Photosynthesis – Exploring Energy Transformation

This unit plan for the Light Reactions module of the Meta!Blast 3D game (metablast.org) is based on the Science Writing Heuristic (SWH) Approach to science learning. While the usefulness of this plan does not depend on a familiarity with SWH, the theory, logic and rationale for the plan might be more clear to teachers who have explored the SWH approach. For more information about SWH please consider the book *Negotiating Science: The Critical Role of Argument in Student Inquiry* by Hand, et al.

Suggested student prior knowledge

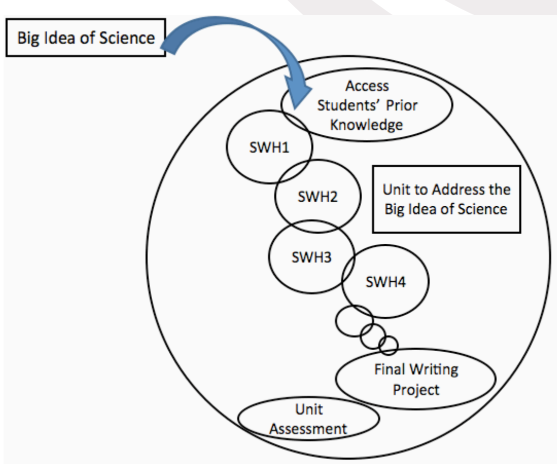
Students should be able to correctly answer some or all of the following questions before undertaking this unit. Teachers should consider completing an SWH on the topic of energy prior to embarking on an SWH about photosynthesis.

- What are some possible ways to correctly describe/define energy?
- What are some of the different forms/types of energy?
- How might we accurately describe what occurs when energy changes from one form to another?
- What are some of the possible units (and methods) for measuring energy?
- How might we accurately contrast energy and matter?

As students negotiate answers to the above questions they should design investigations that allow them to observe energy transformations (simple circuits, calorimeters, solar cooker, ramps, hammers, elastic materials, flame tests or spectral analysis, etc...). This prior knowledge will support their understanding the transformation of energy in living systems.

Graphic overview of an swh unit

The image below was modified from the original published in *Negotiating Science* pg. 80 (Hand, et al. 2009). This graphic shows the flow of an SWH unit from establishing the big idea(s), to formative assessment, to several inquiries (SWH 1-4), to a final writing project and unit assessment.



DETAILED OUTLINE FOR IMPLEMENTING SWH INSTRUCTIONAL UNITS

This outline is based on one teacher's experience and should be considered an example, rather than a lock-step sequence.

1. Teachers identifies the big ideas that will be taught in this unit.
   - **a.** Teacher constructs a concept map of photosynthesis that depicts their conceptual understanding of the process. This is a visual representation of the teacher's conceptual understanding. These maps should include words on each line between boxes or circles. These connecting words demonstrate the relationships that exist in the mind of the teacher.
   - **b.** Teacher identifies questions they have about their own understanding of photosynthesis and use reference materials to answer questions, clarify, and check understanding. Suggested resources can be found at the following links:
     - **i.** http://www.project2061.org/publications/bsl/online/index.php
     - **ii.** http://www.project2061.org/publications/sfaa/online/sfaatoc.htm
     - **iii.** http://www7.nationalacademies.org/bose/Standards_Framework_Preliminary_Public_Draft.pdf.
   - **c.** Teacher reviews the list of potential big ideas for this unit that has been provided (Section I and III of Apendix A) and based on this information, and their own research, determines which of these big ideas will be the focus of the unit.
2. Teacher plans instructional activities for this unit.
   - **a.** Teacher reviews the instructional implications that are summarized in the Curriculum Topic Study Summary for Photosynthesis (Section II of Appendix A).
   - **b.** Teacher reviews the suggested components of the SWH (below) and collects other lessons and ideas (from their own research and experience) for instruction.
   - **c.** Teacher determines which lessons will best help students develop conceptual understanding of the big ideas selected in step 1.
   - **d.** Teacher determines how these lessons can be structured/modified to best promote studentcentered engagement. This would include creating a variety of settings where students can negotiate their understanding of photosynthesis (individual, small group, and whole class). Activities in these different settings should be planned to give students "...a chance to have a voice in explaining what is going on and how they have put the pieces together." (Hand, et al. 2009 pg. 52)
3. Teacher plans the final writing project and develops a scoring device for this project. If possible have students write to an audience that can actually participate in the assessment of a draft document. Consider using the following online resource when developing this plan:
   - **a.** http://olc.spsd.sk.ca/de/pd/instr/strats/raft/
4. Teacher determines what questions he or she will ask during the lessons that will promote student thinking and the construction of student conceptual understanding. Refer to the Metablast Educators guide for examples. The teacher should also select a question that will be used to probe the students preconceptions (see #5 below). The teacher should also think about the misconceptions that students already have (Section IV Appendix A), or will develop during the learning activities. In order to promote conceptual change, the teacher can plan to ask these questions at crucial times during the lesson, rather than simply correcting the students.
5. Students develop a concept map to help the teacher learn what the students understand about photosynthesis. Teacher should ask a question that students answer by creating a representation of their conceptual understanding - a concept map or knowledge model. The following resources from the Institute of Human and Machine Cognition describe the characteristics of a quality concept map, and the underlying theory. Also available is free software to use when constructing concept maps.
   - **a.** http://cmap.ihmc.us/Publications/ResearchPapers/TheoryCmaps/TheoryUnderlyingConceptMaps.htm
   - **b.** http://cmap.ihmc.us/conceptmap.html

6. Teacher determines what the first SWH activity will be and develops a scoring device for the SWH template (template can be found in Appendix C).
7. Students complete the first SWH using the framework in appendix . Hand, et al. discuss examples and describe potential challenges the teachers will face in Chapter 6 of *Negotiating Science: The Critical Role of Argument in Student Inquiry* (2009).
   a. Teacher helps students develop and refine questions for their own research or tests.
   b. Teachers facilitate student design of investigations and/or research which is based on the studentgenerated questions.
   c. Teacher incorporates discussion and group work.
   d. Teacher collects data for making instructional decisions about subsequent activities and scoring guides.
8. Student completes additional SWH activities in the same fashion.
9. Students complete the final writing project.

AN EXAMPLE SWH IMPLEMENTATION PLAN

THE BIG IDEAS:

- "Plants capture the sun's energy and use it to synthesize complex, energy-rich molecules from molecules of carbon dioxide and water." These molecules provide structure and energy for the plants and the consumers/decomposers that live off of the plants. (food webs)
- The elements of these organic molecules are recycled within a system (cells, organisms, ecosystems).
- Within the cells are specialized parts for energy capture.
- Almost all life on earth is ultimately maintained by transformations of energy from the sun.
- The chemical elements that make up the molecules of living things pass through food webs and are combined and recombined in different ways. Continual input of energy from sunlight keeps the process going.

PROMPTS FOR CONCEPT MAPS (PRE-ASSESSMENT)

In attempting to answer the following questions with a concept map, students should demonstrate their preconceptions of energy transformation during photosynthesis (and possibly cellular respiration).

- What are some possible ways for our food (e.g. cheeseburger and fries) to get its energy?
- How might we describe how energy travels through life, what are some of the possible "paths" it takes?

POTENTIAL SWH QUESTIONS AND ACTIVITIES

Appendix B contains the SWH framework for students. This document can be given to the students to complete and teachers should create a scoring guideline to accompany this framework for each SWH. Note that the first phase of this framework is: Beginning Ideas: What questions do I have? The teacher will need to select and implement a strategy to facilitate the generation and the subsequent refinement of student-generated questions.

The importance of developing the initial question to the SWH is described with excerpts from Inquiry and the National Science Education Standards (National Resource Council 2000):

- Fruitful inquiries evolve from questions that are meaningful and relevant to students, but they also must be able to be answered by students' observations and scientific knowledge they obtain from reliable sources.
- Scientifically oriented questions lend themselves to empirical investigation, and lead to gathering and using data to develop explanations for scientific phenomena

- Skillful teachers help students focus their questions so that they can experience both interesting and productive investigations.

DEVELOPING QUESTIONS FOR SWH #1

The goal of this first SWH is create and answer a researchable question, rather than a testable question. Students will play Metablast to uncover the answer to their questions.

One option is to play the intro to the video game and then start a discussion with the students by asking them questions such as: What might be happening to the plants? Where/how do the plants get the things they need to survive? What might cause an organism to stop growing? From this discussion a brainstorming of questions about energy could evolve.

A second option is to use the students concept maps. Group the students so they can share their work and then ask each group to share something to create a class concept map. Using this map, try to create a single (or maybe several) class questions to record in their framework**.**

The following is a list of questions that the teacher may consider "targets" for their students during the initial SWH activity:

- How does sunlight help plants grow?
- What happens to sunlight when it hits a plant?
- How is the energy in the sun changed to different forms by a plant?
- What form(s) of energy from the sun is used by the plant?
- What is/are the "new" form(s) of energy in the plant after photosynthesis?

COMPLETING SWH #1

Once students have revised (and possibly changed) their questions they should play level one of MetaBlast! Playing level one is essentially the students opportunity to "Test", as described in section 2 of the SWH Framework; it is an attempt to find an answer to their question(s). Students should be able to complete sections 2-4 independently, although a rubric or scoring guideline may prove very useful, especially for students who have
not completed an SWH Framework before. The game can be played in class or at home depending on availability of computers.

Teachers should direct students to use the posters and/or Student Guide (available at www.metablast.org) to complete section 6 of the SWH framework: *Reading: How do my ideas compare with other*? Students then need time to work in groups to discuss what they have learned. This provides a chance to negotiate meaning in a more public manner. Finally a large group discussion may be in order before students complete the Reflection component of the framework.

NOTES

Teachers should take time to discuss how this game is a model of an actual cell and may find this an appropriate time to make connections to the Model Theme as described by the *American Association for the Advancement of Science Project 2061 (2009).*

Teachers should remind the students about scoring guidelines for the framework during each phase of the lesson. Teachers should create scoring guidelines that prioritize those sections of the framework that are most crucial for a given inquiry. For example, a teacher may want to evaluate student abilities to identify appropriate evidence for their claims. The teacher might create a rubric or scoring guideline to describe what characterizes good evidence and weight this section of the framework more heavily.

SUBSEQUENT SWH INQUIRIES

Having played the 1st level, and answering their researchable questions, students should be asked to generate new questions based on their experience. The goal of this second SWH is to create and answer a testable question. Teachers can help redirect students towards questions that can be answered by testing their ideas in the game environment. For example, students might ask questions about the relationship between ATP produced and the amount of light. The students can answer this question by creating more or less light in the chloroplast. This might cause them to edit their question to investigate what parts of the chloroplast, when illuminated, result in the greatest ATP production. The following is a list of questions that the teacher may consider “targets” for their students (for the 1st level - researchable questions might be asked at each level):

- What conditions will generate more oxygen (or ATP, or NADPH) by a plant?
- How will the absence of CO2 effect the plant?
- What will happen to ATP production if there is no light?
- How can the H+ concentration difference across the thylakoid membrane be increased/decreased?
- What happens when ADP and Pi (or NADP) are not present?

FINAL WRITING PROJECT

- Role of the writer - Students are contestants writing an entry for a contest to create the next ‘hero’ for a popular science fiction television series.
- Audience - Students are writing to the producer, director, and the science consultant of the television show. In reality this might be a drama teacher, an English teacher, and a science teacher.
- Format - Online application (google forms) that includes; character name, abilities, scientific soundness of abilities,
- Topic - Students must incorporate the transformation of sunlight into high-energy molecules into their character.

A scoring guideline or rubric for this writing project, although not included in this document, is also an essential part of this lesson plan and should be completed by the teacher. To provide students with invaluable feedback about their writing, the audience should use the scoring guidelines to evaluate the projects.

REFERENCES

American Association for the Advancement of Science Project 2061. (1990). *Science For All Americans*. Oxford University Press, Inc. New York, NY.

American Association for the Advancement of Science Project 2061. (1993). *Benchmarks For Science Literacy*. Oxford University Press, Inc. New York, NY

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APPENDIX A
Curriculum Topic Study Summary for Photosynthesis

I. Adult Content Knowledge (indicating scientific literacy) from *Science For All Americans pages 66-67:* What big ideas and major concepts make up this topic? What are the rich interconnections with other content? What vocabulary and enduring understandings should all adults know?

Bullets in black may be addressed during game play while red bullets draw few connections to game content.

- All systems have some basic rules (laHn, namely the conservation and transfer of energy.
- Conservation/cycling of mass is linked to the transfer of energy. (This connection is most obvious at the molecular level, the game has a lot of potential to model this concept. For example, showing both reactants and products during chemical reactions in which energy is transferred from one molecule to another.)
- "Almost all life on earth is ultimately maintained by transformations of energy from the sun."
- "Plants capture the sun's energy and use it to synthesize complex, energy-rich molecules from molecules of carbon dioxide and water." These molecules provide structure and energy for the plants and the consumers/decomposers that live off of the plants. (food webs)
- The elements of these organic molecules are recycled within a system (cells, organisms, ecosystems).
- "At each stage in the food web, some energy is stored in newly synthesized structures and some is dissipated into the environment as heat produced by the energy-releasing chemical processes in cells." (The 10% rule applies to ecosystems because the chemical reactions in cells are not efficient.)
- It is important to realize that energy flows and matter cycles in both aquatic and terrestrial ecosystems.
- Molecules are continually cycled through ecosystems while energy flows irreversibly from capture sunlight to dissipated heat.
- Biomass of the earth remains fairly constant while biodiversity does not.
- Understanding fossil fuels as the remains of dead organisms.
- The amount of life in an ecosystem is dependant on the amount of resources available.
- Understanding the roles and creation of carbon sinks
- Understand the role of human technology/influence and its ability to interrupt the flow of matter

II. Instructional Implications from *Benchmarks 2061 pages 110 and 118:*
A big picture view of the topic and student learning difficulties, misconceptions, and developmental considerations.

- "Organisms are linked to one another and to their physical setting by the transfer and transformation of matter and energy."
- Energy transfer is difficult to model in living systems.
- Be aware of the misconception that plants get their food from soil.
- Another misconception that student may have is that organisms contain cells and are not made of cells
- Be aware that students have difficulty imagining large numbers.
- "Approach the ideas of functioning microscopic units by first addressing the needs of the macroscopic organism".
- "Neither familiarity with functions of regular-sized organisms nor observation of single-celled organisms will reveal much about the chemical activity going on inside single cells." (This issue is addressed continually during MetaBlast! game play.)
- Students need to have opportunities to observe physical energy transformation to better

understand chemical energy transformation.

- Observing systems at the macroscopic and microscopic levels help reinforce the general idea of systems.
- Students should note that during energy transformations, some energy is given off as heat while other energy is usable for the organisms
- Fossil fuel and recycling of matter are important to pay attention to in high school

III. Concepts and Specific Ideas *from Benchmarks 2061 pgs. 111-114, 119-121*

What concepts, specific ideas, or skills are applicable to the learning goals for this topic?

- Every cell is covered by a membrane that controls what can enter and leave the cell.
- Within the cells are specialized parts for the transport of materials, energy capture and release, protein building, waste disposal, passing information, and even movement.
- In addition to the basic cellular functions common to all cells, most cells in multicellular organisms perform some special functions that others do not.
- The work of the cell is carried out by the many different types of molecules it assembles, mostly proteins. The function of each protein molecule depends on its specific sequence of amino acids and its shape. The shape of the chain is a consequence of attractions between its parts.
- Complex interactions among the different kinds of molecules in the cell cause distinct cycles of activities, such as growth and division. Cell behavior can also be affected by molecules from other parts of the organism or even other organisms.
- A living cell is composed of a small number of chemical elements mainly carbon, hydrogen, nitrogen, oxygen, phosphorous, and sulfur. Carbon, because of its small size and four available bonding electrons, can join to other carbon atoms in chains and rings to form large and complex molecules.
- Some protein molecules assist in replicating genetic information, repairing cell structures, helping other molecules get in or out of the cell, and generally catalyzing and regulating molecular interactions.
- At times, environmental conditions are such that land and marine organisms reproduce and grow faster than they die and decompose to simple carbon containing molecules that are returned to the environment. Over time, layers of energy-rich organic material inside the earth have been chemically changed into great coal beds and oil pools.
- The chemical elements that make up the molecules of living things pass through food webs and are combined and recombined in different ways. At each link in a food web, some energy is stored in newly made structures but much is dissipated into the environment. Continual input of energy from sunlight keeps the process going.

IV. Research on Student Learning From *Benchmarks 2061 pgs. 342-343* and *Making Sense of Secondary Science*

What specific misconceptions or alternative ideas might a student have about this topic?

- The word food is commonly used incorrectly in most classrooms because it is used in many different contexts and we need to address that both plants and animals use the products of photosynthesis as food.
- Food is necessary for both energy and building materials in plants and animals.
- Students often confuse molecules with cells. (for example: protein is made of cells)
- Many pupils do not possess the prerequisite knowledge of living things, gas, food, energy, that are required to understand photosynthesis.
- Teachers must explain where water, CO2, and O2 come from in the plant and how they are taken up by the plant.
- Teachers should make sure that students understand that a function of photosynthesis is carbon fixation and energy storage for plants. (Misconception: students believe plants exist primarily to feed consumers

- Some people think that photosynthesis is a component of the cell and not a process; confusing photosynthesis and chlorophyll.
- Students need to understand that gas has mass to better understand carbon fixation.
- Students do not appreciate/understand the role of chlorophyll in energy transformation
- Some students believe that light is a reactant in the reaction that depicts photosynthesis.
- There is the misconception that plants create energy instead of transfer it.
- Students don't recognize that air is composed of different gases. And confuse the carbon dioxide with air.

V. Section V Coherency and Articulation from the *Atlas of Science Literacy*
What connections can you identify among concepts or skills? How do the conceptual strands in a map help you think about the way to coherently organize the concepts and skills in a topic?

- Understandings about matter cycles and energy transformations are linked to understandings about atoms and molecules.
- Clearly identify what food is (material and energy source) so that students better understand what "plant food" is and how it might be similar or different to animal food, depending on the context in which these terms are being used.

VI. Section VI Clarify *Connections to Iowa Core Curriculum*

- Understand and apply knowledge of the cell.
- Understand and apply knowledge of the inter-dependence of organism.
- Understand and apply knowledge of matter, energy, and the organization in living systems.

References:

American Association for the Advancement of Science Project 2061 and National Science Teachers Association. (2001). *Atlas of Science Literacy Volume 1*. Washington D.C.

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Keeley, Page. (2005). *Science Curriculum Topic Study: Bridging the Gap Between Standards and Practice. Corwin Press*. Thousand Oaks, CA.

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APPENDIX B
Name:
Date:
Class Period:
Science Writing Heuristic Lab:

Beginning ideas…What questions do I have?

Tests…What did I do? (How did you test to answer your questions?)

Observations…What did I find? (What did you find when you tested?)

Claims…What inferences can I make? (Explain what you think happened.)

Evidence…How do I know? (Justify your claims by providing evidence for claims.)

Reading…How do my ideas compare with others?

Reflection…How have my ideas changed?

Hand, B., Norton-Meier, L., Staker, J., & Bintz, J. (2009). ***Negotiating Science: The Critical Role of Argument in Student Inquiry. Heinemann Portsmouth, NH.***