2017

Branching in Nature

Jennifer Welborn
Amherst Regional Middle School, welbornj@arps.org

Wayne Kermenski
Hawlemont Regional School, wkermenski@gmail.com

Patterns Around Us: Branching in Nature

Teacher Resource Page

Part A: Introduction to Branching

Massachusetts Frameworks Alignment—The Nature of Science

- Overall, the key criterion of science is that it provide a clear, rational, and succinct account of a pattern in nature. This account must be based on data gathering and analysis and other evidence obtained through direct observations or experiments, reflect inferences that are broadly shared and communicated, and be accompanied by a model that offers a naturalistic explanation expressed in conceptual, mathematical, and/or mechanical terms.

Materials: None

Background Readings About Branching in Slime Molds and Leaf Venation as a model for efficient road and railway systems

https://www.scientificamerican.com/article/brainless-slime-molds/

http://scienceblogs.com/notrocketscience/2010/01/21/slime-mould-attacks-simulates-tokyo-rail-network/

https://culturingscience.wordpress.com/2010/02/11/nature-inspired-network-design-recent-studies-in-slime-mold-and-leaf-veins/

http://www.cbc.ca/news/technology/slime-mould-mimics-tokyo-s-railway-1.972463

Part B: Regular Branching Patterns

Science Frameworks Alignment:

- Overall, the key criterion of science is that it provide a clear, rational, and succinct account of a pattern in nature. This account must be based on data gathering and analysis and other evidence obtained through direct observations or experiments, reflect inferences that are broadly shared and communicated, and be accompanied by a model that offers a naturalistic explanation expressed in conceptual, mathematical, and/or mechanical terms.
- Identify the general functions of the major systems of the human body (digestion, respiration, reproduction, circulation, excretion, protection from disease, and movement, control, and coordination) and describe ways that these systems interact with each other

Math Frameworks Alignment

- Write expressions and equations that correspond to given situations
- Understand the connections between proportional relationships, lines, and linear equations.

Materials: None

Part C: Viscous Branching

Science Frameworks Alignment:

Differentiate between mixtures and pure substances

Use and refine scientific models that simulate physical processes or phenomena.

Materials: Hele Shaw Cell, glycerin, food coloring, syringe (without needle) or eyedropper, water, oil, cups, 25 ml graduated cylinders

How to make a Hele Shaw Cell

1. Obtain a CD case. It is best to have two clear sides to the cell. If the CD case has only one side that is clear, use two CD cases.
2. Disassemble the CD cases. Drill a hole in one of the covers.
3. When making the cell, separate the two plastic sides with thin pieces of glass or plastic such as cover slips. The plastic sides should be separated only by the cover slips. This allows a material to be injected into the cell.

Part D: Branching in Roots

Frameworks Alignment

- Inquiry, experimentation, and design should not be taught or tested as separate, standalone skills. Rather, opportunities for inquiry, experimentation, and design should arise within a well-planned curriculum. Instruction and assessment should include examples drawn from life science, physical science, earth and space science, and technology/engineering standards.
- Asking questions and pursuing answers are keys to learning. Inquiry, experimentation, and design should not be taught or tested as separate, standalone skills. Rather, opportunities for inquiry, experimentation, and design should arise within a well-planned curriculum.
- Identify the structures in plants (leaves, roots, flowers, stem, bark, wood) that are responsible for food production, support, water transport, reproduction, growth, and protection.
- Recognize plant behaviors, such as the way seedlings' stems grow toward light and their roots grow downward in response to gravity. Recognize that many plants and animals can survive harsh environments because of seasonal behaviors
- Recognize that every organism requires a set of instructions that specifies its traits. These instructions are stored in the organism's chromosomes. Heredity is the passage of these instructions from one generation to another.

Materials: two different kinds of seeds which have similar germination times (corn and peas for example); cups, plastic wrap, 3 different kinds of growing media, cardboard, plastic sandwich bags or quart bags, binder clips

How to Make a Rhizometer

1. Put soil or other growing media into a plastic sandwich or quart bag. Flatten the bag and plant a seed near the top of the soil. Do not completely close the top of the bag. Roots need air!
2. Put the bag in between two pieces of cardboard and use binder clips to keep the cardboard sides closed. Prop up or vertically suspend the rhizometers so the roots grow down.
3. Open up the rhizometer periodically to view root growth.

Readings About Rhizometers

hortsci.ashspublications.org/content/50/2/288.full.pdf

https://www.amerinursery.com/growing/keeping-an-eye-on-root-development/

https://ashs.confex.com/ashs/2015/webprogramarchives/Paper21758.htm

archives.ashs.org/abstracts/2013/abstracts13/abstract_id_15841.html

agris.fao.org/agris-search/search.do?recordID=CA19810635817

Reading about Scaling in Biological Systems

George Johnson, in his New York Times article entitled Of Mice And Elephants: A Matter Of Scale , states:

"scaling emerges from the geometrical properties of the internal networks animals and plants use to distribute nutrients ". Scaling laws arise from a network transport system where (1) a space filling hierarchical branching pattern is required (2) the final branch of the network (where nutrients are exchanged) is a size-invariant unit and (3) organisms have evolved so that the energy required to sustain them is minimized. These networks are fractal -- each small part is a copy of the whole. Scaling laws result from the interplay between the physical and geometric constraints implicit in these three principles.

There is a correlation between the power law model and much of the processes and shapes that define patterns in nature. It is a consistency that is driven by a both interdependency and feedback.

The scale invariant characteristics that are so prevalent in patterns in nature apparently serve to cope with environmental factors that are not scale invariant. These non-scalable factors (those that do not depend on body size, shape, magnification, or symmetry) include physical and chemical constants and water – the universal solvent for life which has non-scalable properties.

http://www.patternsinnature.org/pin_essay_01.html

"… biological systems obey a host of remarkably simple and systematic empirical scaling laws which relate how organismal features change with size over many orders of magnitude. These include fundamental quantities like metabolic rate (the rate at which energy must be supplied to sustain an organism) , time scales (like lifespan and heart rate) and sizes (such as the length of the aorta or the height of a tree trunk). It is remarkable that all of these can be expressed as power law relationships with exponents that are simple multiples of ¼ (e.g. ¼, ¾, 3/8) . They appear to be valid for all forms of life whether it be mammalian, avian, reptilian, unicellular or plant-like. These "laws" are clearly telling us something important about the way life is organized and the constraints under which life has evolved. " West proposes that scaling laws are the unifying feature of patterns in nature.

The Origin of Universal Scaling Laws in Biology

www.darkcoding.net/research/gbwscl99.pdf