Exploring Energy Transformations in Plants

Overview: The ability to explain the processes by which plants capture, store and use energy for growth and development is fundamental to understanding bioenergy. In this set of lessons, students investigate how plants harness and use different sources of energy during germination and growth. Students ask questions and make predictions about the sources of energy that plants use. They then plan and carry out investigations using Wisconsin Fast Plants® to collect evidence to test predictions and construct scientific arguments.

Levels
6-12 grade

Subjects
Biology, Environmental Science, Agriculture, Biochemistry

Objectives
Students will:
- Conduct an experimental investigation to discover how energy from light affects germination and growth/ development
- Develop explanations as to why seeds do not need energy from light to germinate and begin to grow a seedling
- Develop a model to illustrate how a seed gets energy by breaking down stored food in its seed
- Develop an evidence-based explanation for why and how plants need energy from light to grow and develop

Materials
Exploring Energy Transformations in Plants Package (See instructions for detailed materials list)

Activity Time
7-12 class periods

Standards
Next Generation Science Standards (2013)
- Scientific and Engineering Practices: developing and using models; planning and carrying out investigations; engaging in argument from evidence
- Disciplinary Core Ideas: from molecules to organisms; ecosystems
- Crosscutting Concepts: energy and matter
- Performance Expectations: See page 3 for details

NGSS Lead States. 2013. Next Generation Science Standards: For States by States. Washington DC: The National Academies Press

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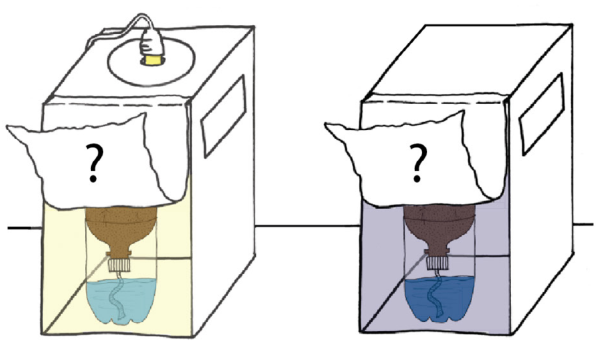
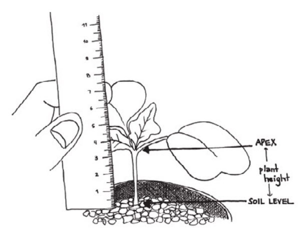
1. Plan Investigations

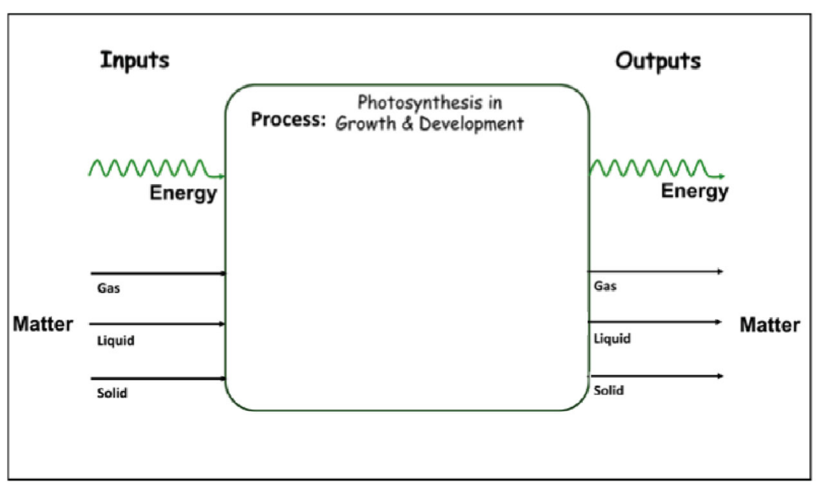
2. Plant Growth Experiments



3. Collect Data



4. Model Energy Transformations



For Teachers - Exploring Energy Transformations in Plants

Overview:

This set of lessons is designed to target students' understanding of energy sources and transformations during germination as well as plant growth and development processes. The primary learning emphasis is on energy transformation, though matter is necessarily involved, too. The lessons draw strength from educational research done on Michigan State University's Environmental Literacy Project (investigating how students develop matter and energy conceptions) and the over 25 years' experience of Wisconsin Fast Plants® in actively engaging students in learning through the scientific practices of inquiry.

The lessons begin with students addressing a question about where plants obtain the energy needed to grow and develop. Then, to challenge students' typical preconceptions (namely, that plants only get and use energy from light directly), the investigation question is extended explicitly to include both germinating seeds and plants that are growing and developing. Next, students make predictions about energy sources for germinating seeds and plants, using those predictions (naive hypotheses) as the basis for designing an investigation with Fast Plants in various light and dark conditions. Students predict, design, conduct an experimental investigation, analyze first-hand observations and give priority to evidence through the course of this investigation. Then, students conclude by constructing and communicating evidence-based explanations for the effects of light and dark conditions on Fast Plants germination and growth/development.

Standards

Next Generation Science Standards (2013)

Performance Expectations

Elementary School:

- **2-LS2-1.** Plan and conduct an investigation to determine if plants need sunlight and water to grow.

Middle School:

- **MS-LS1-5.** Construct a scientific explanation based on evidence for how environmental and genetic factors influence the growth of organisms.
- **MS-LS1-6**. Construct a scientific explanation based on evidence for the role of photosynthesis in the cycling of matter and flow of energy into and out of organisms.

High School:

- **HS-LS1-5.** Use a model to illustrate how photosynthesis transforms light energy into stored chemical energy.

Scientific and Engineering Practices	Disciplinary Core Ideas	Crosscutting Concepts
Developing and using models Planning and carrying out investigations Engaging in argument from evidence	**LS1**: From molecules to organisms: Structures and processes **LS2**: Ecosystems: Interactions, energy, and dynamics	Energy and matter: Flows, cycles and conservation

Learning Outcomes: Students will…

- Conduct an experimental investigation to discover how energy from light affects germination and growth/development
- Develop explanations as to why seeds do not need energy from light to germinate and begin to grow a seedling
- Discover how a seed gets energy by breaking down stored food in its seed, transforming the energy that is stored in chemical bonds to the energy needed to grow and emerge into the light
- Find that plants need energy from light to grow and develop in order to incorporate carbon from CO_2 into their bodies and to store energy in the form of chemical bonds

Summary of Instructional Sequence: This sequence can be adapted and/or shortened to meet the needs of your students and your teaching style.

1. **Pre-assessment using Frayer Model poster** *(1-2 class periods)*: students explore, discuss and ask questions about general forms of energy, energy use and energy transformations.
2. **Preconceptions about plants and energy** *(1-2 class periods)*: students reflect on, ask questions and model the energy transformations associated with stages of plant growth using the Process Tool.
3. **Experimental design** *(1-2 class periods)*: students identify a research question about how plants use energy and plan an investigation.
4. **Data collection and analysis** *(1-2 class periods)*: students collect data on their light/dark growth experiments and develop evidence-based, scientific explanations for observations.
5. **Communication and discussion of results** *(1-2 class periods)*: Students communicate and evaluate their explanations of results. Students revise their explanations (arguments) based upon peer feedback and resources provided by instructor.
6. **Reflection on learning** *(1 class period)*: students discuss what they learned in small groups, revisit questions from Frayer Model and revise their models of how plants use energy in growth and development.

Master Materials List

Planting Materials:

- Standard Wisconsin Fast Plant seeds
- Planting medium (a soilless seed starter mixture)
- Solid fertilizer pellets (like Osmocote)
- Empty, clean 16-20 oz plastic soda-type bottles (2 per student group)
- Wicking material (cotton or polyester macrame cord or thick string)
- Bottle caps or aluminum foil and rubberband to cover bottle opening
- Water

Growing Conditions:

- Lightbox System or fluorescent light bank (see the Wisconsin Fast Plant website to learn how to make your own)
- Dark growing area

Handouts and Other Materials:

- Science notebooks
- Energy Frayer Model handout (included)
- Germination and Growth and Development Process Tool handout (included)
- Bottle growing system planting protocol (included)
- Wisconsin Fast Plants data table (included)
- Explanation Development handout (included)
- Background essays (included, optional)
- Additional grade-level appropriate resources about germination and growth and development in plants (see Step 4)

Sequence:

Part 1. Energy Frayer Model Poster Pre-Assessment
(1-2 class periods)

The purpose of this introductory activity is to gather students' preconceptions regarding energy, energy transfer and bioenergy. Provide each student with a Frayer Model handout and direct students to individually think about their responses to the four facets of energy on the poster. After students have been given a minute or two to think about these ideas themselves have them share ideas in a small group of three to four students.

Have student groups decide what to record on the poster, drawing from their individual ideas. While students are completing their posters in small groups, circulate around the room, listen, and ask clarifying questions to help learners articulate their thinking. Resist the temptation to guide thinking—this is time for preconceptions to be revealed.

When students have finished filling in their group Frayer Model posters, guide them in a whole group discussion of energy transfer. Initial discussion prompts could include:

- How did working together in your small group to build consensus about what to write on the Frayer model affect your thinking about energy?
- Which quadrant(s) did you find most challenging to fill out, and why?

Following a whole class discussion of the Frayer Models, allow time for students to reconvene in small groups to make and additions/changes to the Frayer Models as desired based on new ideas that came from the whole group discussion. Save these posters for reference throughout the lessons on energy.

Part 2. Preconceptions about plants and energy
(1-2 class periods)

During this step in the inquiry students are focused on energy transfer in plants, using a graphic organizer called the Process Tool. Students record their predictions about energy inputs and outputs (transformations) that take place when seeds germinate and when seedlings grow and develop. Later, students will revisit these initial predictions to reflect on their learning.

Introduce the Process Tool and facilitate a discussion comparing and contrasting *forms* and *sources* of energy.

- This introduction to *forms* of energy and explicit support for distinguishing *forms* from *sources* is intended to help students understand how energy can be traced through the processes of germination and photosynthesis (and must be accounted for equally as an input and output).
- Restrict the discussion of energy to no more than five forms of energy (light energy, chemical energy, kinetic energy, electrical energy and heat) to provide a foundation for understanding the conservation of energy (Jin & Anderson, 2012).

Provide each student with a blank Process Tool handout to use to record and communicate their mental models for what takes place during germination and growth/development. Have students reflect on how they believe plants change matter and energy and then individually record their current conceptions, using the Process Tool (this then gets taped into science notebook for later reference). Following the completion of the Process Tool, have students find a partner and discuss their Process Tool responses. Make it clear to the students that they will be expected to share “I wonder” questions that arise during their discussion.

In a shared public space in the classroom (e.g. on poster paper, white board, or SMART Board) have pairs of students post questions regarding their Energy Frayer Model along with any additional questions that arise about energy transformation on germination or plant growth and development.

Once all the pairs have posted their questions (wonderings) about energy transfer in plants during plant growth and development you may choose to facilitate a group discussion about the characteristics of questions that can be investigated scientifically (in the classroom setting).

Guide the class to adopt and adapt a question that can be investigated about how energy from light effects germination and seedling growth in Fast Plants, a question that could be addressed by conducting a controlled experiment with Fast Plants grown in light or dark conditions.

Alternatively, a more teacher-directed approach to this inquiry could be taken by giving the class a single investigation question such as: How does energy from light affect germination and seedling growth in Fast Plants?

Once the investigation question has been established through your choice of methods, post this question prominently in the classroom to reference frequently while students conduct their investigations.

Part 3. Experimental Design
(1-2 class periods)

Guide the class to design an experiment that aligns with the question established during the previous step (e.g. How does energy from light effect germination and seedling growth in Fast Plants?). Depending on students' prior experiences with experimental design, you may choose to do all or some of this design process as an interactive "think aloud" in which the teacher models the decisions and rational used throughout the design process.

The goal of the experimental design will be to control all variables other than light exposure by setting up two identical bottle growing systems planted according to the Fast Plants protocol. One growing system will be exposed to twenty-four-hour fluorescent light; the other will be kept in the dark. You may choose to take a more student- or teacher-directed approach to this experimental design.

Lead students through cutting the plastic bottles and planting Fast Plant seeds in bottle growing systems: one that will be placed in constant light, and one that will be placed in dark.

Part 4. Data Collection and Analysis
(1-2 class periods)

The following progression outlines key activities related to data collection and analysis that fall during the two weeks following planting. Data collection can be done daily or every-other-day for approximately 15-20 minutes from three days after planting until eight or nine days after planting. During the period of data collection, there will be additional class time for students to learn other related ideas in your science curriculum.

Begin making observations after 3 days. Note that even a small amount of light exposure will effect those plants being grown in dark, so any observations that learners make need to be done quickly, and it is best to turn off lights in the room.

By day 5 the differences between the two conditions will be significant. If the plants are kept in the dark beyond day 8 or 9 it will become evident that, while germination and initial growth and development can be supported without energy from light input, further growth and development cannot happen.

Refer regularly to the posted question that is driving students' investigations, and facilitate learners to post sentence strips with their ideas and new questions that arise because of the observations they collect.

After 5 or more days of data collection, have students revisit their original Process Tool and discuss if their observations support or refute their predictions about germination and growth/development processes.

Use the explanation scaffold to teach how to connect claims, evidence and reasoning to build a scientific explanation for how light effects germination and growth/development. Explicitly connect for the students that they are building explanations just like what scientists do as a key part of their practice.

Facilitate learners to connect claims to construct a robust response to the question driving the experiment (*How does energy from light effect germination and seedling growth in Fast Plants?*). Include use of the *Process Tool* as part of students' explanations.

Part 5. Discussion: Communicating Explanations and Connecting Conceptual Models to Scientific Knowledge
(2-3 class periods)

Discussion of explanations, providing additional opportunities for students to learn the accepted scientific knowledge about energy transformations in plants, and allowing time for students to revise their own explanations will take several class periods.

Plan a strategy for having students share their explanations in a manner that engages learners in arguing in support of their logic, reasoning claims, and evidence validity, while also respectfully critiquing their peers' explanations.

Use strategies such as peer reviewers or interactive presentations for students to communicate to others their conceptual models and explanations for observations and inferences about energy inputs and outputs for Fast Plants germinated and grown in light and dark conditions. Encourage students to challenge each others' models and arguments used to justify explanations.

Facilitate a discussion about how explanations that incorporate multiple claims supported by credible evidence and logical reasoning have greater credibility.

Discuss the criteria students' use when determining if evidence is credible and reasoning is logical. Compare this to the types of criteria that are expected in the scientific community, discussing similarities and differences with science class expectations and those expected at home.

Provide additional learning opportunities with outside resources for students to learn about germination and growth/development in plants and photosynthesis using grade-level appropriate multi-media, readings and interactive lectures. Recommended resources available online include:

- Teachers' Domain: Photosynthesis. http://www.pbslearningmedia.org/resource/tdc02.sci.life.stru.photosynth/photosynthesis/#
- Teachers' Domain: Illuminating Photosynthesis. http://www.teachersdomain.org/resource/tdc02.sci.life.stru.methusweb/
- Annenberg Learner. Science in Focus: Energy. http://www.learner.org/workshops/energy/workshop5/?pop=yes&pid=1712
- Michigan State University's Environmental Literacy "Plants Unit" Activities and Resources: http://edr1.educ.msu.edu/environmentallit/publicsite/html/CarbonTIME1314_unit_zip_files.html
- Michigan State University's Environmental Literacy Photosynthesis PowerPoint. https://edr1.educ.msu.edu/EnvironmentalLit/publicsite/files/CarbonCycle/CC%20TeachingExperiment/11-12%20Teaching%20Materials/Plant%20VTTs%20(photosynthesis).ppt

As new sources of information are introduced, pause for students to think about and discuss the ideas presented. Ask questions such as, “Have you seen evidence to support these findings [that plants need sunlight to grow] in our plant investigations?”

- Other important discussion questions include: “How can plants make their own food?” and “Where might plants get their carbon atoms?”
- Stop to check whether students understand that carbon dioxide is a gas (and a material/matter) unlike sunlight, which is energy, not a material/matter.
- After learning from these additional resources, facilitate a class discussion in which students can clarify their understandings of the key ideas related to energy transformations in the biological processes of photosynthesis and growth and development.

Provide time for students to discuss and revisit/revise their models to reflect their growing understanding of the processes and movement of energy (and matter).

Part 6. Reflections on Learning
(1 class period)

Group students in their original small groups-those who worked together to create an Energy Frayer Model poster.

Provide time for students to analyze, update, and reflect with their peers about their learning during these lessons.

- Use a strategy such as a think-pair-share that allows students to reflect both individually and with their group about their learning.
- Refer back to the *Process Tool* that learners completed at the start of this lesson, and facilitate learners to adjust/update according to what they have learned. Facilitate discussion of learning and what helped the learning happen.

Pedagogocal Implications

Our colleagues at MSU along with many other education researchers in the past two decades document how challenging it is for students up to and beyond high school to use scientific models and principles to explain the process involved in the carbon cycle (Mohan & Chen & Anderson, 2009). Instead, students more typically use informal reasons for how matter such as carbon appears or disappears, without regard for the Law of Conservation of Matter that is central to scientific explanations for these processes (Mohan & Chen & Anderson, 2009). Similar confusion shows up when researchers explore students' ideas of energy transformations that occur in carbon-cycle processes—students typically demonstrate (even in high school) naïve ideas that lack reference to the fundamental Laws of Thermodynamics (Jim & Anderson, 2012).

Given the challenge in teaching that is involved when we want students to build toward scientific reasoning we draw explicitly on both the principles of the Laws of Conservation of Matter and processes involved. In addition, in this investigation we scaffold students' emerging understandings of the conservation and degradation of energy by referring to transformations of energy into different forms (e.g. light energy, chemical energy, and heat). While the notion that there are different forms of energy runs counter to our scientifically sophisticated understanding that all energy is the same, we refer to forms of energy in this investigation as a way to help learners focus on the energy and account for its conservation (Jin & Anderson, 2012). Also, by focusing learners solely on energy transforming processes, this investigation is designed to contrast energy with matter and constrain learners to the energy portion of the carbon cycle story.

Even students who can state the Law of Conservation of Energy seldom are able to accurately trace energy through carbon-transforming processes and consistently distinguish energy from matter (Environmental Literacy, 2010). In these lessons, students use the Matter and Energy Process Tool from the Michigan State University's Environmental Literacy Project (see references sections). The Process Tool scaffolds students to communicate their conceptual models for the transformations of energy (and matter) during germination and growth/development.

The other benefit to focusing this investigation primarily on energy is that the resulting inquiry genuinely creates an opportunity for developing both the ability to conduct a controlled experiment and the understanding that such an experiment is one of the scientific practices that can be used to learn.

References

NGSS Lead States. (2013). Next Generation Science Standards: For States by States. Washington DC: The National Academies Press

American Association for the Advancement of Science. (1993). Benchmarks for Science Literacy: Project 2061. New York: Oxford University Press.

Annenberg Learner. Science in Focus: Energy. Retrieved May 19, 2012 from http://www.learner.org/workshops/energy/workshop5/?pop=yes&pid=1712

Environmental Literacy. (2010). Retrieved July 23, 2012 from http://edr1.educ.msu.edu/environmentallit/index.htm

Jon, H. & Anderson, C.W. (2012). A Learning Progression for Energy in Socio-Ecological Systems. Journal of Research in Science Teaching, 49(9), 1149-1180. doi:.10.1002/tea.21051.

Michigan State University, MSP Carbon Assessment [Form A]. (2010). Retrieved May 19, 2012 from http://edr1.educ.msu.edu/EnvironmentalLit/publicsite/html/cc_tm_msp1112.html

National Research Council. (2010). Framework for K-12 Science Education. Retrieved from http://www.nextgenscience.org/framework-k%E2%80%9312-science-education

Teachers' Domain: From Seed to Flower. Retrieved May 19, 2012 from http://www.pbslearningmedia.org/resource/tdc02.sci.life.colt.plantsgrow/from-seed-to-flower/

Teachers' Domain: Illuminating Photosynthesis. Retrieved May 19, 2012 from http://www.pbslearningmedia.org/resource/tdc02.sci.life.stru.methusweb/illuminating-photosynthesis/

Teachers' Domain: Photosynthesis. (2012). Retrieved May 19, 2012 from http://www.pbslearningmedia.org/resource/tdc02.sci.life.stru.photosynth/photosynthesis/

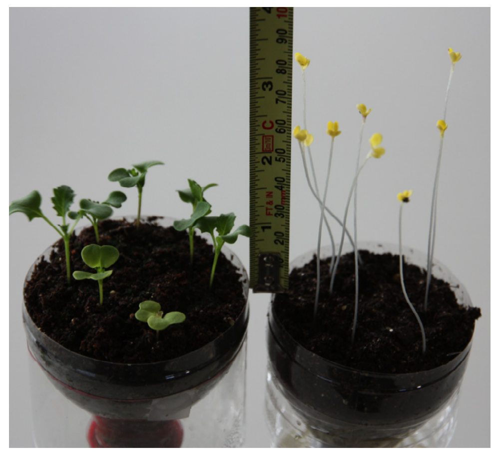
Sample Experiment Observations and Results

Day 2

Day 3

Day 4

Day 7



Day 10

Day 14

Sample Data Table

	Bottle 1	Bottle 2
Planting Variables		
Date Planted	*March 27, 2014*	*March 27, 2014*
Seed Type	*Standard Fast Plants*	*Standard Fast Plants*
# Seeds per Bottle	*8*	*8*
Fertilizer Type	*Ozmocote*	*Ozmocote*
Fertilizer Amount	*8 pellets*	*8 pellets*
Environmental Variables		
Temperature	*Room temp (37C)*	*Room temp (37C)*
Light Conditions	*Full light*	*Complete darkness*
Water	*wicked to reservoir*	*wicked to reservoir*
Soil Type	*standard potting mixture*	*standard potting mixture*

Daily Observations	Condition	# Seedlings	Ave. Seedling Height	# Leaves on Stem	Stem Description	Leaf Description	Other Observations
# Days After Planting: 1	*Light*	*0*	*0*	*0*	*NA*	*NA*	
	Dark	*0*	*0*	*0*	*NA*	*NA*	
# Days After Planting: 2	*Light*	*7*	*4mm*	*2*	*white, straight*	*green, round*	
	Dark	*3*	*4mm*	*0*	*white, curved*	*NA*	
# Days After Planting: 3	*Light*	*7*	*7mm*	*2*	*white, straight*	*green, wider*	
	Dark	*8*	*30mm*	*2*	*white, curved*	*yellow, smaller*	
# Days After Planting: 4	*Light*	*7*	*16mm*	*2*	*purple/white*	*rounded, wider*	
	Dark	*8*	*55mm*	*2*	*white, curved*	*yellow, smaller*	
# Days After Planting: 7	*Light*	*7*	*25mm*	*3*	*green, straight*	*round, toothed*	
	Dark	*8*	*80mm*	*2*	*white, curved*	*yellow, small*	
# Days After Planting: 10	*Light*	*7*	*90mm*	*6*	*pale green*	*large, green, with teeth*	*buds, flowers*
	Dark	*0*	*0*	*0*	*thin, fallen, shriveled*	*small, yellow, shriveled*	*plants dead*

This activity was developed with Hedi Baxter Lauffer with the staff of the Wisconsin Fast Plants® Program, as well as Julie Cunningham affiliated with Central Michigan University. Funding and additional support were provided by the Great Lakes Bioenergy Research Center (GLBRC).

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