Do plants need sunscreen? A lesson for teaching photosynthetic systems in undergraduate biology.

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October 29, 2015

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Introduction and Rationale of the Lesson

Development and expansion of the plant sciences will be of utmost importance to our future as the demand for food and fuel grow in our changing world. However, many people, including scientists and science educators, remain unaware of the importance of plants in the natural world. According to Wandersee and Schussler (Allen, 2003), we as a society suffer from ‘plant blindness’ - a failure to perceive the significance of plants. As a result, undergraduate life science courses tend to be zoo-centric, plants are underrepresented in the classroom and it has been reported that undergraduate students tend to play close attention to animals compared to plants (Balas & Momsen, 2014). For these reasons, we developed a lesson to engage undergraduate biology students in research on plant systems. We hope that this will help to increase students’ awareness, understanding, and excitement about the green world.

Background

Recent reports such as *Vision and Change* (Brewer and Smith, 2009) and the *Next Generation of Science Standards* (http://www.nextgenscience.org/) have provided recommendations, among others, (1) to incorporate the concepts of systems thinking and matter and energy into science curriculum and (2) to engage students in the practices of science. However, teachers face challenges when addressing these concepts and practices in a plant context in the classroom. Several reports have suggested that students vary in how they address biological phenomenon. For instance, Abrams and Southerland (2001) observed that, across many age-groups, students, when asked to answer ‘how’ questions about biological phenomenon - such as how does a plant grow towards a light source - often use ‘why’ explanations. Furthermore, according to Coley and Tanner (2015), when given tasks to elicit cognitive approaches, both major and non-major biology students use intuitive approaches for a range of biological scenarios. These approaches included teleological, essentialist, and anthropocentric thinking; in other words, student rely heavily on the purposes, essential properties, and the relation to humans when approaching biological phenomenon. More specifically for learning plants plants, Parker et al. (2012) found that some students conceptualize photosynthesis as though plants capture *material* from sunlight to produce biomass and that the pigments of plants are a byproduct of photosynthesis. These reports, among others on students understanding plants, provide an opportunity to incorporate recently published science research into the undergraduate biology curriculum to help students develop their conceptions about plants and plant science. To take advantage of this opportunity we designed a lesson around recent work by Li et al. (2009) to teach undergraduate life science students about the responses and adaptations of plant systems in high light conditions. The scientific report provided a potential conceptual model that could used to structure a lesson for teaching light sensing and response systems of plants and, in the process, help students to engage in scientific practices such as modeling, data collection, argumentation, and explanation.

Instructional Design

To develop a lesson for teaching research to understand photosynthetic systems of plant, we used backward instructional design forwarded by Wiggins and McTighe (2005) to identify learning objectives, appropriate assessments, and activities appropriate for an introductory biology course. To design a lesson that would make use of students prior knowledge and engage them in active learning, we also adapted the 5E framework forwarded by Bybee et al. (2006) to guide students to engage, explore, explain, elaborate and evaluate for the topic of plant system response to excess light. According to Tanner (2010), the 5E framework holds promise for instructors to aid learning in a classroom setting.

Identifying Objectives

To develop learning objectives for the lesson, we identified core concepts and research skills for teaching photosynthesis and the adaptations of plants to different light environment. Previously, the MSU STEM departments refined the core concepts for teaching to meet the recommendations of the national documents, and designed specific learning goals. From that list, we selected the following learning goals for our lesson:

•Matter and energy – 2.1 - Free energy and matter are utilized in regulated molecular processes that establish order, support growth and development, and regulate dynamic homeostasis in cells.

•System – 4.2 - Organisms interact with their abiotic and biotic environments at multiple scales (molecules to ecosystems) for the purpose of obtaining materials and resources. These interactions mediate movements of matter, energy, and information in ecological systems and are subject to physical and chemical laws.

In addition to the above core concepts, we selected scientific process skills to engage students in the research of plant systems. The processes we targeted include:

- Developing and testing scientific models for the purpose of explaining and predicting natural phenomena and processes.
- Construct data-oriented arguments by using claims, evidence and reasoning.

Learning Objectives

By combining the core concepts and the process skills, we wrote the following learning objectives:

- Student will describe variation in light intensity during the day in the abiotic environment.
- Students will use a research tool for the purpose of data collection.
- Students will be able to analyze data to make arguments about adaptive features of plants under varying light.
- Given a particular plant and environment, students will be able to create a model to explain the variation of photosynthetic efficiency as it changes with respect to light intensity or development stage.

Instructional Activities

Day One (about 20 minutes)

Engagement

15 minutes - Students are provided the following:

1. Clicker questions to help student recall and discuss of definitions from their prior knowledge to be used in next lesson. The goal of these questions is to help students arrive at the general component model of photosynthesis
2. Explain how and why photosynthesis reaches a maximum rate while considering the trade-offs of photosynthesis (Figure on right from Li et al., 2009).
3. The instructor will briefly explain certain terms that are in the homework reading assignment.

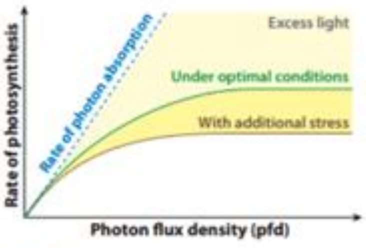


Figure 1
Light response curves for photosynthesis compared with the rate of light absorption.

5 minutes - group work:
Students are given the following prompt:
It's a blistering hot and sunny day in Michigan. Unlike humans that can move to shade, plants are fixed where they place their roots. How do plants handle the sunny days? Do they wear sunblock?
As a group using your white boards, create a graph that predicts changes in light intensity during the hours of a day in one of the 3 cases:

1. A sunny day
2. A cloudy day with clouds moving in and out,
3. A sunny day that becomes a cloudy day around noon.

Students will include a figure legend and label the axes, and, in one sentence, predict what could happen to the efficiency of photosynthesis in the varying light conditions.
Homework is assigned. See below.

Day Two (about an hour and 20 minutes)

Engage (continued)

II. (Homework to be done before class starts)- Reading assignment , discuss in groups before class.
Students will be assigned to read either the introduction or one-page modified summary from Li Z, Wakao S, Fischer BB, & Niyogi KK. 2009. Sensing and responding to excess light. *Annual Review of Plant Biology*, *60*, 239-260.

Students will do the following:
Answer following questions in one short sentence or bullet-point! (Not graded, just marked if they have answers and thought about this).

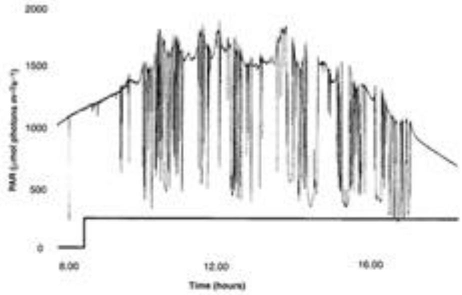
As light intensity goes up during the day, what do you think happens to the efficiency of photosynthesis?
Name one mechanism that plants have developed to protect themselves from too much light?
Watch the presentation at the top of the page of the photosynQ blog to learn about the instrument that you will be using in the next class: http://blog.photosynq.org/. Furthermore go to http://blog.photosynq.org/how-it-works/ and get a feel on how the instrument works and what the measurements can potentially tell us.

Explore: (30 mins)

Introduce students to the research tool and the data collection website (http://photosynq.org).
Provide students with the research tool to explore measurements of light intensity, efficiency of photosynthesis in different environmental settings (shade, sun, under canopy etc.) (Research tool is still in a beta-test version on not available everywhere)
Send students outside to collect data (this is weather dependent, not a winter activity). Alternatively students can works with a specific dataset selected from the page that is already existent and study parameters that way. For example go to http://photosynq.org/projects/evaluation-of-sunflower-hybrid-genotypes.
Students should plot Light intensity [PAR] vs LEF (linear electron flow, which is a parameter for efficiency of photosynthesis) and Light intensity vs ΦII (which can be an indicator for plant health, values around 0.8-0.83, very health plant, values below 0.4 plant is suffering). This data will show students changes in efficiency of photosynthesis in higher light intensities and that plant health decreases over time in higher light intensities.
In the sunflower example, the data can also be sorted by different leaf ages (top, middle, bottom). This can show that development stage causes changes in the efficiency of photosynthesis. Old leaves have poor efficiency, while young leaves are very efficient.

Explanation: (20 mins)

Interpret the graph which was collected on a partly cloudy day in a field in Sweden with the students' prior understanding.
At this point also analyze graphs that students generated as a homework assignment before class.



Külheim et al., 2002

Fig. 3. Light conditions during the experiments. The upper curve shows actual incident light [PAR in μmol photons m^{-2} s^{-1}] measured at the experimental site during one representative day. For comparison, the intensity of the (average) light in the climate rooms is also indicated (solid horizontal line).

Explain the mechanism that the plant uses to adapt to light intensity (chloroplast movement, heat dissipation (PsbS), changes in gene expression, sensing mechanisms for adaptation). Explain why adaptive mechanisms are important in respect to changes in the light intensity during a day and establish that plants adapt as best as they can to their environment.

Elaborate: (30 mins)

Students analyze the entire dataset collected by classmates to generate additional models and hypotheses about trends and patterns in the data. As an example using the sunflower data: Plot the data and sort by different leaf ages (top-young, middle, bottom-old). This can show that development stage causes changes in the efficiency of photosynthesis. Have students observe that old leaves have poor efficiency, while young leaves are very efficient. Students will construct an argument in groups from the dataset given in class and connect this argument to previous literature to support their claims warrants and reasoning.

End of class assessment

At the end of the class, as for an exit ticket of a 1-minute paper. Students have one minute to make a claim about the data with appropriate evidence, warrants and reasoning. Collect these papers as students exit the class and evaluate for their inclusion and sophistication of each argumentative criteria.

Out of class work

Evaluate (activity done at home)

Groups will be evaluated for a report that they produce about their classroom data and produced model of variations in light, photosynthetic efficiency for different environments. The report will have to include a model of how plants protect themselves.
(4 points) Based on the lesson, work in your groups to draw a box and arrow model that explains what can happen under excess light:
Your model should include the following terms :
Signal Transduction, Sensing Mechanisms, Excess Light, Acclimation Responses.
Then correctly identify where following mechanisms belong to and include them in your model:
Chloroplast avoidance movement, Non-photochemical quenching - heat dissipation, Photoreceptors, pH change in the thylakoid lumen, changes in gene expression.
(1 point) Write a figure legend.

(15 points) Summative assessment assignment:

> *With your group, you will perform a scientific investigation to better understand the interaction between the light environment and plants. You will be asked to make a report of your investigation into the adaptive features of plants in varying light environments. You are free to design an experiment or research investigation so long as it meets the following criteria:*
>
> - *Builds on the previous literature and models that were produced in class to ask a novel research question.*
> - *Limits measurements to variables associated with plants and light.*
> - *Connect to previous literature and the models of photosynthetic mechanisms and features of plants.*
> - *Use the PhotosynQ for data collection and to upload project data.*
>
> *For this assignment you will be asked to report by following the sections outlined in the attached rubric. Please include an introduction, methods, results, and discussion*

section along with references. The rubric (table 1) indicates what should be included to indicate your groups mastery of plant science research.

Table 1: Holistic rubric for evaluating the scientific report made by students. Five levels are available with intermediate scores 4 and 2 possible.

Section	5 - Mastery	3 – Developing competency	1 – Needs improvement
Introduction [Modeling]	Report provides clear description of previous research accompanied by an initial model what is known and states an aligned purpose of report with well-articulated research questions and/or hypothesis.	Report indicates a description of previous research, model and purpose with questions or hypothesis, but clarity and interconnection of ideas could be improved.	Report fails to make connections between background information and the purpose of the report. Research questions, hypotheses, or models are missing or poorly aligned to the literature.
Methods	The experimental design and approaches to sample, gather, and analyze data are appropriate for answering the research questions to test the hypotheses and models.	The sampling, data collection, analysis, and design are articulated but could be improved or restated to better align with the research questions to test the models and hypotheses.	The sampling, data collection, analysis and design are unclear, missing or inappropriate for answering the research question, testing the model or hypotheses.
Results	The data are presented in a way that makes the results of the tests clear and analyzed in a manner that aligns with the questions and hypotheses.	The data are presented and analyzed appropriately but the clarity and alignment to answer the research questions and hypotheses could be improved.	Data are not presented clearly or misrepresent the results of the tests and data analysis is misaligned with the research questions and hypotheses.
Discussion [Modeling and argumentation]	Discussion revisits previous literature, proposes a modified validated model informed from the results with a well-articulated rationale for the modification, and makes appropriate claims about the hypotheses and research questions.	Discussion links to previous literature, and includes a modified or validated model, but fails to provide appropriate rationale for the modifications. Claims made about the hypotheses and research questions are inappropriate.	Discussion fails to incorporate previous literature or a model. Rationale for a modified model is not evident. No claims are made about the research questions or hypotheses.
References	Report includes appropriate references for any and all claims, methods, or previous works and these are clearly indicated by in-text citations and bibliography in the correct format.	Report includes appropriate references for any and all claims, methods, or previous works and these are clearly indicated by in-text citations and bibliography but some formatting is inconsistent.	Report fails to include references for all claims, methods, or previous works. The document is missing one or more in-text citations or bibliography entries.

Discussion

With the proposed lesson design including objectives, activities and assessments, we have provided a lesson which can be easily adapted for other educational contexts to teach about photosynthetic systems and their response to varying light condition. By teaching the proposed lesson, students may develop competence around key concepts such as matter and energy and systems and around disciplinary practices such as modeling, argumentation, data collection and explanation. Table 2 indicated the tight alignment of this lesson between the objectives, activities and assessments described above.

Table 2: Alignment of the learning objectives assessment and lesson activity.

Learning Objective	Core Concept	Activity	Assessment
Describe variation in light intensity during the day in the abiotic environment.	Matter and Energy	Explore and Explain	Formative assessment of student group daylight models, sentences of about light interaction, and final

	Systems		report.
Use a research tool for the purpose of data collection.	Matter and Energy Systems	Explore and Explain	Formative assessment made by data upload to research database. Summative assessment of data collected and reported in final report.
Analyze data to make arguments about adaptive features of plants under varying light.	Matter and Energy Systems	Elaborate and Evaluate	Formative assessment of the one minute paper at end of course Summative assessment of final report.
Create a model to explain the variation of photosynthetic efficiency as it changes with respect to light intensity or development stage.	Matter and Energy Systems	Elaborate and Evaluate	Summative assessment of final report.

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http://www.nextgenscience.org/