CHAPTER TWO

# Teaching Photosynthesis: Some Thoughts

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**Abstract** '*Life is Bottled Sunshine'* is a four-word summary of the significance of photosynthesis for life on Earth. We all know the importance of the audio visual tools for communicating scientific principles to the students. During my 40 years of teaching BS to PhD level students, I have found that they have learned some of the photosynthesis concepts faster and with ease when they were encouraged to imagine themselves either (a) as molecules participating in exciton transfer from antenna to reaction center molecules, or as electrons/ protons moving through the Z-scheme; or (b) as scientists of the past describing their own results. Further, the inclusion of analogies, photographs and personal aspects of the discoverers fascinates students as they absorb the scientific concepts. In addition, simple movies such as those showing Photosystem II, exciton transfer, and rotating ATP Synthase imprint the dynamic nature of the processes in their minds. In this Chapter, I discuss some thoughts about teaching. In my experience, a historical perspective inspires students to learn and encourages a desire to solve problems.

**Keywords** Significance of photosynthesis, history, students as molecules, web sites for teaching, books

## Introduction

This chapter has the purpose of providing some selected general comments on various topics from which other educators may extract information as to their own needs. I provide here some comments on: the significance of Science (and thus of photosynthesis); use of historical aspects; use of analogies, and students themselves, acting as photosynthetic molecules; use of the Internet, particularly from Orr and Govindjee (2007); and use of a time sequence concept of the entire process.

## Significance

In 1961, Jawaharlal Nehru (1889–1964), India's first Prime Minister, spoke about Science:

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> It is science alone that can solve the problems of hunger and poverty, of insanitation and illiteracy, of superstition and deadening custom and tradition, of vast resources running to waste, of a rich country inhabited by starving people…who indeed could afford to ignore science? At every turn, we have to seek its aid….The future belongs to Science and those who make friends with science!

Today, we know that the science of photosynthesis is a master key for providing us with not only food and oxygen, but fuel of the future, to sustain the growing population of humankind and decreasing oil reserves of our World. Perutz (1989, p. 8) had cited Jonathan Swift long before the present biotechnology era began about improving plant productivity:

> In Gulliver's Travels, Jonathan Swift wrote of the king of Brobdingnag that "he gave it for his opinion that whoever could make two ears of corn, or two blades of grass to grow upon a spot of ground where only one grew before would deserve better of mankind and do more essential service to his country than the whole race of politicians put together…."

## History

About the use of history, I like what Ramasarma (2007) recently wrote while giving his view of the history of biochemistry in India:

> History relates to conquests and defeats and to successes and failures of human activity. It is about places, people and progress. It takes different forms according to the knowledge and perceptions of historians. A failure for one is a strategy for another. A success highlighted by one is ordinary for another. It can be twisted, distorted and fixed. It can inspire and make you feel good.

In my 40 years of teaching experience, I found that a historical perspective inspires many students to learn and encourages a desire to solve problems facing our world. Thus, I recommend its use, but it needs to be done in a way that it does not stray away from the significance and the basic scientific concepts that we are trying to teach.

### A historical approach to teach photosynthesis to non-science majors

Non-science majors need to be taught science of photosynthesis as they are the ones who are often decision makers in Politics, Business, and Law, for example, and they have a major role in running our countries and thus the World. A majority of our undergraduate students are non-science majors. It seems to me that it is essential that we be able to teach Science in an effective manner and show them how basic process of photosynthesis can be linked to biotechnology that would give us "two ears of corn" or "two blades of grass" where only one grew before! A historical approach reflects Science to be an ongoing, but continuously changing, and an uplifting endeavor. Teachers may strive to show that photosynthesis has been and continues to be related to them (the students) and their future generations. We expect this to enhance their positive attitude towards the study of photosynthesis in fulfilling the energy needs of our future generations.

In my opinion, interest in the study of photosynthesis may be sparked by reading the story of the discovery of "oxygen" by the English chemist Joseph Priestley (1733–1804), through the mouse and the plant studies, and by the chemist French Antoine-Laurent Lavoisier (1743–1794) (Jackson 2005). However, to be effective, historical aspects need to be integrated in science curricula (Mamlok-Naaman et al. 2005).

### Can the history of science help science educators anticipate students' misconceptions?

Wandersee (1985) raised the question whether history of science can be of use in removing students' misconceptions in Science. He devised detailed questionnaires that dealt with the experiments of Jan Baptista van Helmont (1577–1644) on growth of plants in soil, of Joseph Priestley on mouse and mint plant, and of Jan Ingenhousz (1730–1799) on light and $CO_2$ as the major raw material for making food by plants. Based on his research, Wandersee (1985) concluded that "the history of science can help science educators anticipate students' misconceptions about photosynthesis concepts." Thus, he stated that teachers "can plan instructional experiences to modify students' invalid or inappropriate subsuming concepts and increase the probability of meaningful learning in their classrooms."

Considering the above and my own experience, I urge photosynthesis educators to seriously consider integrating historical aspects in their teaching to undergraduates; even graduate students enjoy and benefit from it. Govindjee and Krogmann (2006) have provided a timeline of oxygenic photosynthesis, whereas Gest and Blankenship (2005) have provided one for anoxygenic photosynthesis. Many stories and discoveries in photosynthesis, written by the discoverers themselves, may be found in Govindjee et al. (2005).

## Use of analogies and students acting as molecules

### Analogies, some examples

Rabinowitch and Govindjee (1969) adopted several analogies to teach some basic concepts in photosynthesis. These included: (i) use of pump and water wheels to explain photosynthesis and respiration; (ii) comparison of life with steam engine and turbine functions; (iii) use of ski run (for respiration), and ski jump (for luminescence); (iv) use of roof and ceiling concepts to explain the curves for the rate of photosynthesis as a function of light intensity, as well as of carbon-dioxide; and (v) analogy of cobblestone pavement with the proteins on a membrane, among many others. These and other analogies, to be invented by the teachers, can help many students learn concepts easily.

### Students acting as molecules

In my own lectures, I have used throwing and transfer of tennis balls and different colored balloons from one student to the other to explain the transfer of electrons and protons. The most effective tool I found was to have students volunteer to become specific molecules, both for the excitation energy transfer process and for the electron and proton transfers. In addition, we also had students who volunteered to become inhibitors, e.g., Diuron. These students would learn their chemical structures and their physico-chemical properties from books and/or from me. Then, they would participate in the entire process, with a couple of students acting as photons. We would cover the entire process of water oxidation, NADP reduction and ATP formation (see Fig. 1 of students in my class, ready to act as molecules). We would make sure that the Photosystem I and the Photosystem II reactions started simultaneously, not PS II and then PS I. The entire show was presented either on the stage in a large auditorium or outdoors on the campus. Through this demonstration, students learned the concepts of Antenna and Reaction Centers, of Excitation Energy Transfer, of the Two Light Reactions and Two Pigment Systems, of

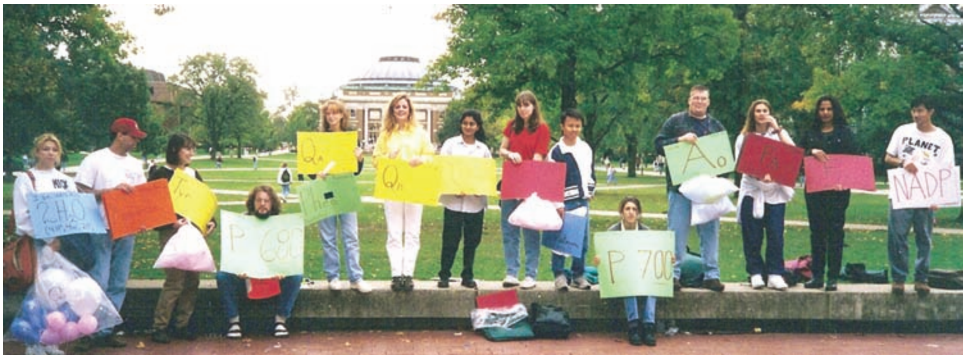


**Fig. 1** Undergraduate students, in Govindjee's class, assembled in the Quad of the University of Illinois at Urbana, with names of the molecules they represent, and balloons of different sizes and color, representing electrons, protons, and oxygen atoms. Note that P680 and P700 students are sitting down (ground state) and when they receive photons, they stand up simultaneously to indicate that both PS I and PS II start almost at the same time

Energy Drop for ATP Synthesis, of ATP Synthesis, and of the Manganese Clock for oxygen evolution, and of how herbicides inhibit electron flow. The best show on the above idea was presented at the University of Indore (Indore, India) during a Fulbright Lecturer Award in 1996. Here, the show was for the public; it included molecules (students) performing an Indian dance; photons (a student acting as the Sun God, delivering photons), and an herbicide (a student, dressed up as a devil) to kill the plants.

## Internet

The Internet, especially the Google search engine, has been the biggest boon in teaching. The availability of pdf files of research papers and reviews is fantastic for the job we do.

- The master site, with links to most of the useful web sites in photosynthesis, is that published by Orr and Govindjee (2007) (see Fig. 2). 'Photosynthesis and the Web: 2008' (http://www.life.uiuc.edu/govindjee/photoweb/ or http://photoscience.la.asu.edu/photosyn/photoweb) leads the readers to almost all the major sites related to photosynthesis. Please contact Larry Orr (larry.orr@asu.edu) or Govindjee (gov@life.uiuc.edu) to alert us to errors and to provide further suggestions.
- An innovative site, where a team (Eve Syrkin Wurtele, Diane Bassham, Julie Dickerson and Steve Hernnstadt) at Iowa State University is making a video game for teaching cell and metabolic biology, is at: http://metnet.vrac.iastate.edu/MetNet_Meta!Blast.htm.
They hope to release their first version (that includes photosynthesis) by October 15, 2007. Their wiki site is at: http://virtualcellproject.net/wiki/index.php?title=Main_Page.
These sites have some very nice stuff, and are still evolving. Please contact Eve Syrkin Wurtele (mash@iastate.edu) for further details.
- For fun, I recommend the Z-Scheme videos by the Ohio State Football team: http://www.youtube.com/watch?v=XsZlPeT3D10&eurl=. There are two very distinct versions of the Z-scheme play: one lasts for about 4 min, and the other 2 min.

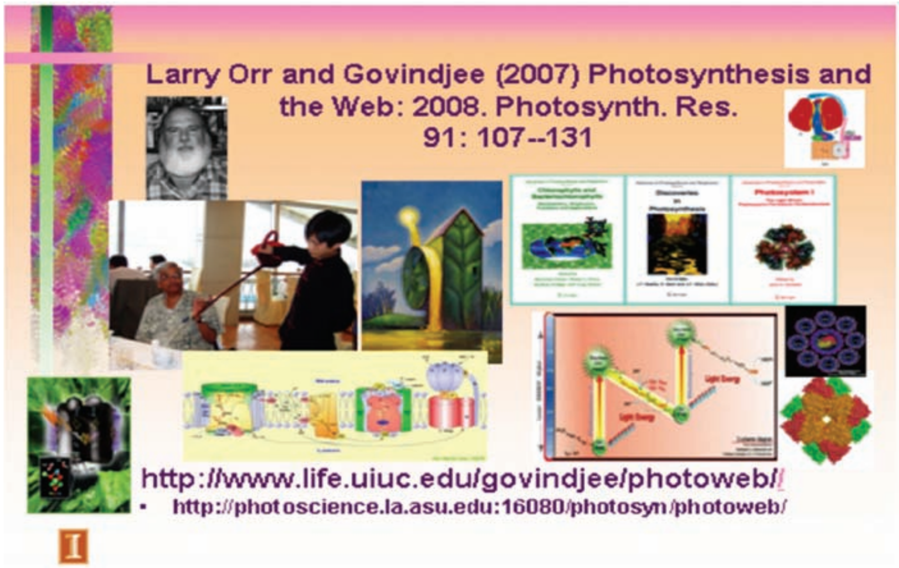


**Fig. 2** A copy of the slide, shown in the talk at the Glasgow Congress, includes photographs of Larry Orr, Govindjee (in China), covers of three of the books in the Advances in Photosynthesis and Respiration Series, protein complexes, and the Z-scheme poster of Wilbert Veit (and Govindjee) (Orr and Govindjee 2007)

http://www.youtube.com/watch?v=XsZlPeT3D10&mode=related&search=
http://www.youtube.com/watch?v=OnvuYLvInWE&mode=related&search=

- An interesting and enjoyable site on 'Plants in Motion', although not directly related to photosynthesis, is that by Roger Hangarter (why not enjoy it and let students get excited about plants?): http://plantsinmotion.bio.indiana.edu/plantmotion/starthere.html.

## Books and encyclopedia articles

There are books, encyclopedia articles, many papers and reviews on the Internet. It is not my intention to list them here as the list is just enormous, and most can be found through Orr and Govindjee (2007). However, I recommend that in addition to the beautiful chapters in various high quality text books, teachers of photosynthesis must read the books by Blankenship (2002); and by Falkowski and Raven (2007). In addition to the many beautiful Encyclopedia articles, and the Wikepedia site for photosynthesis (http://en.wikipedia.org/wiki/Photosynthesis), I recommend the photosynthesis-related articles I have coauthored for the tenth Edition of the McGraw Hill Encyclopedia of Science and Technology (Berkowitz et al. 2007; Blankenship and Govindjee 2007; Govindjee et al. 2007a, b).

A major point that I had particularly enjoyed in my teaching was to present lectures on a time scale from femtoseconds to a season (see Kamen 1963, for a diagram). Here, I reproduce a simple block diagram of the same concept from Blankenship and Govindjee (2007) (see Fig. 3). For details, consult Rabinowitch and Govindjee (1969), Blankenship (2002) and Falkowski and Raven (2007).

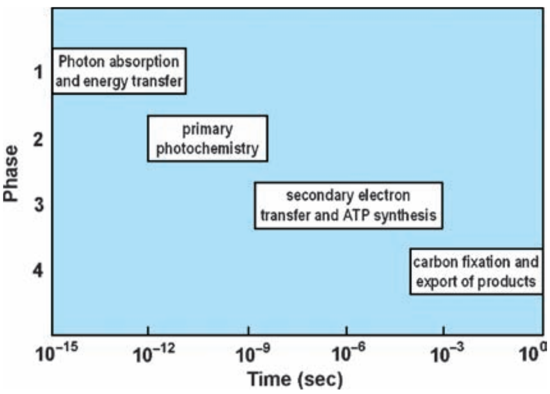


**Fig. 3** Time sequence of photosynthesis (Redrawn by Hyungshim Yoo, from Blankenship and Govindjee 2007)

### Advances in photosynthesis and respiration series

Since papers and reviews in photosynthesis are published in journals of many different disciplines, it is essential to have different sub-areas summarized in separate books for the benefit of not only graduate students, and research associates, but also for the Professors and Principal Investigators of all research areas related to Biochemistry, Biophysics, Microbiology, Plant Biology, Agriculture, and now in the area of Bioenergy and Biofuels. For this purpose, Springer has published 28 volumes, thus, far (see the following web sites: (1) Springer: http://www.springer.com/west/home/life±sci?SGWID=4-10027-69-173624465-0&changeHeader=true, (2) Arizona State University: http://photoscience.la.asu.edu/photosyn/books/advances.html, and (3) University of Illinois at Urbana-Champaign: http://www.life.uiuc.edu/govindjee/newbook/Vol19-25.html and http://www.life.uiuc.edu/govindjee/Reference-Index.htm).

### Music of sunlight

Wilbert Veit (2000) has authored a very interesting book "Music of Sunlight". In this book, a boy enters a leaf and becomes an electron, and the book follows his path inside the leaf for the entire photosynthesis process. The book includes a Z-scheme diagram. Adoption of the theme of this book into a video game and or a movie is highly desirable.

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