Student Progress in Understanding Energy Concepts in Photosynthesis using Interactive Visualizations

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Abstract: This study explores student progress in understanding energy flow in photosynthesis while studying a technology-enhanced inquiry science project using interactive visualizations. Eight classes of 7th grade students (N=220) completed the project. Students generated narrative explanations and visual representations of their ideas. Students made significant gains in understanding of energy source, energy transformation, and energy transfer in photosynthesis.

Introduction

Although energy is a unifying concept across all science domains, it is often neglected in current science curricula (Van Huis & Van Der Berg, 1993; Solbes, Guisasola & Tarin, 2009). Energy has received little attention in photosynthesis instruction, although energy plays complex roles in this process. Learning about photosynthesis requires students to distinguish different forms of energy, understand how energy is transformed from one form to another, and explain how energy flows from place to place. However, science textbooks mainly focus on the mechanism of photosynthesis, such as reactants and products of photosynthesis. To help students build a coherent understanding of energy concepts in photosynthesis, we designed the photosynthesis project (1) for Cumulative Learning using Embedded Assessment Results (CLEAR), using the Web-based Inquiry Science Environment (WISE, Slotta & Linn, 2009). In this study, we explored student progress in understanding energy source, energy transformation, energy storage, and energy transfer in photosynthesis as a result of using the CLEAR project.

The CLEAR Photosynthesis Project

The CLEAR Photosynthesis project was created in partnership with 7th grade science teachers, discipline experts, and educational researchers. Teachers helped develop the activities and figure how to support cumulative learning over the middle school years. Using a series of powerful interactive visualizations developed by the first author, the project consists of three activities to help students understand how energy is involved in photosynthesis (see Figure 1). The first activity introduces the overall process of photosynthesis showing how the sun serves as the energy source for plants through animated instruction. The second activity teaches how light energy is converted into chemical energy in the chloroplast using animations and simulation. Students observe animations that visualize how light energy breaks up CO_2 and H_2O molecules and they combine as glucose. The third activity shows students how plants use the chemical energy produced in the chloroplast and how the energy is transferred to other animals in the form of food through virtual experiments. For example, students conduct virtual experiments to explore how the amount of light affects the plants' growth and draw conclusions from their investigations.

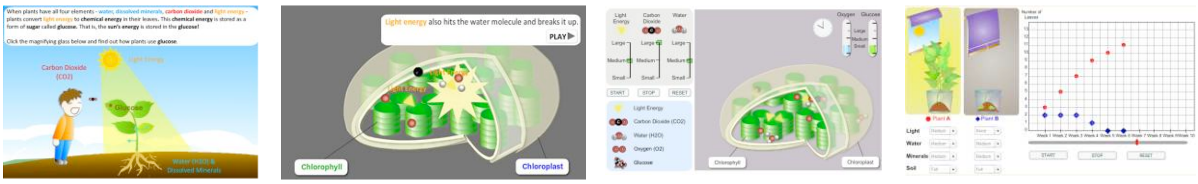

Figure 1. Examples of Interactive Visualizations Used in the Project

Assessments and Methods

The CLEAR Photosynthesis project developed new assessment types, Energy Stories and MySystem, to measure students' growing repertoire of energy ideas in photosynthesis. Energy Stories ask students to provide narrative explanations about how energy is involved in photosynthesis, and MySystem, a computer-based diagramming environment, asks students to visually relate energy concepts.

Seventh-grade students from eight classes (N=220) at a middle school completed the project. Before the project, students took the pretest that elicited students' initial ideas about energy in photosynthesis using Energy Stories and MySystem diagrams. After completing the project, students reflected on what they learned and responded to the posttest. New Knowledge Integration rubrics were developed to score the Energy Stories and MySystem. The rubrics have additional levels including full link (one scientifically valid link between ideas), complex link (two scientifically valid links), and advanced complex link (three or more scientifically valid links).

Results and Discussions

For energy stories, paired t-tests reveal significant gains from the pretest to the posttest (M = 3.96, SD = 1.12 pretest; M = 5.02, SD = 0.78 posttest), $t(219)$ = 10.26, p<.001, d = 1.10). On the pretest 28% of the students presented disconnected or alternative ideas about how energy is involved in photosynthesis. For example, some students were confused about different forms of energy (e.g., the plant grows by the sun giving off chemical energy")) and where energy ends up (e.g., "the energy ends up in the soil"). 44% of the students provided one scientifically valid link between ideas, but most students' ideas were limited to the role of sun as the energy source. After completing the CLEAR project, students not only provided a more broad range of energy concepts, but they also made more scientifically valid links between these concepts and told a more coherent story. In particular, 73% of the students identified both the sun as being the energy source and how light energy is converted into glucose in their post-Energy Stories (e.g., "First, the plants get the energy to grow from the sun. Second the energy from the sun goes into the leaf and it starts photosynthesis. Thirdly the energy in the plant is turned into glucose using CO2, sunlight, and water to make glucose which feeds the plant").

Consistent with their learning gains in the Energy Stories, students demonstrated an improved visual representation of their understanding about energy flow in photosynthesis using MySystem diagrams (M = 3.41, SD = 0.96 pretest; M = 4.86, SD = 1.13 posttest), $t(109)$ = 14.71, p<.001, d = 1.38). Students initially presented a variety of often isolated ideas related to energy flow generally without any valid connections (see Figure 2). However, on the posttest, students created a more integrated representation of how energy source, energy transformation, energy storage, and energy transfer are involved in photosynthesis. They also provided more detailed descriptions of what each arrow indicated in their MySystem diagrams.

These results demonstrate how a technology-enhanced inquiry curriculum can help students integrate their abstract science ideas and show potential advantages of explanatory narrative and visual representation as assessment tool to document student progress in understanding energy concepts.

(a) (b)

Figure 2. Knowledge Integration Scores of Energy Stories and My System (a) and MySystem Examples (b)

Conclusions

This study explores the progress students make in developing an integrated understanding of energy source, energy transformation, energy storage, and energy transfer around photosynthesis using the CLEAR curriculum. The findings from students' responses to Energy Stories and MySystem show that students made significant gains of their understanding in energy concepts from using the project. They also indicate that instruction using powerful visualizations can clarify energy flows and improve students' understanding of the complex roles of energy in science. Additionally, it is critical to align the instruction and assessment to emphasize energy concepts in science if the goal is to enhance students' understanding of energy ideas.

Endnotes

(1) Project URL: http://wise4.telscenter.org/webapp/previewprojectlist.html

References

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