas, principles, and theories.
  ○ Make a quantitative and/or qualitative claim regarding the relationship between dependent and independent variables.
  ○ Construct and revise an explanation based on valid and reliable evidence obtained from a variety of sources (including students’ own investigations, models, theories, simulations, peer review) and the assumption that theories and laws that describe the natural world operate today as they did in the past and will continue to do so in the future.
  ○ Apply scientific ideas, principles, and/or evidence to provide an explanation of phenomena and solve design problems, taking into account possible unanticipated effects.
  ○ Apply scientific reasoning, theory, and/or models to link evidence to the claims to assess the extent to which the reasoning and data support the explanation or conclusion.
  ○ Design, evaluate, and/or refine a solution to a complex real-world problem, based on scientific knowledge, student-generated sources of evidence, prioritized criteria, and tradeoff considerations.

- Engaging in argument from evidence ...in 9-12 progresses to using appropriate and sufficient evidence and scientific reasoning to defend and critique claims and explanations about the natural and designed world(s). Arguments may also come from current scientific or historical episodes in science.
  ○ Compare and evaluate competing arguments or design solutions in light of currently accepted explanations, new evidence, limitations (e.g., trade-offs), constraints, and ethical issues.
  ○ Evaluate the claims, evidence, and/or reasoning behind currently accepted explanations or solutions to determine the merits of arguments.
  ○ Respectfully provide and/or receive critiques on scientific arguments by probing reasoning and evidence, challenging ideas and conclusions, responding thoughtfully to diverse perspectives, and determining additional information required to resolve contradictions.
  ○ Construct, use, and/or present an oral and written argument or counter-arguments based on data and evidence.
  ○ Make and defend a claim based on evidence about the natural world or the effectiveness of a design solution that reflects scientific knowledge and student-generated evidence.
  ○ Evaluate competing design solutions to a real-world problem based on scientific ideas and principles, empirical evidence, and/or logical arguments regarding relevant factors (e.g. economic, societal, environmental, ethical considerations).

- Obtaining, evaluating, and communicating information ...in 9-12 progresses to evaluating the validity and reliability of the claims, methods, and designs.
  ○ Critically read scientific literature adapted for classroom use to determine the central ideas or conclusions and/or to obtain scientific and/or technical information to
summarize complex evidence, concepts, processes, or information presented in a text by paraphrasing them in simpler but still accurate terms.

○ Compare, integrate and evaluate sources of information presented in different media or formats (e.g., visually, quantitatively) as well as in words in order to address a scientific question or solve a problem.

○ Gather, read, and evaluate scientific and/or technical information from multiple authoritative sources, assessing the evidence and usefulness of each source.

○ Evaluate the validity and reliability of and/or synthesize multiple claims, methods, and/or designs that appear in scientific and technical texts or media reports, verifying the data when possible.

○ Communicate scientific and/or technical information or ideas (e.g. about phenomena and/or the process of development and the design and performance of a proposed process or system) in multiple formats (i.e., orally, graphically, textually, mathematically).